BIODIVERSITY OF PREDATORY BEETLE GROUPS, CARABIDAE AND COCCINELLIDAE AND THEIR ROLE AS BIOINDICATORS IN WHEAT AGROECOSYSTEMS

by

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DECLARATION

Biodiversity of predatory beetle groups, Carabidae and Coccinellidae and their role as bioindicators in wheat agroecosystems

I, Maria Mammolawa Makwela declare that the above dissertation is my own original work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references. Furthermore, this dissertation has not been submitted for any degree or examination at any other university.

SIGNATURE DATE

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ABSTRACT

Predatory Ground beetles (Coleoptera: Carabidae) and Lady beetles (Coleoptera: Coccinellidae) are two of the most diverse groups found in wheat agroecosystems, globally. These groups are important from both an economic and ecological perspective due to their natural services provision. The effect of wheat agroecosystem management on species diversity, abundance, biomass and composition in South Africa is not yet documented, and there is no existing data indicating which predatory carabid and coccinellid species provides essential ecosystem services and bioindicator roles. Therefore, we examined the effects of organic, conventional and intercropped agroecosystems on ground beetle and lady beetle abundance, dried weight (biomass), composition and diversity. Sampling of wheat agroecosystems was conducted in three systems i.e. organic, conventional and organic intercropped. *Post-hoc* Tukey test indicated a statistically significant difference between species diversity, biomass and abundance in organic and intercropped systems compared to the conventional systems. Regression analysis indicated significant positive correlation between aphid's density and predatory carabid and coccinellid beetles in the intercropped systems. Amongst the weather factors temperature influenced aphid density and carabid and coccinellid beetles' abundance. PCA (Principal Component Analysis) revealed significant positive correlation between individual biomass and cropping system. Conventional system showed a negative correlations with carabid and coccinellid individual biomass. We found that some carabid and coccinellid species can be used to measure the quality of agroecosystems. This study provides a fundamental basis for identification and monitoring of carabid and coccinellid species and their role as bioindicators of ecological disturbance. The identified bioindicator species in this study can assist in developing conservation and biomonitoring strategies within agroecosystems.

Keywords: Aphids, Biodiversity, Bioindicators, Biomass, Carabid beetles, Coccinellid beetles, Wheat agroecosystems

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DEDICATION

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ARC-PPRI	Agricultural Research Council - Plant Health and Protection
ARC-SG	Agricultural Research Council – Small Grain
FAO	Food and Agriculture Organization
LSD	Least Significant Difference
MEA	Millennium Ecosystem Assessment
SA	South Africa
SANC	South African National Collection of Insects
PAST	Paleontological Statistics Software
PCA	Principal Component Analysis

DISSERTATION CHAPTER OUTLINE

The following dissertation consists of six chapters and the content of each chapter is as follows:

Chapter 1: Is an introductory chapter that discusses the background of the dissertation, state the research motivation and problem statement, as well as the aim and objectives of the study.

Chapter 2: Consists of the literature relevant to the study. This chapter has sections on the carabid and coccinellid as bioindicators, ecosystem services, and management practices as well as information on weather factors.

Chapter 3: Focuses on comparing the biodiversity of predatory beetle groups, Carabidae and Coccinellidae as indicator species of wheat agroecosystem managements (organic, conventional and organic intercropped); by determining species diversity i.e. richness, evenness and dominance in each agroecosystem for both families.

Chapter 4: Assess the relationship between aphid density and predatory beetle groups from the three agroecosystems. Ecosystem services provided by predatory beetle groups are important for future sustainability.

Chapter 5: Looks at how organic, conventional and organic intercropped systems affect the biomass of predatory beetle groups' abundance.

Chapter 6: The overall discussions, conclusions and future research recommendations are given in this chapter.

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CHAPTER 1
DISSERTATION INTRODUCTION

1.1 INTRODUCTION

Agriculture provides a massive amount of food and contributes to economic development worldwide. However, it poses a major environmental threat due to environmental and soil fertility degradation, climate change and biodiversity loss. The biggest challenge is due to the global food demand that is estimated to double by 2050 while natural resources remain at a constant decline (Truter, Van Hamburg & Van Den Berg, 2012). Sub-Saharan Africa, one of the four major food consumers, will contribute approximately 70% of the world's food demand by 2020 (FAO, 2016). Wheat is a stable food for about 2.5 billion populations, worldwide (Dixon, Braun and Crouch, 2009; FAO, 2015) and thus, the production of wheat should ideally see an annual increase of at least 17% by 2025, as it is currently still 25% lower than what is needed to feed the estimated 7 billion people at that time (FAO, 2017). Wheat agroecosystems are largely managed by monoculture systems, which depend only on a single crop year to year. Such systems however, are not sustainable and with challenges of biodiversity loss, climate change and habitat alteration, it is important to adopt production practices that are sustainable despite the prevailing biotic and abiotic stress (Brown, 2011).

Invertebrates are becoming more desirable for a sustainable future, as indicators of environmental changes/ or habitat quality. Sustainable agroecosystem is largely dependent on biodiversity and if we are to examine an ecosystem, species diversity in relation to their indicator potential must be taken into consideration (Holland, 1998; Schmidt *et al*., 2004; Agarwal *et al*., 2009). Biodiversity of predatory beetle groups is vital for developing conservation biological control and biomonitoring strategies. Predatory beetle groups are an important component of agroecosystems and are classified into two groups: foliar searching beetle and ground dwelling beetle predators (Niemela, 2001; Raino & Niemela, 2003; Kris *et al*., 2013; Sharma, Chauhan & Sharma, 2015). Foliar searching predators include Coleoptera: Coccinellidae (Lady beetles). Coccinellid beetle are predators of cereal aphids due to their dispersal ability to search for their prey on the plant leaves (Symondson, Sunderland & Greenstone, 2002; Obrycki *et al*., 2009). Ground dwelling predators include Coleoptera: Carabidae (Ground beetles). Carabid beetles are mostly found in agricultural soils and are considered generalist predators as they prey on diverse insect species and other alternative food sources (Symondson, Sunderland & Greenstone, 2002). In most studies these species are found to be potential predators of cereal aphids (Losey & Denno, 1999; Lui *et al*., 2016). Subsequently, the interaction of these predatory beetles have been proven to effectively provide an important natural service of pest control (Schmidt *et al*., 2004; Safarzoda *et al*., 2014), this has been demonstrated in the field and laboratory experiments (Van Emdem & Harrington, 2007). In addition, their ecosystem service is functional in both natural and managed ecosystems (Brown, 2011; Winqvist, 2011).

Coleopteran families Coccinellidae and Carabidae are focal groups for this study because of their great functional importance within most agroecosystems. Due to their diversity in most ecosystems these beetles are considered "bioindicators" of habitat disturbance or change (Winqvist, 2011; Anbalagan, Paulraj & Ignacimuthu, 2013). Gerlach, Samways & Pryke (2013) describe 'bioindicator' as species or group of species that are used to monitor the health / or quality of a habitat, while McGeogh, (1998) relates the term bioindicator '*to species that reflect the status of an environment, representing the effect of environmental changes on a habitat or ecosystem'*. Gerlach, Samways and Pryke (2013) further divides bioindicator into three categories; environmental, ecological and biodiversity. Environmental and ecological indicators are used to detect status of an ecosystems due environmental disturbance and biodiversity indicator reflects the biodiversity of the overall biota (McGeogh, 1998).

Body size is also one of the important morphological traits that can be used to detect the status of habitat quality/or of functional diversity (Chown & Gaston, 2010). However, the use of predatory beetle assemblages as bioindicators is based on several selected criteria; wide geographical distribution, abundance and riches, functional importance, ease to sample, sort and identify and their quick response to climate and environmental changes and potential economic importance (Rainio & Niemelä, 2003). However, in agroecosystems carabid and coccinellid beetles can possibly be used as biological indicators of the species biodiversity, habitat disturbance and climatic changes (Dufrene & Lengendre, 1997; Garrat, 2010; Brown, 2011; Lui *et al*., 2016).

However, biodiversity loss of these beetle groups is caused by constant use of agrochemicals in agroecosystem thus, weakening their beneficial effects. Moreover, pesticides can reduce the quality of the soil, influencing ground dwelling organisms by reducing food availability and habitat suitability (Garratt, 2010). Climate change also cause decline of species biodiversity as low precipitation, extreme fluctuations in temperature and atmospheric CO_2 strongly alter the distribution and diversity patterns in arthropod communities **(**Sharma, 2014).

To minimize the risk of abiotic factors, habitat disturbance as well as ensuring the food production for approximately nine billion people in 2050 (FAO, 2016), it is important to adopt strategies that will increase production sustainability and resilience while reducing habitat fragmentation and destruction (Elbehri, Elliot & Wheeler, 2015). Agricultural management practices depending on continuous use of high chemical inputs should be altered.

Organic farming practices aim to minimize environmental damage while improving soil quality enhance biodiversity and making use of natural services provided by the agroecosystem. For instance, strategies that increase on-farm biodiversity, such as habitat restoration could positively benefit farmers by providing improved biological pest control provided by predatory groups (Altieri, 1992). According to (FAO, 2016), small-scale farmers depend on limited resource and lack external inputs due to financial limitations. They use farming practices such as organic and polyculture systems to preserve diversity on farm niche and barrier against climatic and economic.

These systems contribute positive benefits on nutrient availability, natural enemies, productivity and sustainability (Birkhofer *et al*., 2008; Etile, 2012). Traditional farmers produce healthy and productive crops, while promoting the ecosystem services of the natural resources base of their farms. Sustainable agroecosystems are derived from appropriate balance of natural services provided by a variety of organisms in agroecosystems (Josson *et al*., 2008). Therefore, agroecosystems will remain productive and healthy when natural services are properly maintained. Agricultural practices need to change and become more sustainable in order to meet the goal of providing sufficient food for the global growing population, while conserving biodiversity within agroecosystems and enhancing the diversity of naturally occurring enemies.

This research study, therefore, seeks to answer the following question- “what is the influence of wheat agroecosystem management practices i.e. organic, conventional and organic intercropped systems on the diversity in the coleopteran families Carabidae and Coccinellidae?” These two families will be used as bioindicators of the sustainability of each agroecosystem management approach.

1.2 PROBLEM STATEMENT

The major current challenge for agriculture and natural resources is to meet the global food demand for the ever growing human population while preserving environmental sustainability (FAO, 2016). Not only do farmers have to keep up with the current global food production demand, they also need to adopt sustainable farming strategies on their land. Traditionally, agricultural production used to be safe guarded against outbreaks of pest, diseases or severe weather by growing more than one crop or varieties in a field as an insurance. Today conventional monocultures have increased dramatically as modern farmers are focusing on single crops year to year without crop rotations and intercropping. Increases in monocultures contribute to soil degradation, water scarcity, climate change and loss in biodiversity of insect fauna which provides necessary ecosystem functions such as pest control (Symondson, Sunderland & Greenstone, 2002). Predatory beetles are considered potential biological control agents of agricultural pests and biological indicators of habitat quality in most agroecosystems (McGeogh, 1998). The biodiversity of predatory groups is threatened by unsustainable practices through intensive agriculture. Effects of organic, conventional and intercropped agroecosystems on predatory beetle groups' abundance and their predation ability have received considerably less attention. In South Africa little has been documented about beetle predators and their bioindicator role. Therefore, predatory species need to be sampled and monitored, and the extent at which these organisms are influenced by management under different environmental conditions also needs to be documented.

1.3 JUSTIFICATION AND MOTIVATION

South Africa has to meet challenges of food demand for the rapid global growing population, increased fragmentation and destruction of natural habitat and climate change. The need to adopt to sustainable production strategies that protect biodiversity without environmental cost demands require a new approach. The greatest challenge facing humanity is how to maintain biodiversity and ecosystem services in order to sustain efficient food productivity. Farm diversity and conservation agriculture has been shown to be the prominent farming to achieve food security and resilience despite the abiotic and biotic stresses. The provision of ecosystem services is currently noted as natural insurance policy against major challenges land use change and climate change, be it in the forestry or in agriculture (Chapin *et al*., 2000; Diaz *et al*., 2006). Using predatory beetle groups as bioindicators have practical application to agriculture, by assisting farmers, researchers and policy makers about management practices that maximize predatory groups' diversity and their ecosystem services.

- Results of this study will contribute to the understanding of predatory beetle assemblages’ responses to different farming practices and may assist in developing conservation biological control and biomonitoring strategies.
- Outcomes may be useful and documented in the foundation of coleopteran research at the South African National Collection of Insects (SANC) for future IPM strategies and bioindicators protocol.
- Knowing the effect of agricultural management practices and environmental conditions on predator species will channel policy makers to focus most of their resources to conserve and protect ecosystem services provided by predaceous arthropod within an agroecosystem.

1.4 STUDY AIM AND OBJECTIVES

The aim of this study is to evaluate the biodiversity of predatory beetles (carabid and coccinellid), their body size and role as bioindicators in organic, organic intercropped and conventionally managed wheat agroecosystems.

Objectives:

1. To investigate the composition, abundance and diversity of predatory beetle groups in organic, conventional and organic intercropped systems.
2. To determine the effect of wheat agroecosystem managements on aphid density and their predatory carabid and coccinellid beetle abundance in organic and conventional and organic intercropped systems.
3. To determine the effect of wheat agroecosystems (i.e. organic, conventional and organic intercropped agroecosystems) on carabid and coccinellid beetle body size.

1.5 HYPOTHESES

Based on the above objectives

1. Organic and intercropped agroecosystems will support a greater diversity of predators than conventional systems.
2. The higher the abundance and diversity of carabid and coccinellid beetles the higher the numbers of pests it predates.
3. Predatory beetle body size will be smaller in the conventional agroecosystems compared to the organic and intercropped agroecosystems.

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CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND

The order Coleoptera is the most diverse order within the class Insecta, with over 350.000 described species in 100 different families (Elzinga, 1992). It has received attention because of a wide range of trophic interactions and as well as its role as indicators of ecosystem functions and species diversity (Epstein & Kuhlman, 1990; Kromp, 1999). According to McGeogh (1998) Coleopteran beetles comprise diverse assemblages, which include major families such as, Carabidae and Coccinellidae. These predatory groups are the most studied fauna worldwide due to their wide distributions and economic importance as beneficial insects (Bhargava, 2009). Ground beetles are common generalist predators found in agricultural systems while most Lady beetles are classified as specialist predators in most literature as they are considered potential predators of aphids (Colunga-Garcia, Gage & Landis, 1997) but there are other coccinellid species that are considered generalist feeding on alternative resources (Symondson, Sunderland & Greenstone, 2002; Brown, 2011). Coleopteran predators are important indicators of ecosystem stability and are commonly used to examine the effects of agricultural practices such as pesticides usage on/for agricultural sustainability (McGeogh, 1998; 2008; Paoletti *et al*., 1999).

2.1.1 Carabidae species (Ground beetles)

Ground beetles (Coleoptera: Carabidae) is considered a large family of beetles, with about 40 000 described species. The Majority ground beetles (Figure 2.1) are active generalists feeding and consuming on live prey and other alternatives such as plant material (Lövei, 2008). Ground beetles are extremely diverse species in most ecosystems worldwide. They have been successfully used in different biodiversity and conservation studies as excellent biological indicators of ecosystems quality (Lovei, 2008) and mostly focusing on their response to agroecosystems management practices (Rainio & Niemela, 2003). In terms of agroecosystem quality, carabid beetles are sensitive to habitat perturbations such as pesticides (Birkhofer *et al*., 2008), landscape heterogeneity (Chapman, 2014) and non-cropped habitats (Östman, Ekbom & Bengtsson, 2001). Similar studies have reported such disturbance in the management of pasture (Byers *et al*., 2000), forest (Bhagharva, 2009), and arable land (Lemic *et al*., 2017).

Figure 2.1. Carabidae: *Calosoma caminara (*Lowerland Farm, 2017)

2.1.2 Coccinellidae species (Lady beetles)

About 90% of 6000 Coccinellidae species have been described worldwide (Brown, 2011; Iperti 1999; Stals & Prinsloo 2007; Brown, 2011). Anderson (1999) indicated that Coccinellidae (Lady beetles) are diverse and abundant species in most agroecosystems and are regarded as biological indicators of environmental changes (Iperti 1999; Ahmed *et al*., 2017). Additionally, Zahoor *et al*. (2003) mentioned that the diversity and sensitivity of Coccinellid beetles (Figure 2.2) in most agroecosystems is an indication of habitat quality. Based on other studies, particularly in Europe and India, carabid and coccinellid beetles have received attention not only on their role as predators, but also on their role as biological indicators of different ecosystems quality for sustainable purposes. Iperti (1999), also has described the biodiversity and bioindication role of predaceous Coccinellidae. Most studies have focused on how management practices affect their diversity, abundance and richness in agricultural landscapes in order to implement ways in which these species can be protected and preserved as a tool for ensuring sustainability (Bhargava, 2009; Anbalagan *et al*., 2013). Swart (2014) mentioned that understanding the effect of management practices on more than one indicator species is a necessary step towards a sustainable future.

Figure 2.2. Coccinellidae: *Hippodamia variegata* (Lowerland Farm, 2017)

2.2 THE ROLE OF PREDATORY BEETLE GROUPS AS BIOINDICATORS

According to Bishop *et al*. (2009) indicator species are recognised in beetle species because of their well-known taxonomy and ecological responses to changing environments. A number of biodiversity studies have demonstrated that the diversity, ubiquity and sensitivity of beetle species in most agroecosystems can be used to indicate the level of ecosystem disturbance (Noss, 1990; Zahoor *et al*., 2003; Swaminathan, 2014). Bioindicator is species or group of species that are used to monitor the health / or quality of a habitat due to environmental changes. Amongst beetle groups, Carabidae and Coccinellidae have been used in most diversity studies for examining ecosystem processes and as bioindicators used for environmental monitoring (Khan *et al*., 2007; Akhavan *et al*., 2013; Hayat *et al*., 2016; Lemic *et al*., 2017).

2.3 ECOSYSTEM SERVICES PROVIDED BY CARABID AND COCCINELLID BEETLES

Ecosystem services represent benefits provided to humankind and agroecosystems by functioning organisms. Ecosystem services are classified into provisioning services (food, fibre, fuel and biological resource) and regulating services (pest and disease control, pollination and climate control), (MEA, Millennium Ecosystem Assessment 2003; 2005; Power, 2010). In agricultural systems, essential ecosystem services include recycling of nutrients, biological production, i.e. via soil formation and biological pest control, enhancing the sustainability of natural ecosystem (Foley *et al*., 2005). The tenacity of renewal biological process of natural services basically depend on maintaining their biodiversity within agroecosystems. Biodiversity is not only about individual species, but relevant to food and agriculture worldwide (Thrupp, 2000; Hooper *et al*., 2005; Power, 2010). Most carabid beetles are polyphagous feeding on a wide range of prey (Toft & Bilde, 2002; Baehr, 2003). Although, the abundance of carabid beetles in wheat agroecosystem is less known especially in South Africa, generalists carabid beetles have been found to feed on a number of aphids in wheat agroecosystems during the seedling stages of cereal crop, when aphids are begin to colonize plant (Snyder *et al*., 2003; Winqvist, 2011; El-Wakeil & Volkmar, 2013). Even though they are ground dwelling predators their dispersal ability is, however, limited because most species are unable to fly (Liu *et al*., 2016). Only *Pterostichus cupreus* amongst other carabid species have been found to be capable of climbing the plants to prey upon aphids (Winqvist, 2011), with subsequent reduction of pest density by up to approximately 70% (Symondson, Sunderland & Greenstone, 2002). With regards to coccinellid ladybeetles very few coccinellid like Epilachninae are phytophagous (Anbalagan**,** Paulraj & Ignacimuthu, 2013). Coccinellid beetles have received consideration from agriculturalists because of their potential predaceous role on cereal aphids (Brown, 1969; Colunga-Garcia, Gage & Landis, 1997; Khan *et al*., 2007). In spite of their polyphagy, aphidophagous coccinellid are abundant predators of aphid populations, and can survive on some alternative food sources like flower, pollen, nectar, and honeydew (Ahmed *et al*., 2017). The adult of *C. septempunctata* prefers aphids feeding on wheat. Both the larvae and adult coccinellids have proven to minimize the population growth of aphids later in the season and are able to consume about 33 aphids per day (Dixon, 2000; Snyder & Ives, 2003).

2.4 BIODIVERSITY AND AGRICULTURE

According to Nellemann *et al*. (2009) biodiversity refers ‘to the range of organisms within an ecosystem’. The interaction and associated biological, chemical and physical process provided by species communities in ecosystem drive’s the earth natural cycle that is vital in maintaining ecosystem stability (Altieri, 1992). Agricultural expansion is a major source of biodiversity loss (Foley *et al*., 2005). According to FAO (1999; 2015), about 60% of the worlds' terrestrial surface has been converted to agricultural land, because of the pressure of feeding the global growing population, which has been predicted to reach 9 billion people by 2050 (Tilman *et al*., 2011). This will result in higher competition among humankind over land uses, harvesting, water, and expansion of farmland. Such pressures continuously disrupt natural services on which agriculture itself depends on for food productivity (Landis, Wratten & Gurr, 2000). Agricultural sustainability particularly includes maintenance of the productive capacity of the agroecosystem, with the ability of the agroecosystem to be resilient following perturbation and maintain itself by preserving sustainable ecosystem services and functional biodiversity. Figure 2.3 illustrate the consequences of agricultural expansion on agrobiodiversity, ecosystem service and consequently the effect on sustainability and productivity. The direct effects of agricultural management are those associated with the reduction of crop diversity and abundance in the ecosystem. The indirect effects amongst others include resource utilisation and wide spectrum of agrochemicals which significantly reduce the total biodiversity (Gliessman, 2001).

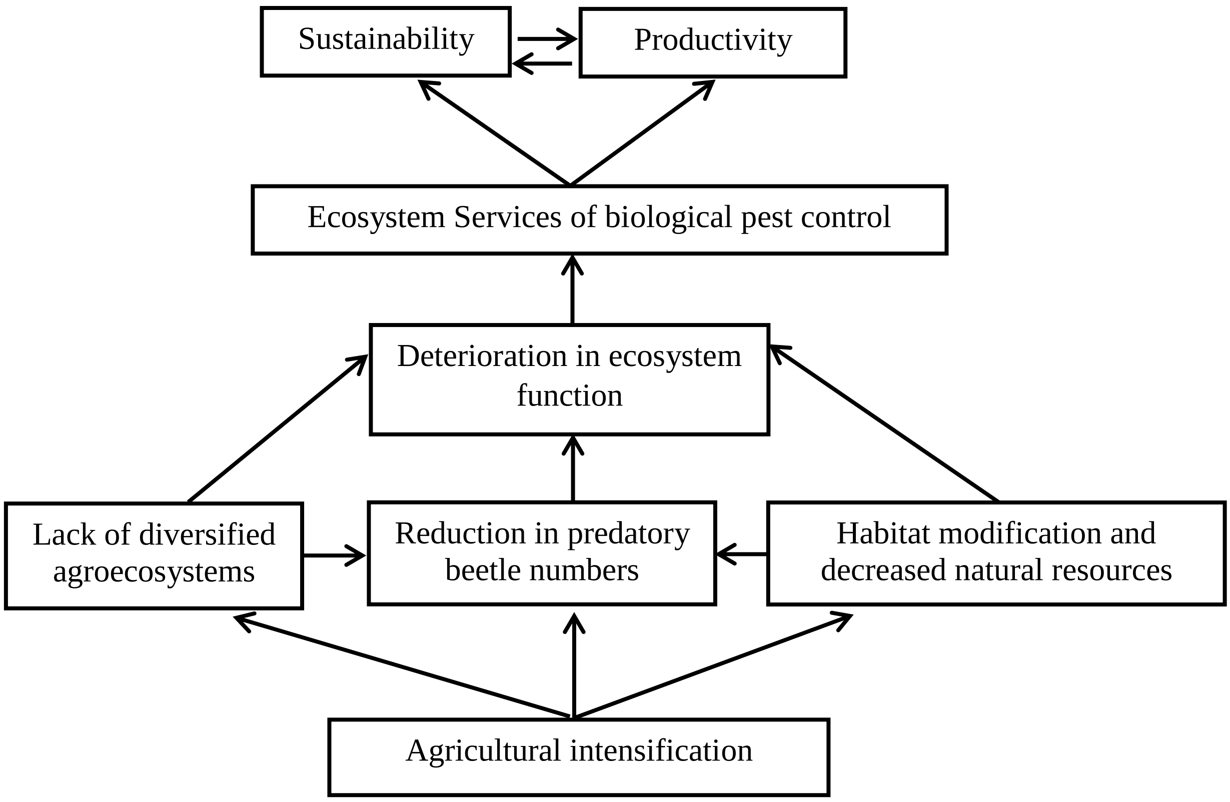

Figure 2.3. Illustrate the ultimate effect of agricultural intensification on agroecosystem biodiversity, ecosystem service, sustainability and productivity (modified from Swift & Anderson 1993; Swart, 2014).

2.5 AGRICULTURAL MANAGEMENT TECHNIQUES AND PREDATORY BEETLES DIVERSITY

The diversity, abundance and body size of predatory beetles in agroecosystem are affected by the type of agricultural farming systems. It has been shown that agricultural management techniques threaten the biodiversity of predatory arthropod communities (Table 1). This can, however, have significant implications for biological control of insect pests if predatory species are affected by farm management practices (Letourneau & Goldstein, 2001). In addition, predatory species total richness and abundance is the fundamental measurement of diversity in ecological communities and a primary indicator of an ecosystem health/quality (Gotelli & Colwell, 2001). However, the aim of adopting sustainable practices is not only to enhance species diversity but also to improve the resilience and stability of the systems and reduce the need for human disturbance (Jankielsohn, 2017; Botha *et al*., 2018).

2.5.1 Polyculture systems

Polyculture is defined as diversified system in which two or more useful crops are grown simultaneously, in order to promote natural services within agroecosystems (Altieri & Nicholls, 1992; Landis, Wratten & Gurr, 2005). Intercropping systems of mixed, strip and traditional intercropping result in pest management benefits due to increased diversity. This is also supported by Jankielsohn (2017), who highlighted that intercropping systems play an important role in attracting beneficial arthropods. Biological pest control by natural enemies can be improved by such habitat techniques (Birkhofer *et al*., 2008; Gardiner *et al*., 2009), furthermore, these results were affirmed by Andow (1991), that phytophagous pest were higher than 50% in abundance in monocultures and less than 15% in abundance in polyculture systems. This results can be explained further by one hypotheses which is “natural enemies hypothesis” proposed by Root, (1973); according to which predatory groups were more abundant in polyculture systems and providing efficacy of phytophagous pests’ regulation.

2.5.2 Monoculture systems

Monoculture systems are unsuitable habitats in which efficacy of biological pest control is not improved because these systems lack adequate resources that allow a diverse and abundant population of predatory groups. The expansion of conventional monocultures has led to considerable biodiversity loss of arthropods that are beneficial (Altieri & Nichollas, 1999; Letourneau *et al*., 2010; Etile, 2012; Jankielsohn, 2017). Studies have assessed the effects of natural enemy’s diversity in varying agroecosystems and found that predatory groups of both carabid and coccinellid beetles were more diverse in organic and intercropped agroecosystems than in conventional agroecosystems (Puech *et al*., 2014). The decrease in predatory groups in these habitats is a result of decreased plant diversity, tillage practices and heavy pesticides use, favourable microclimate (Brust, 1990; Aqueel and Leather, 2010) leading to a higher activity rate of predators' dispersal to better habitat quality and continuous pest outbreaks (Schmidt *et al*., 2004; Tscharntke *et al*., 2005).

2.5.3 Organic agroecosystems

Implementation of lower intensity agricultural practices or use of organic farming techniques are potential solutions to the challenges associated with agricultural intensification (Kraus, Gallenberge & Steffan-Dewenter, 2011). According to Sandhu *et al*. (2008), ecosystem services provided by natural enemies are of economic importance in organic farms. Based on several studies, organic farming has been recognized to enhance biodiversity, including important functionality of predatory groups in agroecosystem with subsequent natural pest control (Kromp, 1999; Bengtsson, Ahnstrom & Weil, 2005; Birkhofer *et al*., 2008; Kraus, Gallenberge & Steffan-Dewenter, 2011; Wagan *et al*., 2014). However, if an organic agricultural approach is going to provide a significant alternative to conventional agriculture, then its impact on agricultural pest and natural enemies within the agroecosystem needs to be understood (Shah, 2003; Moschini *et al*., 2012; Vandercycken, 2013).

Table 2.1. Farming management practices that can sustain and decrease predatory fauna biodiversity in agroecosystem (Modified from Paoletti 1999; Altieri 1999; 2004)

Sustained predatory beetles	**References**	**Decreased predatory beetles**
Polycultures	Baliddawa, 1985; Altieri, 1992; Paoletti, 1999; Losey and Deno, 1999; Winqvist 2011; Swaminathan 2014	Monocultures
Organic sustainable	Shah *et al*., 2003; Birkhofer *et al*., 2008; Vandercycken *et al*., 2013; Wagan *et al*., 2015	Intensive farming
On farm research	Thiele, 1997; Lockeretz, 1987; Kromp, 1999; Winqvist, 2011; Etile, 2012	Conventional plot
Organic fertilizers	Schmidt *et al*., 2005; Siddiqui *et al*., 2005; Garrat, Leather & Wright, 2010; Aqueel & Leather, 2010; Moschini *et al*., 2012	Chemical fertilizer
Biological pest control	Pimentel *et al*., 1993; Paoletti *et al*., 1993; Östman, Ebkmon & Bengtsson, 2001; Winqvist 2011	Conventional pest control

2.6 STUDIES AND RESEARCH ON BIOINDICATORS AND SPECIES BIODIVERSITY- STATUS IN SOUTH AFRICA

Beetle predatory groups play a crucial role of ecosystem functioning in most agricultural landscapes. This realization however, has resulted in a broad discussion and assessment of the use of terrestrial arthropods in order determine their bioindicator role, and this concept has been applicable to a variety of taxa's such as coccinellid and carabid beetles, habitats and environmental scenarios. Ecological studies have used one species/ or assemblages of, for example, lady beetles, ants, nematodes, ground beetles, and dung beetles (McGeoch 1998; Magagula and Samways 2001; Jankielsohn, Scholtz and Louw, 2001; Magagula, 2004; Gelarch, Samways & Pryke, 2013; Du preez *et al*., 2014; Munyai and Foord, 2015) in habitats such as forests, grasslands, disturbed agroecosystems, subterranean ecosystems, mountains and urban areas. However, biodiversity of invertebrates in South Africa is a major current research focus. Studies have documented arthropods diversity in agroecosystems more particularly in maize (Truter, Van Hamburg and Van Den Berg, 2012; Botha *et al*., 2018) and Swart (2014), investigated the biodiversity of arthropods that can be useful indicators to develop robust method for sustainability of ecosystem services on pistachio orchards. These studies have managed to document species that can be useful indicators of the specific agroecosystems they selected. However, ecological research based on indicators using model organisms in wheat agroecosystem managements is still limited in South Africa. Gerlach, Samways and Pryke (2013) selected taxa's that can be used as indicators and Carabidae species was noted as potential keystone predators and indicators of environmental changes. With regard to Coccinellidae McGeogh, (1998; 2008) mentioned that due to their diversity and their predaceous nature coccinellid beetles can be used as bioindicators of environmental quality. Their predaceous potential is documented in several South African studies and they are also classified as potential keystone predators (Magagula & Nzima, 2015). However, the role of Carabidae and Coccinellidae species as bioindicators in most South African agroecosystems is less documented, only few studies in South Africa (Magagula and Samways, 2001; Magagula, 2003) have documented their diversity. Despite the various arthropods biodiversity studies, not much consideration has been given to understanding the goal of '*bioindication*' using predatory beetle groups.

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CHAPTER 3

COMPARATIVE BIODIVERSITY OF PREDATORY BEETLE GROUPS, CARABIDAE AND COCCINELLIDAE AS INDICATORS OF MANAGEMENT

ABSTRACT

This study was conducted to assess the biodiversity of carabid and coccinellid beetle species in different wheat agroecosystems and to determine their roles as biological indicators. Species were sampled using pitfall traps, sweep netting and visual sampling methods in three agroecosystems. Carabidae and Coccinellidae biodiversity distribution varied across the different wheat agroecosystems. A total of 1648 carabid beetles belonging to 11 genera with 11 species, and 2565 individuals of coccinellid beetles belonging to 6 genera consisting of 6 species were recorded, across the three agroecosystems. The organic system had the highest species richness. Coccinellidae species *Cheilomenes lunata* was the most abundant species contributing 52% of the total individuals captured in the organic intercropped system followed by Carabidae species *Calosoma caminara* contributing 27% of species composition in the organic agroecosystem. Comparatively, carabid and coccinellid diversity as measured by Shannon diversity index was statistically higher in both the organic, and the intercropped systems than in the conventional systems (P<0.001). The higher coccinellid beetle (H' = 1.6) and Carabid beetle (H' = 2.2) diversity in organic and organic intercropped were clearly exhibited by high evenness distribution (J' = 0.9) and less dominance (D' < 0.01) of species. The organic and the intercropped systems supported a greater diversity of carabid and coccinellid species.

Keywords: Biodiversity, Bioindicators, Carabidae, Coccinellidae, Wheat agroecosystems

3.1 INTRODUCTION

Biodiversity is defined as a variety of organisms living in a particular habitat. The components of biodiversity are genetic, ecosystem and species diversity. This variety provide natural services within agroecosystems. For instance, a variety of species provide ecological functions within agroecosystems which global growing population and food production depend upon. Apart from provision of genetic diversity, farmers can utilize biological diversity in order to produce healthy crops while enhancing species diversity (Altieri, 1999; FAO, 2015; 2016). According to Hayat *et al*. (2016) species diversity consist of three components i.e. richness, dominance and evenness". Richness is the total number of species in habitat, dominance is the abundant species in a particular area whilst evenness is the relative abundance of each species. Understanding species diversity in different agroecosystems can be helpful in their role as biological indicators and their provision of ecosystem functions.

Coleoptera families of Carabidae (Ground beetles) and Coccinellidae (Ladybird beetles) are considered suitable bioindicators because of their wide geographical distribution, abundance and richness, functional importance, ease to sample, sort and identify, their quick response to climate and environmental changes and potential economic importance (Spellerberg, 1993; Ipeiti *et al*., 1999; Andersen, 1999; Rainio & Niemelä, 2003; New, 2007). Their combined association in a system can potentially create an ecological insurance against stress and indicate disturbances. This is also supported by Niemela *et al*. (2000), who articulates that the abundance and diversity of these beetle groups give evidence about the quality of the ecosystems since their diversity is related to habitat fragmentation in agroecosystems. Despite the documented information on significance of these species as bioindicators, not many detailed South African studies (Botha, 2014) about ground beetle biodiversity and their response to management practices, especially on wheat agroecosystems, have been documented. Some recent studies in South Africa focused on other agroecosystems such as maize (Magagula & Nzimba, 2015) and sugarcane (Magagula, 2003). In the case of Lady beetles, the most comprehensive South African Lady beetle studies documented on South African wheat crops was done more than 40 years ago by Brown (1969), in which only four species were identified. Subsequently only a few South African researchers examined Lady beetle diversity in agroecosystems including maize (Truter, Van Hamburg & Van Den Berg, 2012; Both *et al*., 2018) and savannah land mosaic (Magagula & Samways, 2001).

In most ecosystems, predatory beetle groups have been reported to be negatively influence by farming practices i.e. intercropped, monocultures, mixed crops and organic farming (Cardinale *et al*., 2003). According Puech *et al*. (2014), the instability of agroecosystems is directly linked to the expansion of monoculture systems. Unfortunately, monoculture systems are unsuitable habitats in which the population diversity of predatory groups is diminished due to chemical inputs, lack of adequate resources, unfavourable microclimates and absence of refuge from environmental disturbances (Altieri, 1999; Letourneau & Bothwell, 2008; Etile, 2012; Jankielsohn, 2017). Several studies related to the effects of habitat disturbance on natural enemy's diversity showed that predatory groups of Carabidae (Schmidt *et al*., 2003; Tscharntke *et al*., 2005) and Coccinellidae (Moschini *et al*., 2012; Anbalagan *et al*., 2015) species can be conserved in organic agroecosystems compared to monoculture systems. The decline of diversity in predatory groups is of particular concern as these species provide essential natural services of pest control and give status of environment disturbance (Akhavan *et al*., 2013; Lemic *et al*., 2017). Owing to their wide range of feeding behaviour and diversity, they provide essential ecosystem services of agricultural pest control of phytophagous pests such as cereal aphids and small-scale insects. The potential risk of predatory beetles' diversity decline can be prevented by making responsible management decisions. Implementation of sustainable farming strategies is one of the prospective solutions to the challenges associated with modern practices leading to biodiversity loss is to implement (Kraus, Gallenberge & Steffan-Dewenter, 2011; Anbalagan *et al*., 2015) which provide suitable conditions for arthropods.

Experimental studies further suggest that the biodiversity of predatory beetles can be enhanced and well-maintained by management practices that are suitable to support their diversity and abundance (Zahoor *et al*., 2003; Rainio & Niemelä, 2003). A study on the biodiversity of Carabidae and Coccinellidae families in different wheat management practices needs to be understood in order to improve indicators that act as early warning signallers. The objective of the study was to assess the composition, abundance and biodiversity, (diversity, dominance, evenness and richness) of Carabidae and Coccinellidae families from three wheat agroecosystems (Organic, organic intercropping and conventional agroecosystems) and to estimate their role as bioindicators of farming management.

3.2 MATERIALS AND METHODS

3.2.1 Ethical approval

Lower land farm (Prieska) allowed for the study to be conducted in their wheat trials. The collection of data and sampling procedures does not have destructive influences on Lower land farm trials and the environment. This research study does not contain any hazardous materials and therefore has received ethical approval; Appendix A, **[Ref no. 2017/CAES/182]**.

3.2.2 Description of the study location

The study was conducted at Lower-land Farm located near Prieska, Northern Cape (S29.50161°E23.00156). Sampling sites consist of three differently managed agroecosystems; (1) organic crop rotation, (2) organic intercropped and (3) conventional monoculture (Figure 3.1; Table 3.1). The systems under crop rotation and intercropping have been under organic management ever since the year 2010. The organic system is cultivated under no-tillage with maize residues, there are no agrochemicals applied into this system; the organic intercropped system, is also cultivated under no-tillage with no chemical inputs, in this system wheat is intercropped with legumes (*Trifolium* sp.) and a mixture of grasses such as oats and barley; the conventional system is cultivated with monoculture wheat under conventional tillage with full chemical applications (Insecticides; herbicides and fertilizers), this system is older than 10 years. The average annual temperature in the study area was 19 °C during the study period, with an average high of 28°C during planting period. The average annual precipitation in this area was 325 mm. Wheat is planted from June to August and harvested from November to December.

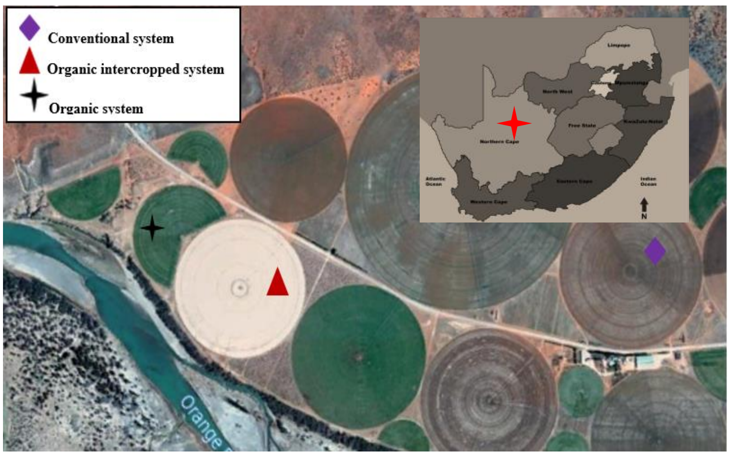

Figure 3.1. Location of sampling points at Lower Land Farm study site in the Northern Cape, South Africa. Source: https://www.google.com/earth/

Table 3.1. The three agroecosystems and sampling methods used in this study

Sample area	Agroecosystems	Management	Photo (Lowerland Farm, 2017)	Sampling methods for all systems: A. Pitfall trap, B Yellow sticky trap, C Sweep net, D Visual sampling
WHEAT	ORGANIC	Wheat is cultivated under no-tillage, with maize residues and rotated with soybean, sunflower and maize.		 Ground beetles
	ORGANIC-INTERCROPPING	Cultivation of more than one species or cultivar on the same piece of land. In this system, wheat is intercropped with legumes such as clover plant and mixture of grass species such as barley and oats.		  Lady beeetles
	CONVENTIONAL	Wheat is planted in homogenous monoculture without any crop rotation, using methods that employ high inputs of agrochemicals (fertilizers, fungicides, insecticides) and machinery (tillage, burning).		 Lady beetles

3.3 Sampling methodology

To assess the difference in abundance, evenness, and richness of coccinellid and carabid beetles between the different systems, sampling sites were chosen randomly in each production system *as per* procedure described by Gadagkar, Chandrashekera and Nair (1990). To avoid pseudo replication four sampling point distanced 50m apart were randomly arranged for each system. Four set of traps were placed at approximately 10m apart per sampling point. Data of 16 trap samples (6 sampling months x 4 sampling point per transect x 4 set of traps) were summed to analyse each study site. All traps were monitored each month from July to December 2017 during the wheat growing season.

3.3.1 Carabidae: Ground beetles sampling

According Woodcock (2005) pitfall trapping is one of sampling methods used in ecological studies to trap epigeal arthropods in order to estimate richness and abundance (Hoekman *et al*., 2017). This method provides efficient means of sampling ground beetle activity responses to environmental change and is commonly used for biological and ecological monitoring studies (Cheli & Corley, 2010). It is convenient, cost-effective and labour-efficient and allows collection of ground beetles (Spence & Niemela, 1994). For this study wet pitfall traps were used to collect ground beetles (Table 3.1a). Thomson and Hoffman (2010), describe wet pitfall traps as a trap containing a certain solution designed to preserve invertebrates. The mixture used as a preservative solution for this study was non-toxic and environmentally safe, cost-effective, and suitable for long term trapping because it doesn't evaporate fast relative to other preservative solutions which are commonly used such ethylene glycol. The preservative solution is made of a mixture of salt, and small amount of detergent to reduce surface tension (Thomson & Hoffman, 2010). Pitfall traps (110 mm diameter x height 40 cm) consisted of 2L bottles with the top half cut and inverted to form a 5 cm funnel with a smaller opening suitable to only trap ground beetles and prevent non-targeted organisms such as shrews and snakes from being trapped (Miller, 2000). Traps were fitted with a raised roof cover to limit dilution of preservatives during heavy or prolonged rains. To avoid [1]digging-in effect, pitfall traps were left for 3 days before the beginning of monthly sampling and were serviced every one week by removing any litter, debris and any other form of obstruction.

[1] Digging-in effect refer to the higher number of capture immediately after pitfall trap installation (Parr & Chown, 2001).

3.3.2 Coccinellidae: Lady beetles sampling

Coccinellid beetles were sampled using three sampling procedures including yellow sticky traps, sweep netting and visual observation for each study site. Yellow sticky card traps were placed within each system at a height of 1 m (Table 3.1b). Sticky traps were arranged using the same methodological design as the pitfall traps and were sampled at approximately 10m apart from the pitfall traps. Coccinellid beetles in the crop canopy were collected using a sweep net (Table 3.1c). Sweeping was done in a cross line transect in each system. The net used for sweeping was made of thick cotton cloth, consisting of a diameter of 25 cm at the mouth and bag of 55 cm in length. Sweep net was done following the procedure described by Lester & Holtzer (2009), in this method 16 sample units with four replicated sweeps were taken randomly in each system. Sweep net samples were collected for 5 consecutive days in each month; non-targeted species i.e. wasps, butterflies, green flies were released back to the field after sorting of coccinellid beetles. Twelve visual observations were performed randomly in a cross transect. All coccinellid beetles were counted while walking randomly through the field and pausing after a distance of 30 m to observe for 5 minutes. This was done for 5 consecutive days each month prior to all the samplings (Table 3.1d).

3.4 Identification and Preservation of predatory beetles

Predatory carabid beetles collected from each wheat system were transferred into 200g plastic jars containing 2 ml preservative solution mentioned above and coccinellid species were emptied into ziplock bags. Carabid and coccinellid specimens were counted, sorted and identified to species level by using taxonomic keys (Brown, 1969; Rafi *et al*., 2005), and with the assistance of specialist researchers. Samples that were difficult to identify were sent to ARC-Plant Health and Protection: Biosystematics division for accurate identification.

3.5 Biodiversity and Statistical Analysis

Species from organic, intercropped and conventional systems were designated in terms of abundance, richness and diversity. Abundance was determined by counting the total number of individuals of each identified species (N) in each system. Species richness (S) represent the total number of species collected from each system. Rank abundance graphs were compiled to compare both carabid and coccinellid beetle richness and evenness between the three agroecosystems, in which evenness is indicated in the slope line that fits the graph which assumes a linear series: logarithmic series. The rank graph data was not normally distributed since the species richness was ranked from the highest to lowest along the horizontal axis (x), with their abundances typically displaying in a $\log_{10}$ format on the y-axis. Diversity was expressed by combining the biodiversity indices to provide indices of both richness and diversity (Magurran, 2004), namely Shannon-Wiener diversity index (H'), Margalef's species richness index (M'), Pielou's evenness (J') and Berger- Parker Dominance Index (D'). Bray Curtis similarity index which is based on abundance data was also determined with a range from 1 to 0. A value of 1 indicates that communities being compared share all their species and 0 means that they share none. Diversity index values were calculated using Paleontological Statistics Software Package (PAST version 3.20) (Hammer *et al.*, 2001). Data were further subjected to one-way Analysis of variance ANOVA and *post-hoc* Tukey tests (5%), were performed to test for significant differences in abundance and diversity across different wheat agroecosystems.

The following equations were used (Magurran 1988; 2004)

i. Berger-Parker Dominance Index: $\mathbf{D}= \frac{\mathbf{Nmax}}{\mathbf{S}}$

$\mathbf{N_{max}}$ = the number of individuals of the most abundant species, **S** = the total number of observed species.

ii. Bray Curtis similarity index: $\mathbf{BC_{ij} = 1 - \frac{2Cij}{Si+sj}}$

C_{ij}= is the sum of lesser values for those species in common between both sites, S_i and S_j= are the total number of specimen counted

iii. Margalef's index: $\mathbf{Ma}= \frac{\mathbf{s-1}}{\mathbf{lnN}}$

S= Total number of species in sample, **N**=Total number of individuals of all species in a sample and **ln** = log to base n.

iv. Pielou evenness index: $\mathbf{E}= \frac{\mathbf{H}}{\mathbf{lnS}}$

H- Shannon Wiener Index: **S** = number of species and **ln** = log to base n.

v. Shannon –Wiener index: $\mathbf{H'\text{-}\sum [pi\text{-}Ln\ (pi)]}$

Σ = Sum, ***Pi*** = Proportion of individuals of $\boldsymbol{i^{th}}$ species, $\boldsymbol{n^i}$ = Number of individuals of each species in a sample and **N**= Total number of individuals of all species in a sample.

3.3 RESULTS

Table 3.2 Collective Rank list of carabid and coccinellid beetle composition and abundance recorded from three wheat agroecosystems ([2]ORG-[3]Organic agroecosystem, ORG-INTER-Organic-Intercropped agroecosystem and [4]CONV-Conventional agroecosystem).

RANK	SPECIES	WHEAT AGROECOSYSTEMS							
		ORG	ORG-INTER	CONV	Total	ORG	ORG-INTER	CONV	%Total
	Carabidae	**(N) Abundance**				**% Composition**			
1	*Calosoma Caminara*	168	196	21	385	19.8	27.5	23.9	23.7
2	*Amara eanea*	153	88	16	257	15.9	12.4	18.2	15.5
3	*Pterostichus aethiops*	98	88	12	198	11.6	12.3	13.6	12.5
4	*Agonum gracilipes*	86	71	12	169	10.1	10.0	13.6	11.2
5	*Bembidion lampros*	76	67	10	153	9.0	9.4	11.4	9.9
6	*Agonum gracilipes*	75	60	9	144	8.8	8.4	10.2	9.2
7	*Bembidion properans*	69	48	8	125	8.1	6.7	9.1	8.0
8	*Pterostichus madidus*	65	45	-	110	7.7	6.3	-	4.7
9	*Agonum viduum*	54	44	-	98	6.4	6.2	-	4.2
10	*Thermophilum homoplatum*	13	4	-	17	1.5	0.6	-	0.7
11	*Graphiptes auratiacus*	9	1	-	10	1.1	0.1	-	0.4
	Total individuals	848	712	88	1648	100	100	100	100
	Total species	11	11	7					
	Coccinellidae								
1	*Hippodamia variegata*	387	624	61	1072	32.6	52.9	30.8	38.8
2	*Cheilomenes lunata*	234	133	53	420	19.7	11.3	26.8	19.3
3	*Proplylea dissecta*	204	115	51	370	17.2	9.7	25.8	17.5
4	*Coccinella septempunctata*	151	109	33	293	12.7	9.3	16.7	12.9
5	*Lioadalia flavomaculata*	135	101	-	236	11.4	8.6	-	6.7
6	*Stethorus punctum*	78	96	-	174	6.6	8.2	-	4.9
	Total individuals (n)	1189	1178	198	2565	100	100	100	100
	Total species (S)	6	6	4					

[2] ORG: Organic
[3] ORG-INTER: Organic intercropped
[4] CONV: Conventional

3.3.1 Coccinellid beetle distribution and composition

3.3.1.1 Richness and Abundance

The (Table 3.2) above indicate that the highest abundance and species richness (6 species and 1189 individuals) was observed in the organic system. Followed by the organic intercropped agroecosystems (6 species and 1178 individuals) and the conventional systems had the lowest Coccinellidae abundance and species richness (4 species and 198 individuals). *Hippodamia variegata* was the most abundant species contributing an overall composition 38.8% of the species composition; followed by *Cheilomenes lunata* with 19.3% and *Proplylea dissecta* with 17.5%. The species *Stethorus punctum* contributed the least with 4.9% respectively (Table 3.2). Anova revealed a significant effect on the total abundance of coccinellid beetles across the systems. Coccinellid species were differed significantly across the systems (P<0.001), being greater in both the organic and intercropped systems than the conventional system (Figure 3.4).

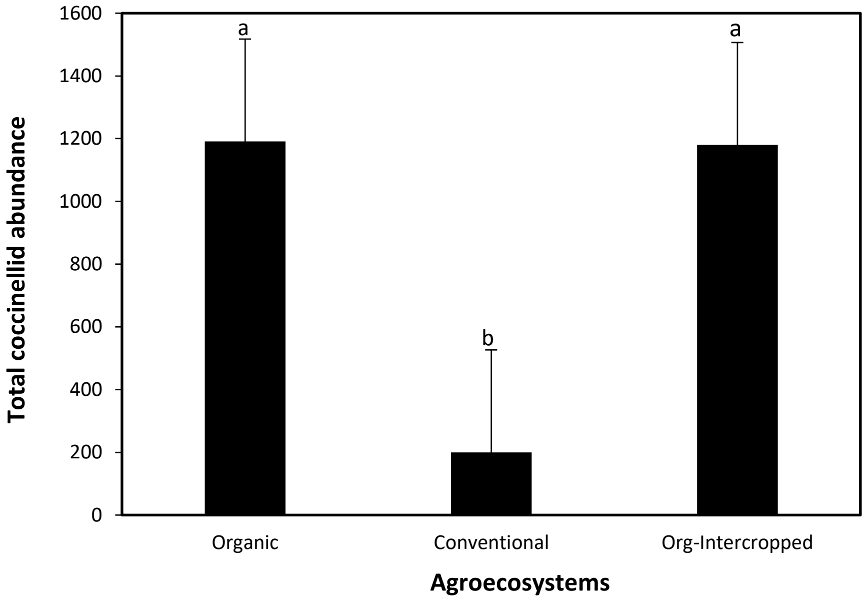

Figure 3.4 Total abundance of coccinellid beetles in the (ORG, CONV and ORG-INTR). Bars (± S.E) with the same letter do not differ significantly

Regarding rank abundance *H. variegata* ranked first, as the dominant species while *S. punctum* ranked last in all the systems. *S. punctum* and *Lioadalia flavomaculata* were considered rare species as they did not occur in the conventional systems, indicating that they are more affected by management practices in these systems than the other species (Figure 3.5). According to t test there was statistical significant in the total abundance of coccinellid species within the three systems. The species *H. variegata* (F=11.2; P=0.009), *C. lunata* (F=13.5; P=0.006) and *P.*

dissecta (*F*=44.1; *P*=0.0002) were significantly higher in abundance among the three agroecosystems. In contrast the analysis of variance showed that there were no significant difference between the species *S. punctum* (*F*=1.5; *P*=0.2) and *L. flavomaculata* (*F*=4.4; *P*=0.06) (Table 3.3).

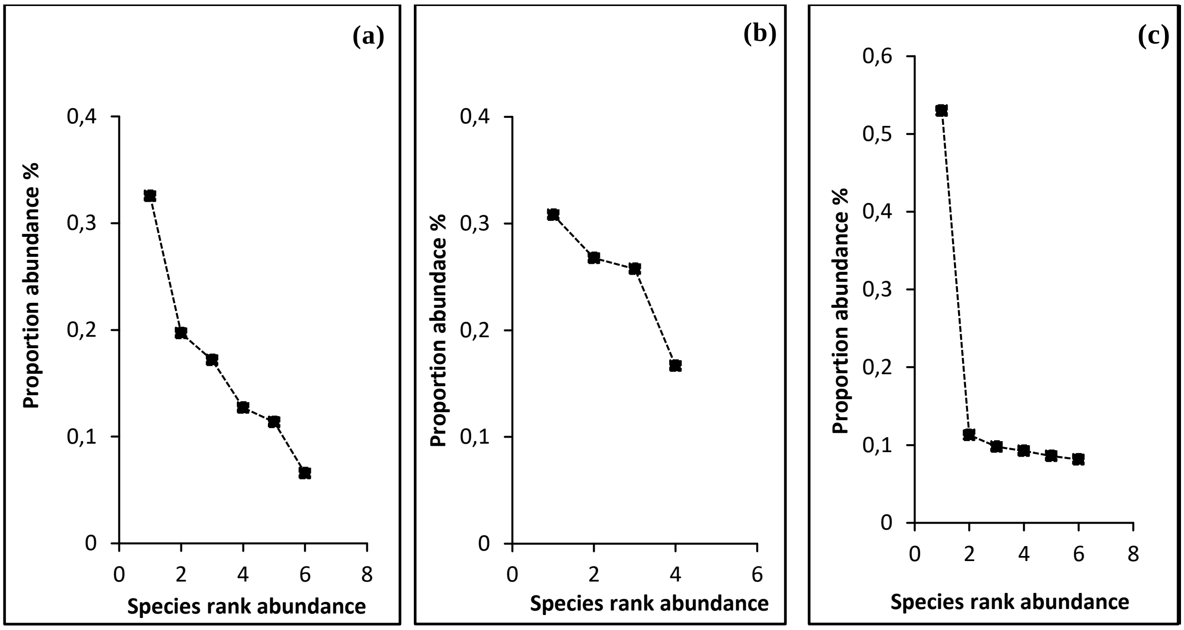

Figure 3.5 Species rank abundance for cocinellid beetles in the (a) ORG, (b) CONV and (c) ORG-INTR

Table 3.3 Coccinellid species abundance (mean ± S.E) as influenced by different agroecosystems (ORG, CONV and ORG-INTR). Values with the same lowercase letters in a row did not differ significantly (*P*<0.05)

Species	**Agroecosystems**			**ANOVA**		
	ORG	CONV	INTER	df	*F*-value	*P*-value
Hippodamia variegata	63.0 ± 9.41^{a}	13.25 ± 6.41^{a}	156.0 ± 36.1^{b}	6	11.2	<0.001
Cheilomenes lunata	51.0 ± 8.70^{a}	12.6 ± 4.05^{b}	36.0 ± 3.08^{a}	6	13.5	<0.001
Proplylea dissecta	95.2 ± 11.7^{b}	15.3 ± 2.30^{a}	28.6 ± 3.71^{b}	6	44.2	<0.001
Coccinella septempunctata	38.8 ± 9.60^{b}	8.25 ± 3.91^{a}	28.6 ± 3.07^{b}	6	9.30	<0.001
Stethorus punctata	19.5 ± 5.52^{a}	0.00 ± 0.00^{a}	23.6 ± 6.91^{a}	6	1.51	>0.051
Lioadalia flavomaculata	33.8 ± 5.11^{a}	0.00 ± 0.01^{a}	27.3 ± 11.5^{a}	6	4.40	>0.051

*df: degrees of freedom; *F*: significance of f-value; *P*: significance of *P*-value

3.3.1.2 Diversity measures

Shannon Diversity Index: The Shannon diversity index values were significantly higher in the organic agroecosystem, followed by the organic intercropped agroecosystem and the lowest in the conventional agroecosystem. There were significant differences between organic and conventional systems (P<0.01), while no significant differences were observed between the organic intercropped and conventional agroecosystems (P>0.05) (Table 3.4).

Margalef's Richness index: Both the organic and organic intercropped systems indicated similar species richness compared to the conventional agroecosystem with lower species richness. Differences in Margalef richness index among the three agroecosystems were not significant (P>0.05) (Table 3.4).

Pielou's Evenness index: Evenness was higher in the conventional agroecosystem compared to the organic agroecosystem and the organic intercropped agroecosystem. Higher evenness in the conventional agroecosystem indicates that the species are evenly distributed within this system. (Figure 3.6). These differences were however not significant (P>0.05) (Table 3.4).

Berger Parker Dominance index: A higher dominance was recorded in the organic intercropped agroecosystem than the conventional agroecosystem, while the lowest dominance was observed in the organic agroecosystem. The high dominance in the organic intercropped was the result of a single abundant species *H. variegata* (N = 624), which contributed an overall of 53% of the species composition. Differences between the dominance index of coccinellid individuals for the three agroecosystems were statistically significant between the organic agroecosystem and the conventional agroecosystem (P<0.005) (Table 3.4).

Bray Curtis similarity index: The maximum similarity value was 0.65 (65%) between organic and organic intercropped agroecosystems, and the minimum similarity was between both organic agroecosystem and conventional agroecosystem 0.28 (28%) (Table 3.5).

Table 3.4 Mean (± S.E) values for coccinellid diversity indices; H': Shannon-Wiener Diversity, M': Margalef Richness, J:' Pielou's Evenness and D': Berger-Parker Dominance in different wheat agroecosystems. Values followed by the same lowercase letter within columns are not significantly different

Systems	**Biodiversity Indices**			
	H' ± S.E	R' ± S.E	J' ± S.E	D' ± S.E
Organic	1.32 ± 0.02^{a}	0.59 ± 0.03	0.94 ± 0.01	0.28 ± 0.01^{a}
Conventional	0.76 ± 0.24^{b}	0.52 ± 0.16	0.86 ± 0.06	0.58 ± 0.14^{b}
Organic-Intercropped	1.61 ± 0.04^{a}	0.60 ± 0.03	0.89 ± 0.04	0.30 ± 0.02^{a}
df	9	9	9	9
F-value	15.7	0.31	9.20	8.42
P-value	<0.001	>0.05	>0.03	<0.01

Table 3.5. Bray Curtis similarity index of coccinellid individual abundance in the ORG, CONV and ORG-INTR

	ORG	**ORG-INTER**	**CONV**
Organic	1	0.65061	0.28551
Organic-intercropped	0.65061	1	0.28779
Conventional	0.28551	0.28779	1

3.3.2 Carabid beetle distribution and composition

3.3.2.1 Richness and Abundance

Carabid abundance (N=712) and richness (S=11) was higher in the organic agroecosystem, followed by organic intercropped system (S =11; N = 848) and conventional system with the lowest abundance (S = 7; N = 88), (Table 3.2). *Calosoma caminara* (23.7%), *Amara eanea* (15.5%), *Pterostichus aethiops* (12.5%), *Pterostichus aterrimus* (11.2%), *Bembidion lampros* (9.9%), *Agonum gracilipes* (9.9%) and *Bembidion properans* (8.8%) were present in all the agroecosystems, while *Pterostichus madidus* (4.7%), *Agonum viduum* (4.2%), *Thermophilum homoplatum* (0.7%) and *Graphiptes auratiacus* (0.4%) were only found in the organic and intercropped system. *C. Caminira* (N = 385), was the most abundant species contributing 24% to the species composition and *Graphiptes auratiacus* (N = 10) had the lowest abundance contributing only 0.4% to the species composition (Table 3.2). Figure 3.7 indicate that total abundance of different carabidae species differed significantly across the agroecosystem (F=9.07; P=0.01).

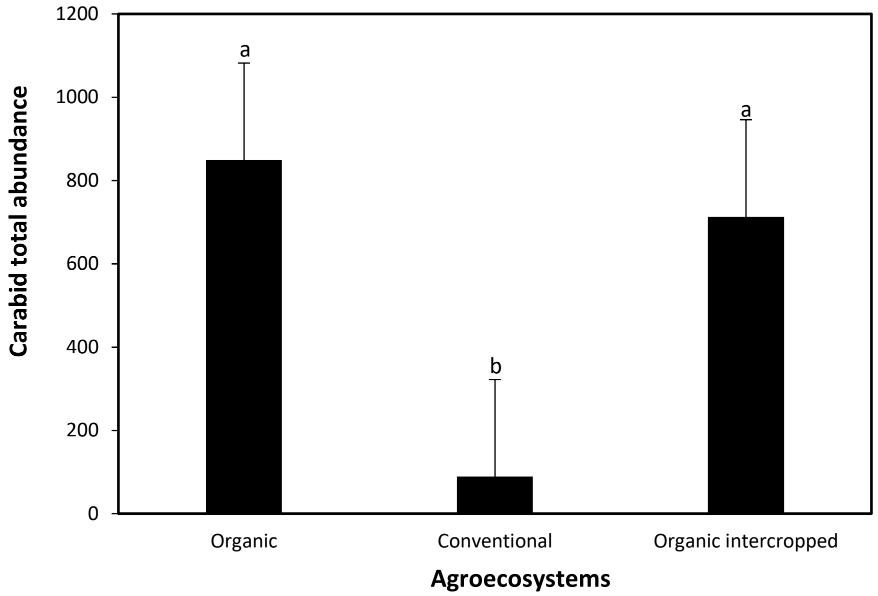

Figure 3.7. Total abundance of carabid beetles in the (ORG, CONV and ORG-INTR). Bars (± S.E) with the same letter do not differ significantly

The overall ranking of carabid individuals based on the proportional abundance showed that *C. caminara, A. eanea, P. aethiops,* and *P. aterrimus,* were the dominant species ranked from 1 to 4, respectively having proportional abundance percentage of 62.9% of the total individuals. The other species were ranked from 5 to 11 with a proportional abundance ranging from 9.0%

to 4.0% and together accounted for 28.2% of the total abundance. From the observed abundance curve (Figure 3.8) the steep slopes indicate that species were not evenly distrubuted in the organic, organic intercropped and conventional systems. Lower proportion in the conventional systems is ascribed to the dominance of a few individuals (Figure 3.8). Higher proportion observed in the organic and intercropped systems can be explained by common abundant species whereas other few species were rare.

Table 3.6 indicates significant differences within species *C. caminara* (F=46.37; P=0.0002), *A. eanea* (F=16.09; P=0.003), *P. aethiops* (F= 12.9; P=0.006), *P. aterrimus* (F=20.54; P=0.002), *A. gracilipes* (F=26.17; P=0.001), *A. viduum* (F=6.4; P=0.03) and *B. lampros* (F=12.01; P=0.007). These seven carabid species were significantly more abundant in the organic system (P<0.0001) and organic intercropped system (P<0.01) than in the conventional system (P>0.05) (Table 3.6). Four species in the conventional system *T. homoplatum* (F=5.11; P>0.05), *G. anoora auratiacus* (F=2.85; P>0.05), *P. madidus* (F=3.66; P>0.05) did not differ significantly in total abundance.

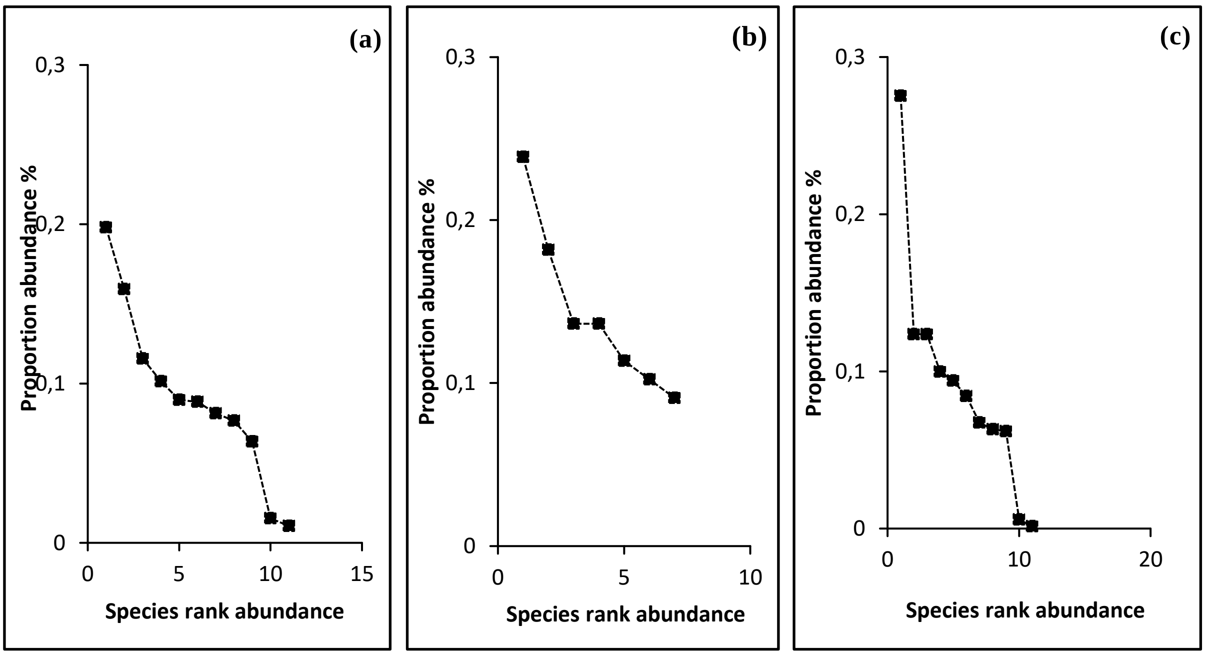

Figure 3.8. Species rank abundance for carabid beetles in the (a) ORG, (b) CONV and (c) ORG-INTR

Table 3.6. Carabid species abundance (Mean ± S.E) as influenced by different agroecosystems (ORG, CONV and ORG-INTR). Mean values followed with the same lowercase letter in a row did not differ significantly (*P*>0.05)

SPECIES	AGROECOSYSTEMS			ANOVA		
	ORG	CONV	INTER	df	*F*-value	*P*-value
Pterostichus madidus	16.3 ± 5.02[a]	5.31 ± 2.10[a]	12.1 ± 3.71[a]	6	3.76	>0.05
Pterostichus aethiops	18.8 ± 4.11[a]	0.00 ± 0.00[b]	15.0 ± 3.70[a]	6	12.95	<0.01
Pterostichus aterrimus	26.1 ± 3.90[a]	2.01 ±1.10[a]	17.8 ± 4.61[a]	6	20.5	<0.01
Agonum gracilipes	22.0 ± 4.02[a]	0.00 ± 0.00[b]	16.8 ± 3.93[a]	6	26.17	<0.05
Agonum viduum	13.5 ± 3.90[a]	3.11 ± 0.70[a]	11.1 ± 3.52[b]	6	6.40	<0.05
Bembidion lampros	19.0 ± 5.07[a]	2.30 ± 0.51[b]	22.0 ± 4.40[a]	6	12.01	<0.01
Bembidion properans	17.3 ± 1.81[a]	3.10 ± 1.30[a]	1.31 ± 5.70[a]	6	3.38	>0.05
Calosoma caminara	42.1 ± 4.50[a]	2.51 ± 0.60[b]	49.0 ± 4.01[b]	6	46.37	<0.01
Amara eanea	33.8 ± 4.21[a]	3.00 ± 0.81[b]	22.1 ± 5.70[a]	6	16.09	<0.01
Graphiptes auratiacus	2.30 ± 1.10[a]	0.00 ± 0.00[a]	0.25 ± 0.25[a]	6	2.85	>0.05
Thermophilum homoplatum	3.31 ± 1.51[a]	0.00 ± 0.00[a]	1.00 ± 0.70[a]	6	5.11	>0.05

***df: degrees of freedom; *F*: significance of *F*-value; *P*: significance of *P*-value

3.3.2.2 Diversity measures

Shannon Diversity Index: The Shannon diversity index values was highest in the organic agroecosystem compared to the organic intercropped agroecosystem and conventional agroecosystem. There were significant differences in Shannon diversity between organic and conventional agroecosystems ($P<0.01$) while there were no significant differences between the organic intercropped and conventional agroecosystems ($P>0.05$), (Table 3.7).

Margalef's Species Richness: Margalef richness index was highest in the organic intercropped agroecosystem and lowest in the conventional agroecosystem. The differences were not significant between the agroecosystems ($P>0.05$) (Table 3.7).

Pielou's Evenness: Differences in species evennesss among the three agroecosystems were not significant, as indicated by similar evenness for all the agroecosystems.

Berger Parker Dominance index: Dominance values were significantly higher in the conventional system than in the organic and organic intercropped systems ($P<0.01$). Moderate higher dominance in the organic and organic intercropped agroecoystems is acribed to higher abundance of *C. caminara, A. eanea and P. aethiops* in this two agroecosystems. The conventional agroecosystems indicated higher dominance due to few species *C. caminara, A. eanea, P. aterrimus, B.* lampros and A. *gracilipes,* (Table 3.7).

Similarity of Bray Curtis index: Showed maximum similarity (0.86 = 86%) between the organic and organic intercropped agroecosystems and minimun similarity (0.18 = 18%) between organic and conventional agroecosystems. Organic intercropped and conventional agroecosystems had a similarity index of 0.22 which is 22% (Table 3.8).

Table 3.7. Mean (± S.E) values for carabid diversity indices; H': Shannon-Wiener Diversity, Mg': Margalef Richness, J': Pielou's Evenness and D': Berger-Parker Dominance in different wheat agroecosystems. Values followed by the same lowercase letter within columns are not significantly different

SYSTEMS	**BIODIVERSITY INDICES**			
	H'± S.E	M'± S.E	J'± S.E	D'± S.E
Organic	1.25 ± 0.04[a]	0.7 ± 0.02	0.9 ± 0.01	0.3 ± 0.01[b]
Conventional	0.74 ± 0.18[b]	0.71 ± 0.07	0.9 ± 0.02	0.6 ± 0.1[a]
Organic-Intercropped	1.07 ± 0.12[a]	0.67 ± 0.07	0.8 ± 0.002	0.4 ± 0.06[b]
d.f.	27	27	27	27
F-value	3.75	0.11	0.97	3.79
P-value	<0.01	>0.05	>0.05	<0.01

Table 3.8. Bray Curtis similarity index of carabid individual abundance in the (ORG, CONV and ORG-INTR)

	ORG	**ORG-INTER**	**CONV**
Organic	1	0.86154	0.18803
Organic-Intercropped	0.86154	1	0.22
Conventional	0.18803	0.22	1

3.4 DISCUSSION

Currently monoculture practices are simplified due to the use agrochemicals. This negatively affects the biodiversity of carabid and coccinellid beetle groups in agroecosystems (Benton, Vickery & Wilson, 2003; Bengtsson *et al*., 2005). The balance between production management practices and predatory species should be investigated for a better and sustainable future. Biologically managed systems have been perceived to favour species biodiversity while intensively managed systems lead to enormous biodiversity losses. For, instance, organic and intercropping are sustainable practices that have been recognized to maintain and promote the biodiversity of naturally occurring invertebrates (Landis *et al*., 2005; Ratnadass *et al*., 2012; Botha *et al*., 2018), as a result of absence of agrochemicals and the provision of adequate resources such as pollen, nectars, shelter and overwintering site (Altieri & Nicholls, 2004).

Abundance and Diversity

The results indicate that different managements in wheat systems have an effect on the diversity of predatory beetle groups. Total abundance of carabid and coccinellid beetles differed significantly between the three agroecosystems. The organic and organic intercropped agroecosystems supported the greatest number of individuals while the conventional agroecosystems showed lower levels of abundance for both families. For Coccinellidae species *Hippodamia variegata* was the most abundant in the three agroecosystems with *Stethorus punctum* (Appendix B.1) the least abundant and for Carabidae species, *Calosoma caminara* was the most abundant species found in all the agroecosystems followed by *Thermophilum homoplatum* which least abundant (Appendix B.2) was found only in the organic and organic intercropped systems. According to Bray Curtis index higher similarity for carabid and coccinellid beetles occurring between the organic and organic intercropped agroecosystems, can be an indication of few common dominant species. The conventional system was dominated by few abundant carabid and coccinellid individuals, while the other species were lower in abundance or rare (Niemelä 1993; Koivula, Kukkonen & Niemelä, 2002). It also supported the theory that more commonly collected species are found at a higher number of study sites than rarer species (Brown, 1984).

The Shannon diversity index and dominance index for both families differed significantly between the agroecosystems. The moderately higher diversity for carabid and coccinellid beetles in the organic agroecosystem compared to the organic intercropped and the conventional systems can be ascribed to higher abundance, moderately high evenness and low dominance (Truter, Van Hamburg & Van Den Berg, 2012; Anbalagan *et al*., 2015). Our results concur with the findings of Shah *et al*. (2003), Moschini *et al*. (2012) and Romero (2016), who concluded that predators like carabid and coccinellid beetles were in greater numbers in organic agroecosystems than in conventional ones. Similar results were described by (Clough *et al*., 2007; Anjum-Zubair *et al*., 2010).

According to the study conducted by Rainio and Niemelä (2003), changes in species abundance patterns are often observed in response to habitat modification and climate changes. Lower abundance and diversity of carabid and coccinellid beetles in the conventional system can be explained by the habitat change with high chemical ratio which can relatively reduce their food sources. In addition, carabid beetles can also be influenced by tillage practices. This is also supported by Vandercycken *et al*. (2013) affirming that one of the dominant factors that could influence the abundance of natural enemies in monoculture systems, is the wide spectrum of agrochemicals used resulting in different impact on coccinellid beetle abundance. The observation that the organic and organic intercropped agroecosystems had a higher abundance and diversity of coccinellid and carabid beetles shows the importance of field management practices (Letourneau & Bothwell, 2008; Krauss, Gallenberger & Steffan-Dewenter, 2011). The organic intercropped systems operate with less synthetic fertilizers and instead depend on the use of legumes, manure, mulches, grass margin and strips, which enhance the diversity of beetle species by providing an alternative resources of prey as well as overwintering sites (Basset, 2007; Jankielsohn, 2017), and the organic systems depends on the use of organic manure, compost and crop residue, reduction of pesticides, and ploughing modification which may also enhance the biodiversity of carabid and coccinellid beetles (Lampkin, Measures and Padels, 2000; Hole *et al.*, 2005). For example, total abundance of Carabidae species *C. caminara* in the intercropped systems comprised high abundance and diversity (Appendix B.3), followed by Coccinellidae species; *H. variegata* found in the organic intercropped with higher abundance and diversity (Appendix B.4). *C. caminara* and *H. variegata* exhibited higher abundance compared to other species.

These results can be compared to those of Liu *et al*. (2017) who observed higher abundance of *H. variegata* in the intercropped systems compared to the conventional monoculture in wheat farming management of China and USA; and further concluded that diversified systems are the most important means for increasing the abundance of beneficial arthropod in farmland, Asiry, (2013) found moderately abundant carabid *P. madidus* and *A. eanea* in wheat organic farming systems compared to the conventional farming systems. Additionally, studies conducted by Botha, (2014) in South African maize agroecosystems indicated high abundance of *H. variegata* accounting 70.29% of the total individuals captured.

Biological indicators

The result study indicates that some carabid and coccinellid species are more susceptible to drastic changes in the conventional agroecosystems, while others can be considered generalists, found in organic, organic intercropped and conventional agroecosystems. Amongst the 11 carabid species, 7 species can be considered habitat generalists, occurring in all systems: *Calosoma caminara, Amara eanea, Pterostichus aethiops, Pterostichus aterrimus, Bembidion lampros, Agonum gracilipes* and *Bembidion properans* comprised 89.2% whereas among 7 Coccinellid species only 4; *Hippodamia variegata, Cheilomenes lunata, Proplylea dissecta* and *Coccinella septempunctata* accounted for 88.5% were found in all three systems. The abundance and presence of these species in the conventional agroecosystems is an indication of tolerance to environmental changes (Birkhofer *et al*., 2008). Due to their ubiquity we can consider these species generalists because they can survive on a wide range of insect pests, more especially in different diversified agroecosystems with adequate food sources such as pollen, nectar and honey dew (Symondson, Sunderland & Greenstone, 2002). Furthermore, these species can be classified as keystone indicators, because their abundance in all agroecosystems might indicate their predaceous potential (Mills, Soule and Doak, 1993), as their abundance is also determined by the presence and abundance of prey density and their resistance to environmental changes. Carabid species *Pterostichus madidus, Agonum viduum, Thermophilum. homoplatum, Graphiptes auratiacus* which accounted 9.8% and coccinellid species *Lioadalia flavamaculata* and *Stethorus punctum* which accounted 11.6% occurred in the organic and the organic intercropped but lower in the conventional agroecosystem suggesting that these species can be classified as indicator species of environmental disturbance (Mills, Soule and Doak, 1993), since they are susceptible to drastic changes in an ecosystem. And due to their lower relative abundance they can be useful indicators of ecological disturbance. From observed studies the rarity of beetle assemblages in agroecosystem management systems might be due to tillage practices, wide spectrum insecticides, and abiotic stresses (temperature, rainfall and relative humidity) which result in species dispersal to other suitable habitat, as most beetles are sensitive and susceptible for environmental changes. Temperature is the most dominant abiotic factor affecting arthropods phenology both directly and indirectly in their agricultural habitats (Knowlton & Graham 2010; Asiry, 2013). Similar study by Koivula (2011), found that generalist predatory groups were more sensitive to abiotic factors and also appeared to be more susceptible to habitat disturbance. According to '*a review on terrestrial invertebrates as indicators*' by Gerlach, Samways and Pryke (2013), species that are found to be sensitive to changes are useful bioindicators of habitat quality can be used as early warning signallers for habitat disturbance and climate change. This can be helpful in developing long term biomonitoring models in different crops using carabid and coccinellid individuals. Carabidae and Coccinellidae species have sensitivity to management practices or habitat disturbance, which is one of the characteristics that make them good indicators.

3.5 CONCLUSIONS

From our results it can be inferred that Carabidae and Coccinellidae families can be useful biological indicators of wheat management practices due to their changing diversity pattern. Biodiversity of dominant and abundant species in organic and intercropped agroecosystems is an indication of generalist species, which can survive in all agroecosystems, whereas low abundance and diversity of species in conventional systems is an indication of beetle species susceptible to severe environmental changes. The latter can be used as indicators of habitat quality with the possibility of developing a long term biomonitoring model and conservation strategies. We observed that a rich biodiversity of predatory beetles is supported by organic and organic intercropped wheat agroecosystems. This can be attributed to sustainable conservation measures encompassed in these systems. Such management practices are documented to be useful to conserve beetle species which can lead to pest suppression and reduction in the use of high chemical inputs. Carabidae and Coccinellidae species can be considered potential taxa in biodiversity studies as biological indicators for conservation purposes. Moreover, this was a novel study of Carabidae species biodiversity in South African wheat agroecosystems and suggestions for further research include the following aspects:

- Studies on more than one species as bioindicators in varying wheat agroecosystems are not adequately documented; more studies should be conducted to assess the diversity of more than one predatory species including generalist predators such as spiders, mites' and other beneficial species contributing towards supporting their diversity and sustainable future.
- Obtaining more detailed and reliable information about indicator species will guide farmers on improving management farming practices that can enhance the biodiversity of predaceous species.

- Carabid beetles can reflect changes in climatic conditions but their season distributions in most agricultural landscape is largely unknown. Further research on indicators species should be conducted in order to develop management and conservation tools.
- This is can contribute to indicator development as this study provides evidence that Carabidae and Coccinellidae species can be a good start in exploring bioindicator species for wheat agroecosystems and other cereal crops.

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CHAPTER 4

ASSOCIATIONS BETWEEN APHIDS AND THEIR PREDATORS (CARABIDAE AND COCCINELIDAE), INFLUENCED BY ENVIRONMENTAL FACTORS IN WHEAT AGROECOSYSTEMS

ABSTRACT

Pests are problematic in agriculture, particularly for smallholder farmers who cannot afford expensive pesticides. Ecological intensification has proven to suppress pest pressure in a system by creating a stable environment, which promotes the population build-up of beneficial natural enemies, which subsequently regulates pest populations. Aphid (Aphididae) pest population density and their natural enemies Ground beetles (Carabidae) and Lady beetles (Coccinellidae), were evaluated for correlations together with climatic parameters (Rainfall, Temperature and Relative humidity) from September to December 2017, using regression analyses with (PAST 3.20 software). Aphid densities were higher in the conventional system and ANOVA test as well as the multiple regression analysis showed some significant and positive correlations between the carabid and coccinellid beetle abundance and aphid density ($P<0.05$). There was a significant positive linear relationship between aphid numbers and carabid beetles ($R^2=0.52$; $P<0.05$) in the organic system, while weak and insignificant correlations were observed in the intercropped and conventional systems. The regression of the best fit found a strong regression value ($R^2=0.63$) ($P<0.01$) between coccinellid beetle abundance and aphid density in the intercropped system. Among the measured environmental variables, temperature correlated with almost all the species variables, while relative humidity did not correlate with any of the taxa (Aphididae, Coccinellidae and Carabidae).

Keywords: Agroecosystems, Aphididae, Predatory beetles, Climatic parameters, Regression

4.1 INTRODUCTION

The management of the biological components in agriculture is becoming a fundamental aspect of sustainable crop production systems. Intensified agriculture through monoculture farming is the main threat of diverse ecosystems. Conservation biological control is becoming increasingly important for pest control to avoid adverse effects associated with the use of on farm inputs (Greyvenstein, 2015). Natural enemies in agriculture are known as organisms that attack and feed on plant feeding insect species (Martin *et al*., 2013), thereby regulating their population and reducing damaging effects on plants. The practice of biological control is environmentally friendly and economically viable, because it does not disrupt the environment like most agrochemicals and is generally cost effective.

The successful production of staple food crops such as cereals is important to achieve food security and agricultural pests remain one of the major constraints. Several studies have confirmed that aphids are the major pests not only of wheat crops but also other small grains worldwide (Plantegenest *et al*., 2001; Haley *et al*., 2004; Rakhshami, Ebadi and Mohammadi, 2009; Li *et al*., 2013), causing yield loss (Khan *et al*., 2012) and poor production quality (van Emden & Harrington, 2007). Cereal aphids that have been recognized as the most economic important pests in wheat agroecosystems include; the bird cherry oat aphid *Rhopalosiphum padi* (L.), Greenbug *Schizaphis graminum* (Rondani), the English grain aphid *Sitobion avenae* (F.), and lastly the most dominant Russian wheat aphid *Diuraphis noxia* (Mordvilko), (Kieckhefer & Gellner, 1992; Pike *et al*., 1997; Brewer & Elliott, 2004).

The significance of predaceous arthropods in suppressing aphid density have been observed in several pioneering studies (Östman, Ekbom & Bengtsson, 2001; Schmidt *et al*., 2003; Brewer & Elliott, 2004; Lee *et al*., 2005; Bianchi, Booij & Tscharntke, 2006). Aphids are suppressed by different occurring natural enemies in most managed agroecosystems (Van Emden & Harrington, 2007), this includes natural enemies such as Ladybeetles (Pennings, 2017) and Ground beetles (Brewer & Elliott, 2004; Lee *et al*., 2005). According to Losey and Denno (1999), Schmidt *et al*. (2004), and Macfadyen *et al*. (2009), predaceous beetles can suppress aphid density either acting independently or as synergetic thereby reducing reliance on the use of insecticides (Östman, 2004). For instance, ground beetle predators prey on aphids that appear to have dropped from the plant due to disturbance. Lady beetle predators may cause aphids on the plants to fall from the plant onto the ground, where they will be consumed by carabid predators (Symondson, Sunderland & Greenstone, 2002; Shah *et al.*, 2003). Losey and

Denno (1999) found that these predator groups can interact in regulating aphid density to a greater extent than only when is one species assemblages.

Abiotic factors i.e. temperature, relative humidity and rainfall influence the density of agricultural pests and their natural enemies' abundance (Garratt, Wright & Leather, 2010; Gosme, Suffert & Jeuffroy, 2010). The ecological function of arthropods is important when observing and predicting effects of abiotic factors (Koivula, 2011). Global climate changes have led researchers to examine the interactions between species that provide important ecosystem functions (Esilva, Varanda & Rassini, 2007; Shukla, 2014). Due to the impact of abiotic factors, the efficacy of natural enemies may decline as their prey decreases (Ameixa & Kindlmann, 2011a; Wang *et al*., 2014) as shown for several predatory groups including Carabidae and Coccinellidae (El-Wakeil & Volkmar, 2013).

There is a need to identify management practices that are resilient following perturbations, environmentally friendly, fostering herbivore-natural enemy dynamics and reduce pest outbreaks in managed ecosystems. To do this, a better understanding of the relationships between wheat management practices, abiotic factors, prey density and predatory beetle abundance is essential for the development conservation (Darwish & Ali, 2001; Gardiner *et al*., 2009; Xie, 2015; Romero, 2016). Studying and explaining the ecological dynamics of aphids and their natural enemies' functional responses might facilitate the implementation of effective strategies for managing the outbreak of cereal aphids in different agroecosystems management practices. This study generalised the common wheat aphids and their corresponding natural enemies (carabid and coccinellid beetles) in different wheat management systems (Organic, conventional and intercropped) associated with selected climatic parameters.

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4.2 MATERIALS AND METHODS

4.2.1 Environmental variables

Climatic variables can potentially influence agricultural pest population dynamics and their natural enemies' abundance (McIntyre, 2000; Sharma, Chauhan & Sharma, 2015). In order to understand the effect of climatic factors on predatory beetle abundance and aphid density, climatic data was recorded monthly prior to sampling. The data on rainfall, minimum and maximum temperatures and relative humidity were obtained from the Agricultural Research Council: Soil, Climate and Water division.

4.2.2 Insect sampling

Coccinellidae and Carabidae data was collected according to the methods and materials fully described in chapter 3 using pitfall, sticky traps and sweep net sampling, a brief summary is however provided; pitfalls were used to sample carabid beetles while sticky traps and sweep net methods were used to sample coccinellid beetles. Aphid samples were obtained through visual sampling. The visual assessment was done 5 m apart from the four sampling points of the same transect used for beetle sampling. From each sampling point eight plants per plot were randomly selected in each agroecosystems and four tillers per plant were observed for the presence of aphids. In total 32 tillers were visually assessed for aphid presence during four sampling periods from September to December 2017 in each agroecosystem. Observations were made once a week, for 3 consecutive days. Aphid samples from each system were placed in a labelled petri-dish, and transferred to the laboratory where they were counted.

4.2.3 Statistical analysis

Bivariate statistics were performed using PAST version 3.20 (Hammer *et al*., 2001). The mean data of aphid numbers and their natural enemies were subjected to one-way analysis of variance. Statistical significance among the mean number of aphids and predators was tested and compared, using *post hoc* Tukey test at 5% level of significance. Linear regression analysis was used to explore the relationship between the aphid, predatory beetle abundance and climatic variables. Statistical analyses for linear regression were performed with log transformed data; however actual data are used in tables.

4.3 RESULTS

4.3.1 Aphid density and predator abundance

Monthly data (Figure 4.1a) shows that aphid densities were the highest in the conventional system in all the sampling months, while the organic and the intercropped systems were almost similar in aphid densities. Aphid population numbers peaked during November in the conventional system, it decreased in both the organic and intercropped system ($F = 9.36$; $P < 0.01$), (Table 4.2). During December aphid densities decreased in the organic and conventional systems, while there was a slight increase in the intercropped system. Aphid density remained significantly ($F = 12.22$; $P < 0.01$) higher in the conventional system. Overall the conventional system seem to maintain the higher aphid densities in contrast to the organic and intercropped systems. Compared to the conventional system, the organic and the intercropped systems maintained the highest abundance carabid and coccinellid beetles and exhibited similar distribution patterns in all the sampling months. Carabid and coccinellid beetles increased with increasing months from September to December more particularly in the organic and intercropped systems (Figure 4.1b; 4.1c). It is evident from (Figure 4.1a; 4.1b) that the abundance of predators was significantly higher in the organic and intercropped systems compared to the conventional system and this explains the higher population number of aphids in this system (Figure 4.1a).

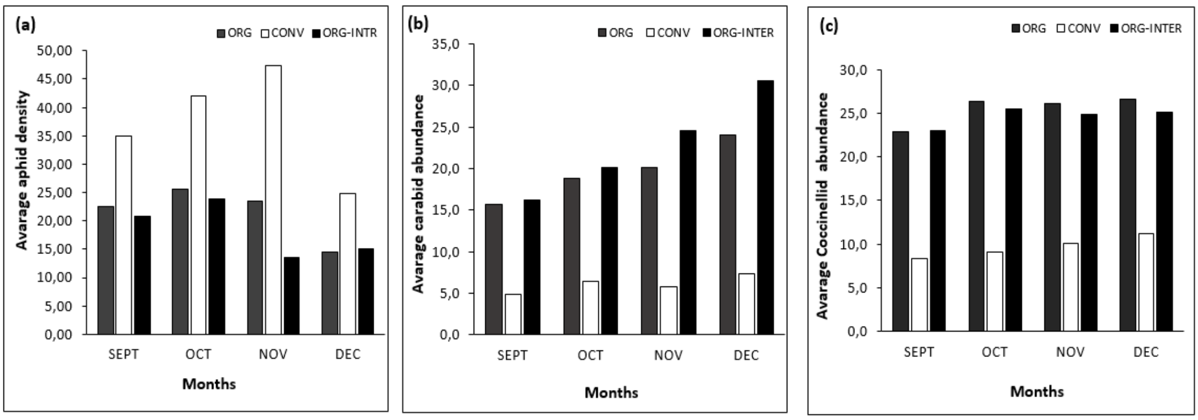

Figure 4.1 Monthly avarage aphid density (a) and carabid (b) and coccinellid (c) beetle abundance for the (ORG, CONV and ORG-INTR)

Table 4.2. Anova test for monthly mean aphid density (a) and carabid (b) and coccinellid (c) beetle abundance in the (ORG, CONV and ORG-INTR)

Months		**Taxa**	**Agroecosystems**			**ANOVA**	
			Organic	Conventional	Intercropped	*F*-value	*P*-value
1.	SEPT	Aphididae	22.6 ± 1.6^{a}	35.0 ± 2.5^{a}	20.8 ± 2.5^{b}	12.33	0.000
2.	OCT		25.6 ± 1.9^{a}	42.0 ± 3.2^{b}	23.9 ± 2.6^{a}	12.90	0.000
3.	NOV		23.5 ± 2.3^{a}	47.4 ± 3.7^{a}	13.5 ± 1.6^{b}	9.36	0.001
4.	DEC		14.5 ± 1.5^{a}	24.8 ± 2.7^{b}	15.0 ± 1.9^{a}	12.22	0.003
		Carabidae					
1.	SEPT		15.6 ± 1.7^{a}	4.9 ± 0.6^{b}	16.3 ± 2.6^{a}	12.22	0.000
2.	OCT		18.9 ± 2.6^{a}	6.4 ± 1.0^{b}	20.1 ± 2.6^{a}	12.92	0.002
3.	NOV		20.1 ± 2.4^{b}	5.6 ± 0.7^{a}	24.6 ± 2.4^{b}	32.13	0.001
4.	DEC		24.0 ± 1.5^{a}	7.4 ± 0.9^{b}	30.5 ± 2.7^{a}	30.48	0.030
		Coccinellidae					
1.	SEPT		22.9 ± 2.6^{a}	8.4 ± 0.9^{b}	23.0 ± 1.8^{a}	23.34	0.050
2.	OCT		26.4 ± 2.1^{a}	9.1 ± 1.1^{a}	25.5 ± 2.1^{b}	27.12	0.000
3.	NOV		26.0 ± 2.0^{b}	10.1 ± 1.2^{a}	24.9 ± 2.8^{a}	18.01	0.000
4.	DEC		26.6 ± 2.4^{a}	11.3 ± 1.9^{b}	25.1 ± 2.3^{a}	14.70	0.000

†Means with the same superscripts in a row did not differ significantly (Tukey's test 5%)

Table 4.2 illustrated that, the distribution of aphids and their predatory assemblages, coccinellidae and carabidae exhibited contrasting patterns in terms of abundance and density across the systems. Aphids were most abundant in the conventional system and least abundant in both the organic and the intercropped systems. Predator assemblages were more abundant in the organic and the intercropped systems while least abundant in the conventional system. These contrasting relationships can be explained by various factors. Fistly, the high density of aphids in the conventional system compared to other systems may be due to the low density of aphid predators in this system due to use of agrochemicals, which disrupts the colonisation and activity of these beetles predators. The organic and the intercropped systems supported higher populations of predators and low aphid density, probably because these systems are not disturbed chemically and mechanically. This provides favourable habitats for predators to reproduce and fully establish because of diverse food sources such as other arthropods, nectar and shelter such as weeds. This enables the predators to control aphids more effectively.

4.3.2 Relationships between Aphid density and predator abundance

Regression and ANOVA summary of the variables (Table 4.3), showed some significant and positive correlations between the predator fractions and aphid densities. There was a strong and positive linear relationship between aphids and carabid beetles (R^2=0.52; P=0.04) in the organic system (Figure 4.2a and Table 4.3). A weak correlation was observed between carabid beetles and aphids in the conventional system (R^2=0.003) (Figure 4.3b), no significant difference was observed in this system (P>0.05). In the intercropped system no significant differences were observed (P=0.22) and regression analysis displayed a very weak correlation between Carabidae and aphids (R^2=0.24) (Figure 4.2c). The regression of the best fit showed a strong regression value (R^2=0.63) between coccinellid beetles abundance and aphid density in the intercropped system (Table 4.3 and Figure 4.2c), suggesting a strong and positive correlation, the correlation also exhibited significant differences across the systems (P<0.01). There was a weak correlation between aphid density and coccinellid abundance in both the organic (R^2=0.4) and the conventional system (R^2=0.02). No significant differences were observed in these systems (P>0.05) respectively, (Table 4.3).

Table 4.3 The associations between aphid density and carabid and coccinellid beetle abundance in (ORG, CONV and ORG-INTER)

Systems	Variables	Estimates	Std. error	T-test	***P*-value**	***R*-equation**	R^2
ORG	Aphids × Cara	1.14	0.45	2.56	0.04*	y=1.114x+2.50	0.52
	Aphids × Cocc	1.20	0.59	2.04	0.09^{ns}	y=1.204x+1.59	0.40
CON	Aphids × Cara	-0.27	6.40	-0.04	0.97^{ns}	y=-0.274x+150.59	0.03
	Aphids × Cocc	-1.41	1.13	1.13	-1.24^{ns}	y=1.407x+180.03	0.02
INT	Aphids × Cara	-1.07	0.78	-1.38	0.22^{ns}	y=-1.071x+105.80	0.24
	Aphids × Cocc	0.95	0.29	3.23	0.002**	y= 0.9486x+18.46	0.63

†Cara= Carabidae; Cocc = Coccinellidae; Std. = Standard error; R^2 = Regression; ns = non-significant; p-values are significant at ****P*≤0.01 and ***P*≤0.05

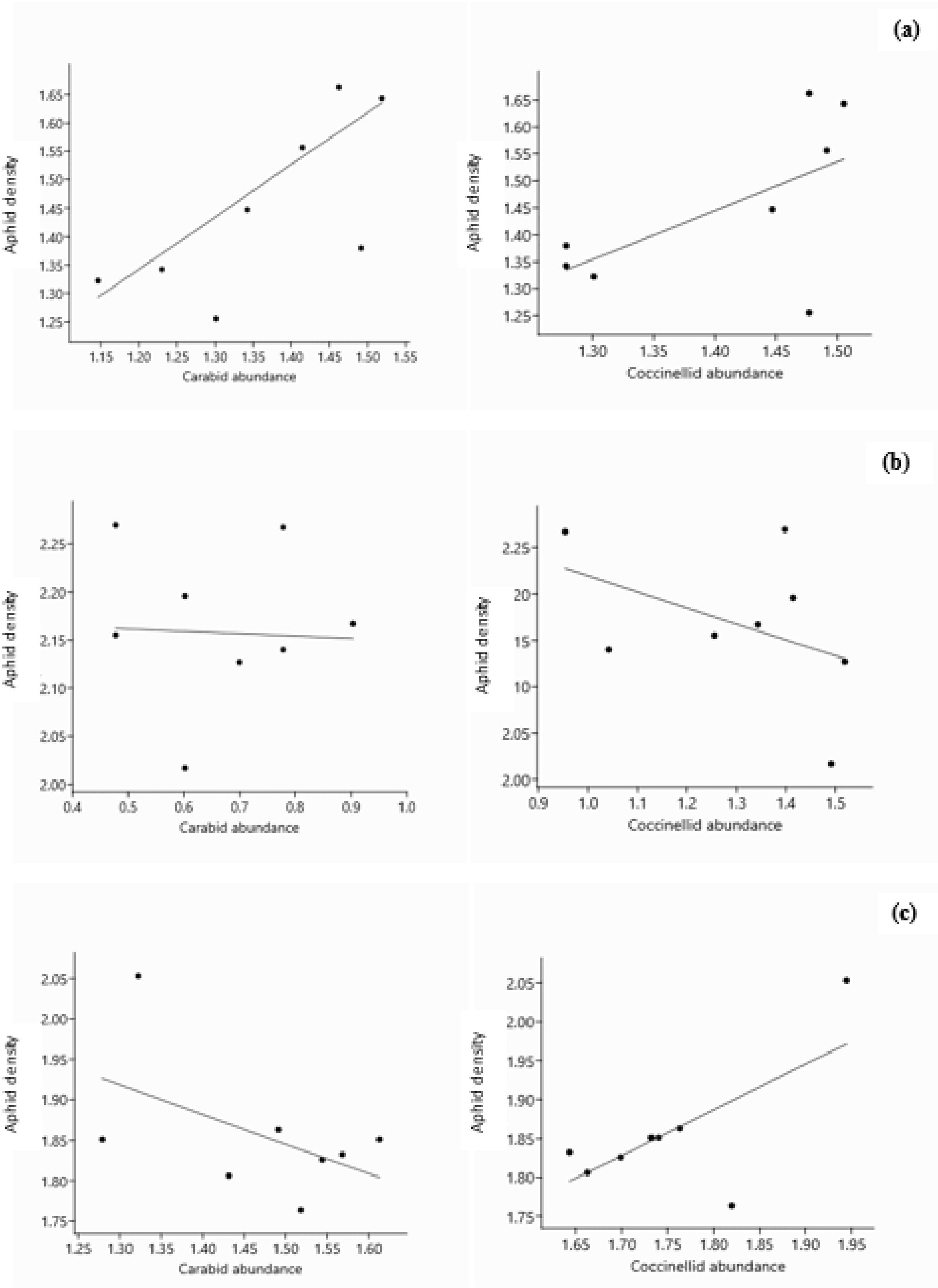

Figure 4.2 Regression relationships between predator abundance and aphid density in (a) ORG, (b) CONV and (c) ORG-INTER), the linear model trend line demonstrates the relationship between variables

4.3.3 Relationships between environmental factors and abundance of aphids and their predators

The multiple regression analysis data showing correlations between aphid numbers and their predator numbers with selected three sets of environmental variables which includes; temperature, relative humidity and rainfall is presented in Table 4.4. Aphid numbers were significantly influenced by temperature (R^2=0.98; P<0.01). A weak correlation was observed between aphid numbers and relative humidity (R^2=-0.077; P>0.05). The correlation between aphid numbers and rainfall was positive but not significant (R^2=0.931; P>0.05) suggesting there is a weak correlation.

Carabid abundance were significantly influenced by two of three environmental variables, namely; temperature (R^2=0.95; P=0.05) and rainfall (R^2=0.96; P=0.03). Relative humidity did not correlate with carabid abundance (R^2=0.14) with no statistical differences observed (P>0.05). Temperature influenced coccinellid abundance (R^2=0.656) compared to relative humidity (R^2=0.027) and rainfall (R^2=0.005) and no significant difference was detected (P<0.05), indicating there were weak correlations between these variables.

Table 4.4 The effect of environmental factors aphid density and predatory carabid and coccinellid beetle abundance

Taxa	Variable	y= a + bx	R^2	*P*-value
Aphididae	Temperature (°C)	**y=0.039+13.83x**	**0.982**	**0.018**
	Relative Humidity (%)	y=-0.002+38.69x	-0.077	0.923
	Rainfall (mm)	y=0.003+-0.3x	0.093	0.069
Carabidae	Temperature (°C)	**y=0.112+6.69x**	**0.950**	**0.050**
	Relative Humidity (%)	y=0.014+36.29x	0.140	0.860
	Rainfall (mm)	**y=0.009+-0.94x**	**0.967**	**0.033**
Coccinellidae	Temperature (°C)	y=0.216+-12.84x	0.656	0.344
	Relative Humidity (%)	y=0.186+8.70x	0.027	0.373
	Rainfall (mm)	y=0.024+-3.614x	0.005	0.095

†Variables with significant (P<0.05) and positive regression are bold

4.4 DISCUSSION

This study provides insights into the density and distribution patterns of cereal aphids in relation to predator abundance, as well as their correlative relationships between differently managed organic, conventional and intercropped wheat agroecosystems. Observations from this study revealed that Aphididae population density were greater in the conventional system, while lowest in the organic and intercropped systems. According to Silva *et al*. (2012) most cereal aphids have been reported to have developed resistance to several insecticides in most mono-cropping systems. The significantly lower density of aphids in the organic and intercropped systems have been observed from other studies by crop protection specialists who have exhibited similar trends (Honek, 1991; Kieckhefer & Gellner, 1992; Hooks & Johnson, 2003; Khan *et al*., 2012). The cereal aphid complex has been documented to have a variety of hosts such as grass species (Blackman & Eastop, 2000; Darwish & Ali, 2001). The fact that the conventional system in our study area (Lower land farm) is surrounded and in a close proximity to uncultivated natural land, which has different grass species, including ryegrass, teff grass and buffalo, can possibly explain high aphid density in this system (Bianchi & Wäckers, 2008; Al Hassan *et al*., 2013). Low aphid abundance in the organic and the intercropped system can be attributed to high predator abundance in these systems. This is supported by strong statistical differences between the agroecosystems (P<0.05; P<0.01). The observed positive relationships between carabid beetles in the organic system appeared to be due to their abundance, which increased with an increase in aphid densities, and were dependant on each other. Carabid beetle correlated with almost all the measured environmental variables with the exception of relative humidity (Sarvendra, Akhilesh & Awasthi, 2005). These results are in agreement with those of Swaminathan, Meena and Meena (2016) who studied aphidophagous predators in maize and observed significant correlations between temperature and aphid population numbers. Among the measured environmental variables, temperature correlated with almost all the species variables, while relative humidity did not correlate with any of the species. This means that temperature significantly influences the abundance of aphids and carabid species as indicated by a positive correlation. The relationships between the climatic parameters and aphids as well as predatory beetles were tested to analyse the influence of climatic parameters on their population abundance. In other studies, (Legg & Brewer, 1995; Al Hassan *et al*., 2013; Sharma, Chauhan and Sharma, 2015; Karuppaiah, and Sujayanad, 2012), aphids highly correlated with all the climatic variables i.e. Relative humidity, temperature and rainfall. However, in this study it was not the case, aphids only correlated with a single variable ‘temperature’ (Table 4.4). Since this study was done in the same area/locality, a variety of gradients such as elevation, latitude and season may possibly explain the observed inconsistencies in the results, because these factors have been documented to influence the population distribution of organisms (Rodríguez & Navarrete-Heredi, 2019). Therefore, intensive sampling across different elevation gradients, regions and seasons is necessary to observe clear differences.

4.5 CONCLUSIONS

Understanding pest control services is important to increase the success of ecological intensification structures. The development of ecological pest management strategy requires knowledge and understanding of predator-prey interactions within agroecosystems. According to Östman (2004), high predatory abundance in the fields were facilitated by high abundance of cereal aphids. This is fundamental for biological control because high predator abundance in a system enhances effectiveness of biological control, even it is expedited by high prey abundance.

Some important observations made from this study are as follows:

- Carabid and coccinellid beetles were highly distributed in the organic and the intercropped systems. These systems resemble natural ecosystems in that there are no chemical practices, while there is a diversity of different plants. Increasing agricultural habitats with high crop rotation, polyculture and cover crops is advantageous to natural enemies and their efficacy of biological pest control of miscellaneous pests such as cereal aphids.

- There was no general relationship observed between coccinellid predator’s population distribution and any of the environmental variables. This suggests that coccinellid predator distribution was not influenced by environmental variables. Nevertheless, we suggest that long term research should investigate other abiotic factors soil pH, soil moisture in relation to carabid beetles.

This agroecological study of predators and their aphid prey relationships with environmental factors provide important preliminary information regarding patterns of abundance and, biotic-abiotic interactions that can be used as model to maximize crop production efficiency and diminish the effects of environmental degradation in agroecosystems.

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CHAPTER 5

EFFECT OF AGROECOSYSTEMS ON PREDATORY BEETLES GROUPS; CARABIDAE AND COCCINELLIDAE BODY SIZE

ABSTRACT

Not much is documented on the effect of different agricultural landscapes on the body size of carabid and coccinellid beetles. Body size is a good indicator of functional diversity. The effect of organic, conventional and intercropped systems on the biomass of carabid and coccinellid beetles was investigated in this study. 4 carabid and coccinellid individuals collected from each system were dried at 48°C and weighed. To determine the total species biomass, species dry mass were multiplied with their total abundance in a system. Biomass of carabid and coccinellid species was significantly higher in the organic intercropped (P=0.01), organic (P=0.002) than the conventional systems (P=0.4). The PCA (Principal component analysis) for carabid and coccinellid biomass accounted a variation of 81.85% to 96.9%. The first PCA was mainly positively associated with carabid biomass of *Amara eanea, Bembidion lampros, Agonum viduum* (r = 0.9) and *Calosoma caminara* (r = 0.08) while coccinellid biomass was associated with *Hippodamia variegata, Coccinella septempunctata (r* =0.4) and *Cheilomenes lunata* (r = 0.5). Differences in management practices revealed carabid and coccinellid body size decrease/or increase in the three systems. Our results indicated that the body size of carabid and coccinellid species were lowest in conventional systems which weaken the ecological function of these beetle species. We suggest that carabid and coccinellid species with larger biomass can be used as dominance and keystone indicators whereas species with lower biomass can used as indicators of environmental disturbance.

Keywords: Abundance, Biomass, Carabid beetles, Coccinellid beetles, Environmental disturbance

5.1 INTRODUCTION

Intensified agricultural activities, which are driven by the need to increase production for a rapidly growing human population, causes more prominent land-use change leading to biodiversity loss (Grau, Gasparri & Aide, 2005; FAO, 2015). Although most biodiversity studies focuses on richness, dominance and abundance to document species diversity loss due to agricultural practices (Laurance, 2007; Flynn *et al*., 2009; Truter, Van Hamburg & Van Den Berg, 2012; Botha *et al*., 2018), information on other important mechanisms of biodiversity, such as the loss of morphological traits remain limited (Hanihara, Ishida & Dodo, 2003; Dorazio & Connor, 2014).

Amongst other morphological traits body size is the most important functional trait of organisms. It differs depending on habitat conditions and can be affected by management practices (Chown & Gaston, 2010; Di Grumo & Lovei, 2016). Body size variation between beetle groups has been reported as an indication of varied environmental stresses (McGeoch, 1998; Ribera *et al*., 2001; Gomez, Nicolas & Dorta-Guerra, 2014). A common trend for this is the "body size hypothesis", which predicts that body size decreases in disturbed ecosystems compared to undisturbed ecosystem (Gray's 1989; Blake *et al*., 1994). Brown and Sibly (2006) further hypothesized that large body sized may be favoured by diversified environments where alternative resources are available to enable large sized species to complete its reproductive ability (Dixon, 2007).

Body size distribution in relation with management practices, for arthropods and Coleoptera in particular is of ecological interest (Basset, 2015). From this perspective, studies have investigated body size in dung beetles between conserved and farmed land and found that species with large biomass seems to be more effective than species with smaller biomass in adapting to changing habitat from natural to disturbed systems (Jankielsohn, Scholtz & Louw, 2001). Garbalinska and Sklodowski (2008) observed that the body size distribution in carabid beetles is induced by environmental changes. Sloggett (2008) and Dixon (2007) mentioned that body size of Lady beetles is determined by their habitat suitability and prey abundance.

Investigating how environmental stresses affect carabid and coccinellid body size can be helpful in determining species that can be used as indicator of functional diversity, habitat quality or can serve as keystone or/dominance indicators (Szyszko *et al*., 2000; Eyre, Luff & Leifert, 2013; Gomez, Nicolas & Dorta-Guerra, 2014). According to Mills, Soulé and Doak, **(**1993) a keystone indicator '*is a species, a group of species, or a structure that affects its* *environment and therefore other species disproportionately strongly relative to its abundance'*. Since the majority carabid and coccinellid beetles are polyphagous feeding on agricultural pests i.e. slugs, aphids and mites, their functionality as predatory groups as well as their body size variation between different management practices need to be assessed. Biological pest control is an ecosystem service that benefits agriculture and it is delivered in part by arthropods such as carabid and coccinellid beetles (Safarzoda *et al*., 2014). The role of carabid and coccinellid beetles is essential within agroecosystems as agricultural pests damage the global food production, causing yield loss and quality, although their control is achieved predominantly by high chemical application, (Symondson, Sunderland & Green, 2002). Carabid and coccinellid beetles are predaceous and diverse, but field-based evidence for functionality as keystone indicators is lacking.

The assessment of body size variation in predatory beetle groups in wheat agroecosystems in South Africa is poorly documented. Enhancement of ecosystem services within agroecosystems will require basic understanding of how their functional traits are affected by different production practices thereby providing practical knowledge on how monitoring of ecosystem services can be implemented (Sukhodolskaya & Eremeeva, 2012).

5.2 MATERIALS AND METHODS

The methodology for sampling the beetles is described in Chapter 3. Carabidae species in the organic (S=11) and in the conventional systems (S=7) were recorded, while Coccinellidae species in the organic and intercropped (S=6) and the conventional (S=4) were recorded. Selected individual carabid and coccinellid beetles from subsamples were dried for 48 hours at 70°C in an oven (Jankielsohn, Scholtz & Louw, 2001). For equality within total individual abundance, four individuals per carabid and coccinellid species were selected per sampling point, species that were found to be rare were not included for biomass analysis. Individuals were weighed and dried to estimate biomass using an analytical weigh balance (0.001 mg) following the procedure of Chungu (2014), (Figure 5.1). The measured individual biomass was used as a proxy for body size. The body size range for individual carabid and coccinellid beetles in each system were categorized as follows: Small (0.0001-0.009 g): Medium (0.01-0.04 g) and Large (0.05-0.1 g) in accordance with Kajita and Evans (2010), respectively (Appendix C.2 and C.3).

Figure 5.1 Weighing dry biomass (mg) of carabid and coccinellid beetles at the ARC-SG entomology laboratory

5.2.1 Statistical analysis

Each dry weight (mg) value was converted to grams (g) using a 1000 to give an estimate of species biomass in grams. The mean individual biomass (MIB) of carabid and coccinellid beetles for each system was calculated by multiplying mean dry weight (g) with the total abundance of collected specimens of each species, using the following formula:

$$\mathbf{MIB}\ (\mathbf{Mean\ Individual\ Biomass}) = \frac{\mathbf{Mean\ dry\ indvidual\ biomass}}{\mathbf{1000}}\ \mathbf{x\ Total\ abundance}$$

Effects of agroecosystems on carabid and coccinellid mean individual biomass were analysed using one-way analysis of variance (ANOVA) followed by *post hoc* Tukey test for statistic significant difference $P \leq 0.01$. Principal component analysis (PCA) was used to assess the relationship between individual biomass and wheat systems (ORG, CONV and ORG-INTR). Statistical analysis was conducted using PAST v3.20 (Hammer *et al*., 2001).

5.3 RESULTS

5.3.1 Coccinellid beetles

Coccinellid mean biomass was significantly affected by different management systems ($P<0.05$). The mean biomass of *Proplylea dissecta* was higher (0.057 ± 0.010 g) within the organic than in the intercropped (0.033 ± 0.005 g) and conventional systems (0.002 ± 0.001 g), while *Hippodamia variegata* had a significantly higher mean biomass in the organic intercropped agroecosystem (0.043 ± 0.006 g) compared the conventional and organic agroecosystems (Table 5.1).

Table 5.1 Coccinellid mean biomass values in the organic, conventiona1 and organic intercropped systems. Mean values with different lowercase letters in a row indicates significant differences according to *post hoc* Tukey test ($P \leq 0.01$)

SPECIES	ORG	CONV	ORG-INTER	STATISTICS
	MIB(g) ± S.E	MIB(g) ± S.E	MIB(g) ± S.E	*P*-value
Hippodamia variegata	0.021 ± 0.005^{a}	0.001 ± 0.000^{b}	0.043 ± 0.006^{a}	< 0.01
Cheilomenes lunata	0.020 ± 0.004^{a}	0.002 ± 0.001^{b}	0.014 ± 0.000^{a}	< 0.01
Proplylea dissecta	0.057 ± 0.010^{a}	0.002 ± 0.001^{b}	0.033 ± 0.005^{a}	< 0.01
Coccinella septempunctata	0.006 ± 0.001^{a}	0.002 ± 0.010^{a}	0.009 ± 0.003^{a}	> 0.01

*****MIB: mean individual biomass; S.E: standard error

The first axes of the PCA, which explained 96.9% of the total variance in the data, was positively correlated with *L. flavomaculata*, C. *septempunctata* and *H. variegata (r* = 0.4). The second axis, which described 3.0 % of the total variation, was negatively correlated with *P. dissecta* (*r* = -0.4) and *H. variegata* (*r* = -0.2) and positively correlated with *C. lunata* (*r* = 0.5) (Table 5.2; Figure 5.3). The organic systems supported two coccinellid species with larger biomass (>0.03 g), the intercropped system supported four species with medium biomass (>0.01 g), while the conventional system supported four smaller species (>0.001 g) (Appendix C.1a).

Table 5.2 Results of principal component analysis (PCA) indicating correlation coefficient for coccinellid species biomass between the systems

Species	PC 1	PC 2
Proplylea dissecta	**0.405**	-0.484
Lioadalia flavomaculata	0.407	**-0.418**
Cheilomenes lunata	0.402	**0.569**
Hippodamia variegata	**0.411**	-0.269
Coccinella septempunctata	**0.409**	0.369
Stethorus punctum	**0.412**	0.236
Eigenvalue	5.814	0.185
% variance	96.912	3.088

†Significant correlations are shown in bold

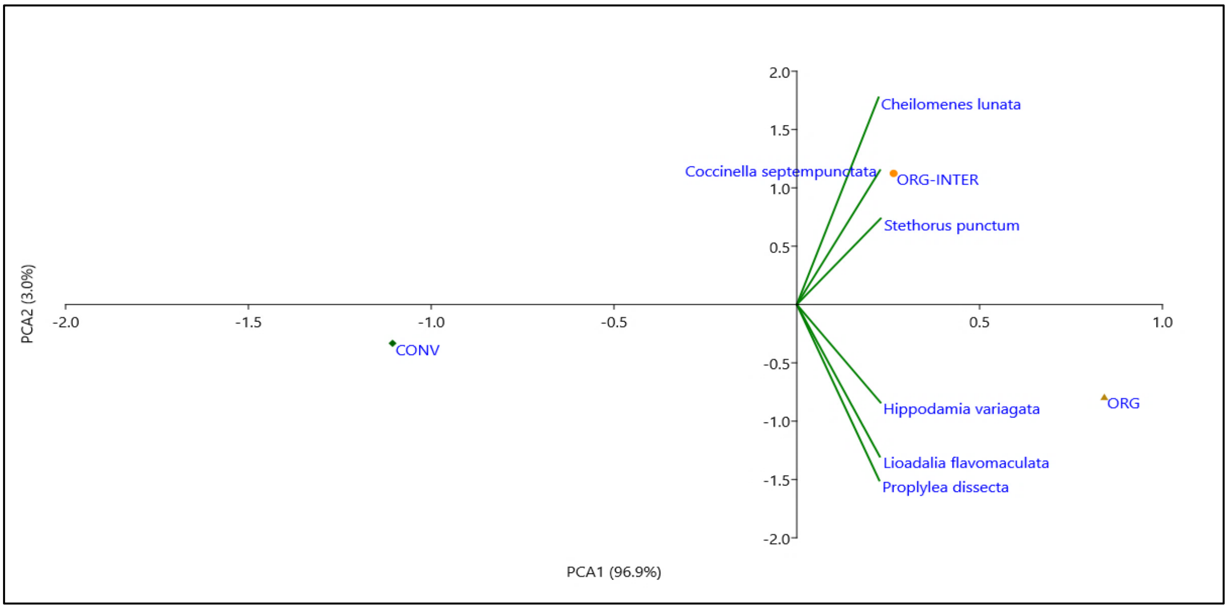

Figure 5.3 Principal component analysis (PCA) biplot representing the relationship between coccinellid biomass and agroecosystems (organic, conventional and organic intercropped)

5.3.2 Carabid Beetles

Intercropped and organic systems influenced carabid mean biomass signifantly (*P*<0.05) as compared to the conventional system. *C. caminira* showed significantly higher mean biomass in the organic system (0.094 ± 0.011 g) compared to the intercropped system (0.114 ± 0.006 g) and the conventional system (0.006 ± 0.002 g). *B. lampros* mean biomass was higher in the organic system (0.027 ± 0.008 g). The mean biomass of *P. aethiops* and *P.aterrimus* was higher in the organic (0.01 ± 0.004 g; 0.014 ± 0.09 g) and intercroppped systems (0.015 ± 0.003 g; 0.012 ± 0.004 g) compared to the convetional system (0 ± 0; 0.001 ± 0.0 g) (Table 5.3).

Table 5.3 Carabid mean biomass values in the organic, conventiona1 and organic intercropped systems. Values with different lowercase letters in a row indicate significant differences according to *post hoc* Tukey tests ($P \leq 0.01$)

SPECIES	ORG	CONV	ORG-INTER	STATISTIC
	MIB(g) ± S.E	MIB(g) ± S.E	MIB(g) ± (S.E)	*P*-value
Pterostichus madidus	0.011 ± 0.004^{a}	0.001 ± 0.002^{a}	0.008 ± 0.003^{a}	> 0.01
Pterostichus aterrimus	0.014 ± 0.091^{a}	0.001 ± 0.000^{ab}	0.012 ± 0.004^{a}	< 0.01
Agonum gracilipes	0.008 ± 0.001^{a}	0.001 ± 0.0001^{a}	0.002 ± 0.000^{a}	> 0.01
Agonum viduum	0.013 ± 0.003^{a}	0.000 ± 0.000^{b}	0.006 ± 0.002^{a}	< 0.01
Bembidion lampros	0.027 ± 0.008^{a}	0.001 ± 0.000^{ab}	0.001 ± 0.00^{aa}	< 0.01
Bembidion properans	0.015 ± 0.001^{a}	0.001 ± 0.000^{a}	0.006 ± 0.002^{ab}	< 0.01
Calosoma caminara	0.037 ± 0.011^{a}	0.006 ± 0.002^{b}	0.114 ± 0.006^{a}	< 0.01
Amara eanea	0.022 ± 0.001^{a}	0.001 ± 0.0001^{b}	0.015 ± 0.003^{a}	< 0.01

*****MIB: mean individual biomass; S.E: standard error

The first PCA axis accounted for (81.85%) of the total variation and second axis explained (18.8%). The PCA1 axis was positively correlated with *A. eanea, B. lampros, P. madidus, A. viduum* (*r* = 0.9), *C. caminara* (*r* = 0.8) and negatively correlated with *P.aethiops* (*r* = -0.9). The second axis of PCA positively correlated with species *G. auratiacus* (*r* = 0.9), respectively (Table 5.4; Figure 5.5.). Carabid beetles in intercropped system was dominated by larger sized carabid species (>0.03 g), followed by five medium sized species (>0.01 g). Whereas the organic system was dominated by two larger sized species (>0.03 g), two medium sized species (>0.01 g) and seven smaller sized species (>0.001 g). The conventional system supported two medium species (0.01 g) and five smaller species (>0.001 g) (Appendix C.1b).

Table 5.4 Summary of principal component analysis (PCA) indicating correlation coefficient for carabid individual biomass between the systems

Species	PC 1	PC 2
Pterostichus madidus	**0.997**	-0.073
Pterostichus aethiops	-0.93	0.346
Pterostichus aterrimus	**0.969**	-0.245
Agonum gracilipes	0.785	0.619
Agonum viduum	**0.983**	0.179
Bembidion lampros	**0.987**	0.156
Bembidion properans	**0.944**	0.328
Calosoma caminara	**0.861**	**-0.508**
Amara eanea	**0.997**	-0.069
Graphipterus anoora auratiacus	-0.170	**0.985**
Thermoliphum homoplatum	**0.982**	0.187
Eigenvalue	8.99	2.003
% variance	81.85	18.81

†Significant correlation are shown in bold

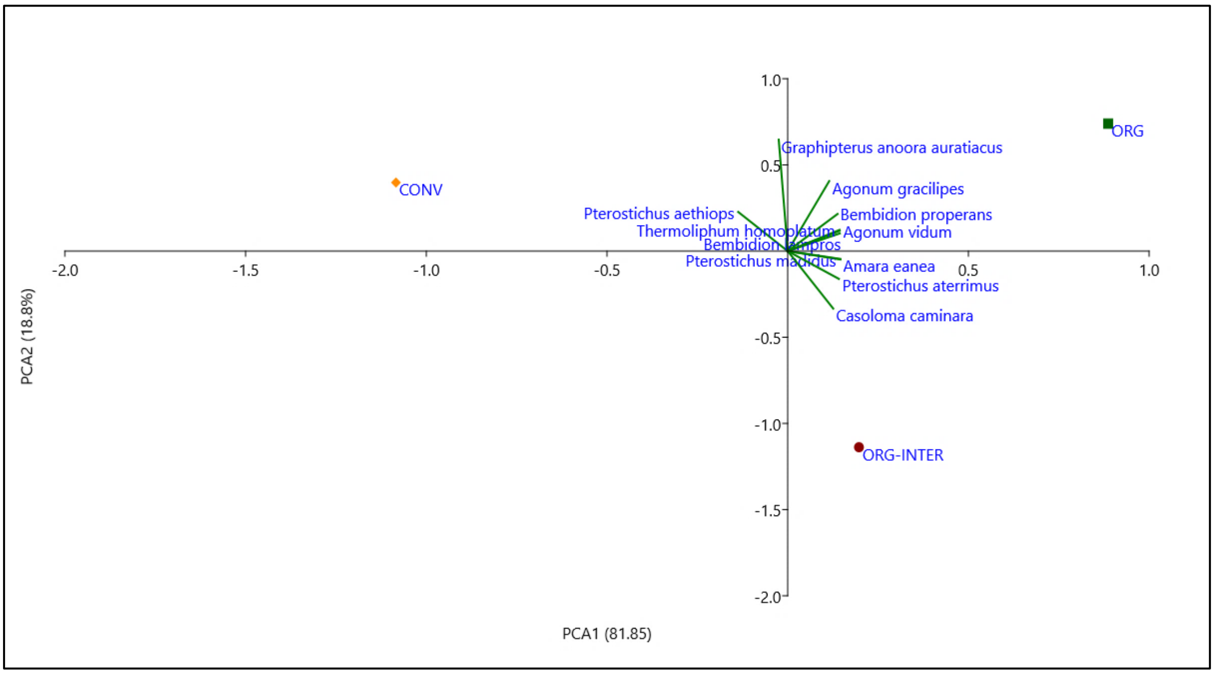

Figure 5.5 Principal component analysis (PCA) biplot representing the relationship between carabid biomass and agroecoecosystems (organic, conventional and organic intercropped)

5.4 DISCUSSION

Beetle predator body size is influenced by agricultural intensification through tillage pratices and high chemical inputs (Woodcock *et al*., 2010; Skalski *et al*., 2016). Size distribution of species present in agroecosystems, either in individual species, is an indication of environmental disturbance. There was a significant decrease in carabid and coccinellid biomass in the conventional agroecosystems comapred to the organic and intercropped agroecosystems. The principal component analysis result showed that the first axes for carabid individual biomass accounted for 81.85% of the total variance, whereas coccinellid individual biomass accounted for 96.9% of the total variance. In addition, our results showed that carabid and coccinellid beetles in the conventional systems were significantly smaller than those in organic and intercroppped systems. Difference in species biomass between the organic and organic intercropped compared to the conventional agroecosytems can be ascribed by higher abudance of *Calosoma caminira*, and the genus *Pterostichus* and *Bembidion*. These species are generally associated with intensively managed agroecosystems (Lövei & Magura, 2006; Kosewska, Skalsk & Nietupski, 2014). The results of this study are in agreement with the body size hypothesis, indicating the mean body size of the species decreases in disturbed habitats (Gray, 1989; Blake *et al*., 1994). Previous studies across different habitats reported that species biomass increased in internsively managed systems compared to disurbed systems (Kotze & O'Hara, 2003; Kajita & Evans, 2010; Tsiafouli *et al*., 2015; Hanson *et al*., 2015). According to Koivula (2011) species with larger body size can be used as dominance indicators. Larger and medium sized carabid and coccinellid beetles can be used as keystone indicators, because the larger the boimass the more prey it consumes. Smaller sized species can be used as indicators of habitat disturbance and mostly considered dietary specialist (Niemelä & Kotze, 2009). Alternative resources within agroecosystems can play an a essential role for enchancing abundance of species as indicated with agroecosystems in our study where carabid and coccinellid beetles were not only smaller but also more abundant (Siemann, Tilman & Haarstad, 1996; Peyras *et al*., 2012).

Hanson *et al*. (2015) found that increasing management intensity reduces body size of ground beetles, and (Woodcok *et al*., 2010) observed that total biomass of ground beetles was negatively correated with landscape habitat diversity and further indicate that frequent agricultural disturbance lead to lower avarage body size of ground beetles. However in order to improve the ecosystem services of pest control, it is a fundamental to understand which management practices influence species abundance, composition and body size. This may partly explain why conventional systems did not have larger carabid and coccinellid beetles.

5.1 CONCLUSIONS

Preliminary conclusions from this study indicate that carabid and coccinellid mean biomass in different agricultural landscapes can be used as an index of habit quality, suggesting that larger species can be used as keystone species. This study suggest that organic and intercropped systems contribute to the maintenance of carabid and coccinellid biomass, since more species showed a medium and large biomass in the organic and organic intercropped systems and a smaller biomass in the conventional agroecosystems. Body size variation across agroecosystems of important crops such as maize, wheat and other cereal crops has not been thoroughly documented in carabid and coccinellid beetles and other predaceous beetles. This is the first study to evaluate the effect of different wheat systems on carabid and coccinellid beetles body size variation. Therefore, we recommend:

- Further biodiversity studies should also focus on the effect of managements on other functional traits such as body length of carabid and coccinellid beetles in order to determine thier functional diversity.

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CHAPTER 6

SUMMARY, CONCLUSIONS, RECOMENDATIONS AND IMPLICATIONS

6.1 SUMMARY AND GENERAL CONCLUSIONS

The major threat underlying the potential loss of biodiversity is habitat modification and climate change. Habitat disturbance is driven by agricultural expansion, through tillage practices and increase use of agrochemicals. We used Coleoptera: Carabidae and Coccinellidae families as focal organisms and explored their biodiversity. The study described for the first time carabid and coccinellid beetle abundance, composition, biomass, and diversity pattern in wheat agroecosystems in South Africa. The hypotheses tested for this study were (1) the conventional monoculture decreases the abundance, composition, diversity and biomass of predatory carabid and coccinellid beetles compared to the organic and intercropped systems. (2) Weather factors influence predatory beetle abundance and their prey (aphids) density. There is also other important questions with regards to agroecosystems management for enhancing predatory carabid and coccinellid beetles biodiversity that have been addressed as follows:

i. How does the conventional, intercropped and organic systems influence the abundance, composition, biomass and diversity of carabid and coccinellid beetles?
ii. Is there a relationship between abiotic factors (temperature, rainfall and relative humidity), wheat agroecosystems (organic, conventional, and intercropped) and carabid and coccinellid beetle abundance and aphid density?

The study aimed to broaden the understanding of the response of predatory beetle groups to different wheat agroecosystems; organic, conventional and intercropped and provide scientific recommendations. We found that richness, abundance and biomass of carabid and coccinellid beetles decreased in the conventional system compared to organic and intercropped systems. Conventional monoculture are unsuitable to enhance nor preserve the abundance of carabid and coccinellid beetles as a result of lack of alternative resources and overwintering sites. With regards to the organic and intercropped systems we observed that these systems improve the abundance and diversity of carabid and coccinellid beetles. By incorporating abundance data and phylogenetic information between carabid and coccinellid species, we documented the effect of wheat agroecosystems on body size in carabid and coccinellid individuals. We discovered that majority of carabid and coccinellid beetles were smaller in the conventional systems and organic than in intercropped systems. Body size variation in carabid and coccinellid beetles can be an index of functional diversity. Furthermore, we observed the association of carabid, coccinellid and aphids abundance in relation to weather factors. Our findings suggest a positive correlation between taxa's and temperature. However, temperature is the most dominant factor that affect the phenology of arthropods. Also carabid and coccinellid abundance increased with aphid's density indicating a significant positive correlation in organic and intercropped systems. Overall, we can conclude that our results provide evidence that wheat agroecosystem managements and weather factors influence the abundance, composition and diversity of carabid and coccinellid beetles. Species that were found rare in conventional monocultures are considered indicators of habitat disturbance, whereas dominant species found in all the systems are considered generalists. This study provided a baseline for future study on biodiversity of predatory arthropods in wheat in South Africa. Identified carabid and coccinellid species that can play a role as bioindicators environmental changes can be useful for future assessment on possible implementation of conservation and biomonitoring strategies.

6.2 RECOMMENDATIONS FOR FUTURE WORK

This dissertation supports the observation that management practices are an important form of global pressure affecting species biodiversity. Our observed results provide answers only to some questions that rise in the context of agroecosystem practices. But many more questions still remain to be investigated further regarding the effect of climate change on biodiversity, managements in other crops such as maize, barley, rice and soybean, monitoring other beneficial arthropods and their role as ecological indicators. For instance, from our second objective, we observed that the response of carabid and coccinellid and aphids abundance in relation to managements need to be conducted using exclusion cages for accurate observations on predation potential. Also the relationship between abiotic factors need to be assessed in different localities and for more than three years in order to compare species seasonal distributions. Due to the fact that there could be many environmental factors affecting the response of beetle arthropods, further research is required in order to pinpoint specific factors such as tillage practices, ploughing and soil moisture that may influence carabid beetles. It is therefore, recommended that:

1. Conservation agriculture need to be adopted for sustainable production practices, more particularly in crops such as wheat, maize and rice in order to conserve natural services provided by species biodiversity.

2. Diversified farming in different crops should be promoted in order to enhance and sustain the biodiversity of natural enemies with subsequent ecosystem services of pest control.
3. Relationship between environmental factors and species functional traits, diversity should be further investigated on beneficial arthropods.
4. Biomonitoring and conservation strategies should be implemented by assessing potential bioindicator species which can be used for sustainable approaches and addressing habitat quality problems under monoculture systems.
5. Further investigations on the diversity of more than one or two taxa's in relation to climate change and land use changes will be essential for improving sustainable production.

6.3 IMPLICATIONS OF RESEARCH FINDING TO BIODIVERSITY OF CARABID AND COCCINELLID BEETLES AS BIOINDICATORS IN WHEAT AGROECOSYSTEMS

- Four carabid species *Pterostichus madidus*, *Agonum viduum, Thermophilum. Homoplatum, Graphiptes auratiacus* and two coccinellid species *Lioadalia flavomaculata and Stethorus punctum* are considered potential bioindicators of ecological disturbance.
- These species were rare in the conventional systems, signifying susceptibility to drastic changes as these systems are unsuitable for this species due to high use of synthetic chemicals and tillage practices.
- Furthermore, seven carabid species; *Calosoma Caminara, Amara eanea, Pterostichus aethiops, Agonum gracilipes, Bembidion lampros, Agonum gracilipes, Bembidion properans* and four coccinellid *Hippomania variegata, Cheilomenes lunata, Proplylea dissect* and *Coccinella septempunctata* were found in the organic, conventional and intercropped systems indicating some of this species are potential generalist predators feeding on alternative resources in order to survive. The abundance of these species in the conventional systems indicate that some species are resistant to drastic changes, some are were able to disperse to suitable habitat, but suggestions need to further be investigated.

- Further studies in South Africa should focus on biodiversity of bioindicator species in order to develop sustainable approaches of biomonitoring, conservation and integrated management strategies.
- Few carabid and coccinellid beetles were higher in biomass, we suggest that such species can be used as keystone predators. For instance, the efficacy of biological pest control does not necessarily depend on diverse predator community, however, the performance of a predator community with regard to pest suppression may be driven by whether keystone species present in an ecosystems and with high consumption rates. Morphological traits of potential predators in relation to their predation potential need to be investigated further in order to identify keystone species.
- The identification of biological indicator species is an extremely subjective process, more particularly linked with sustainability and resilience in agricultural landscapes, for instance by using indicator species, may be a more useful and rapid monitoring technique in different management practices.

APPENDICES

Appendix A. Ethical clearance approval letter

UNISA university of south africa

UNISA CAES ANIMAL RESEARCH ETHICS REVIEW COMMITTEE

Date: 02/02/2018

NHREC Registration # : N/A

ERC Reference # : 2017/CAES/182

Name : Ms MM Makwela

Student #: 49630628

Dear Ms Makwela

Decision: Ethics Approval from 01/02/2018 to 31/01/2019

Researcher(s): Ms MM Makwela
49630628@mylife.unisa.ac.za

Supervisor (s): Prof T Tsilo
tsilot@arc.agric.za; 058-307-3444

Dr A Jankielsohn
jankielsohna@arc.agric.za; 058-307-3431

Working title of research:

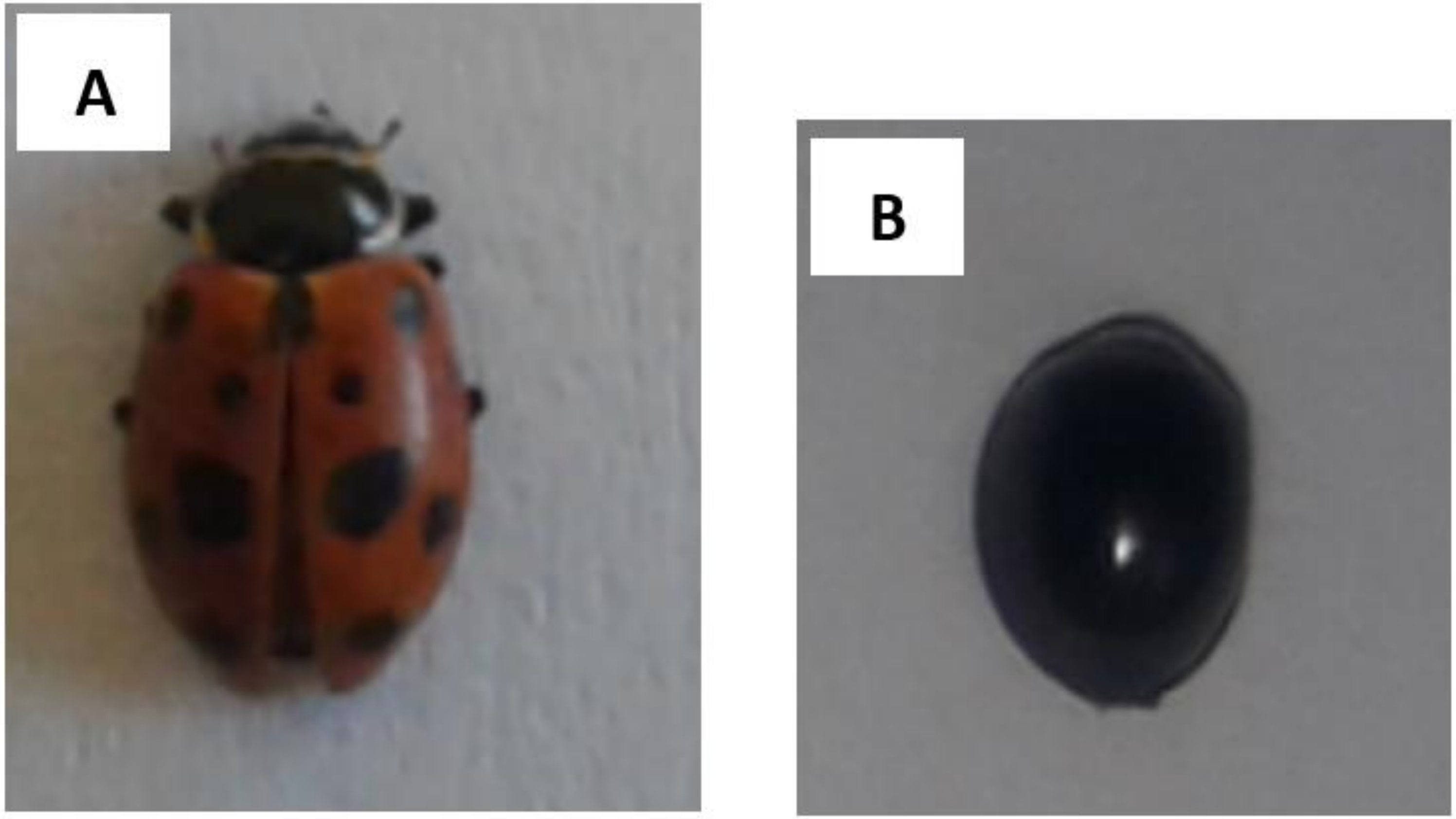
Biodiversity of predatory beetles (Coleoptera: Carabidae and Coccinellidae) and their role as bioindicatorspecies in wheat agroecosystems

Qualification: MSc Agriculture

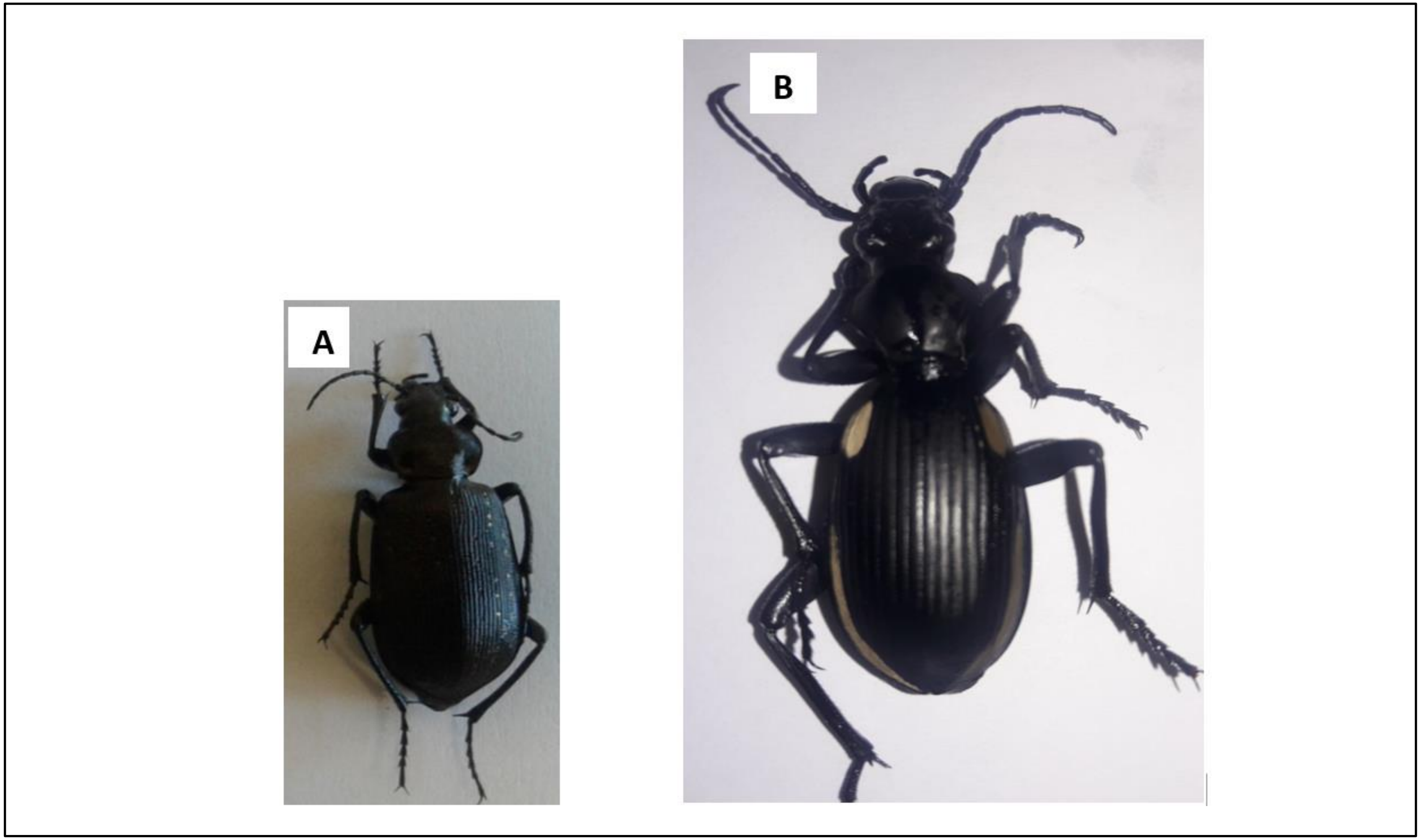
Thank you for the application for research ethics clearance by the Unisa CAES Animal Research Ethics Review Committee for the above mentioned research. Ethics approval is granted for a one-year period. After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 31 January 2019

APPENDIX B: SUPPLEMENTARY FIGURES AND TABLES RELATING TO CHAPTER 3



Appendix B.1. Coccinellidae species: (A) *Hippodamia variegata* was the most abundant species found in all the agroecosystems (B) *Stethorus punctum* less abundant (Lowerland farm, 2017)



Appendix B.2. Carabidae species: (A) *Casoloma caminara* was the most abundant species found in all the agroecosystems (B) *Thermophilum homoplatum* less abundant (Lowerland farm, 2017)

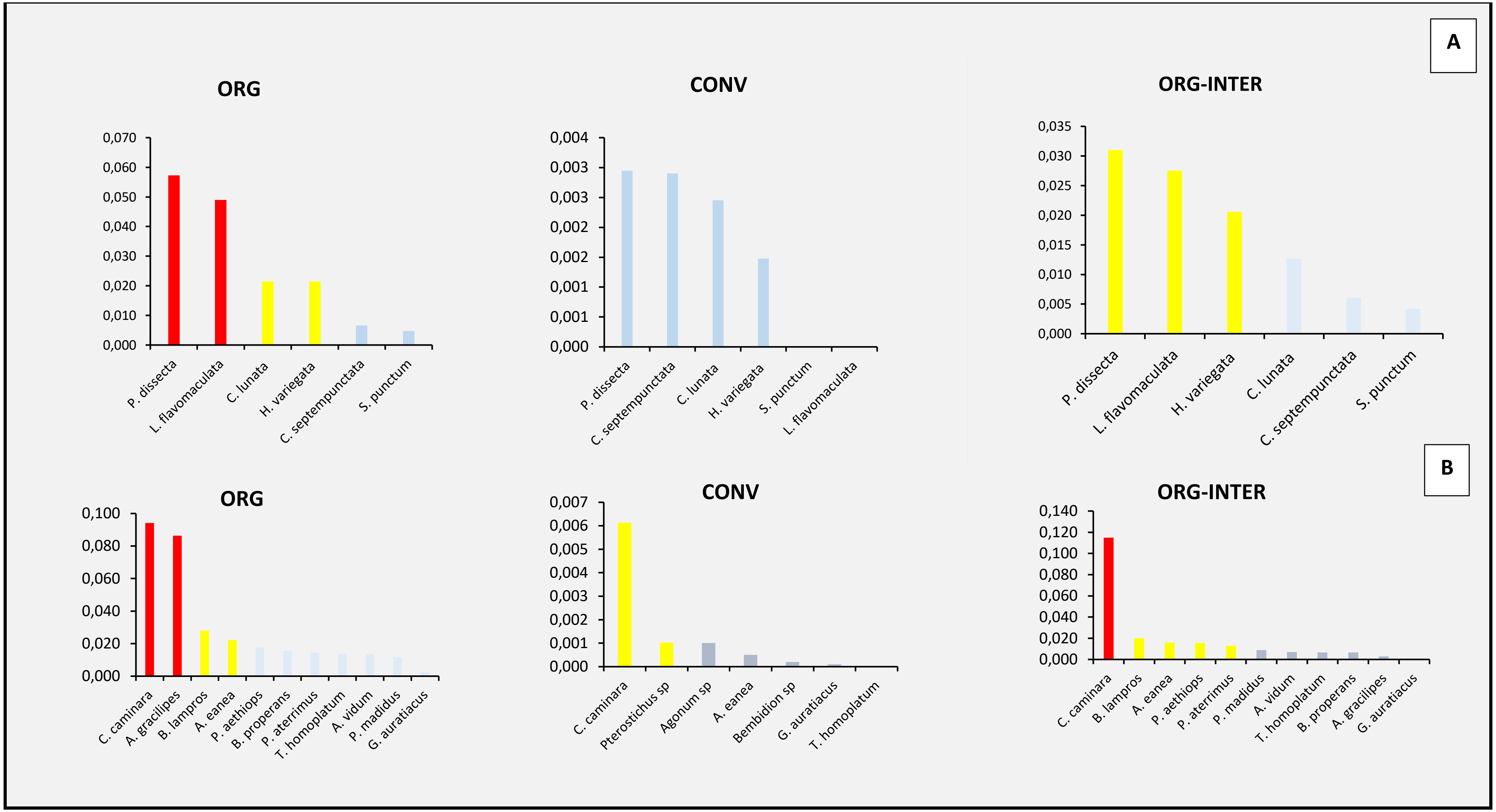
Appendix B.3. Diversity measures and abundance of each carabid individual for the three wheat agroecosystems (N= total abundance, S= Richness, H'= Shannon diversity, R'= Margalef richness, E'= Pielou's evenness and D' =dominance)

Carabidae species	ORG						CONV						INTER					
	N	**S**	**H'**	**R'**	**E'**	**D'**	**N**	**S**	**H'**	**R'**	**E'**	**D'**	**N**	**S**	**H'**	**R'**	**E'**	**D'**
Pterostichus madidus	65	4	1.2	0.7	0.85	0.32	21	3	1.1	0.99	0.77	0.38	48	4	1.2	0.78	0.85	0.32
Pterostichus aethiops	75	4	1.3	0.6	0.93	0.29	1	1	0.0	0.01	1.00	1.00	60	4	1.2	0.73	0.91	0.30
Pterostichus aterrimus	98	4	1.3	0.6	0.96	0.27	8	3	0.9	0.96	0.82	0.47	71	4	1.2	0.70	0.89	0.30
Agonum gracilipes	88	4	1.3	0.6	0.95	0.28	1	1	0.0	0.01	1.00	1.00	67	4	1.3	0.93	0.91	0.29
Agonum viduum	54	4	1,2	0.7	0.86	0.31	12	4	1.2	1.21	0.90	0.29	44	4	1.2	0.79	0.85	0.33
Bembidion lampros	76	4	1.2	0.6	0.87	0.32	9	4	1.3	1.37	0.93	0.28	88	4	1.3	0.67	0.94	0.28
Bembidion properans	69	4	1.3	0.7	0.98	0.26	12	3	1.0	0.80	0.92	0.39	45	4	0.9	0.79	0.65	0.44
Calosoma caminara	16	4	1.3	0.5	0.98	0.20	10	4	1.2	1.30	0.90	0.30	196	4	1.3	0.57	0.99	0.26
Amara eanea	13	4	1.3	0.6	0.98	0.26	12	4	1.2	1.21	0.89	0.31	88	4	1.2	0.67	0.91	0.30
G.anoora auratiacus	9	3	0.9	0.9	0.85	0.43	1	1	1	0	1	1	1	1	0.0	0.01	1.00	1.00
Thermophilum homoplatum	13	3	0.9	0.7	0.89	0.41	1	1	0	0	1	1	4	2	0.5	0.72	0.88	0.63

Appendix B.4. Diversity measures and abundance of each coccinellid individual for the three wheat agroecosystems (N= total abundance, S= Richness, H'= Shannon diversity, R'= Margalef richness, E' =Pielou's evenness and D'=dominance)

	ORG						CONV						INTER					
Coccinellidae species	**N**	**S**	**H'**	**R'**	**E'**	**D'**	**N**	**S**	**H'**	**R'**	**E'**	**D'**	**N**	**S**	**H'**	**R'**	**E'**	**D'**
Hippodamia variegata	234	6	1.35	0.54	0.97	0.27	53	4	1.07	0.76	0.73	0.43	624	6	1.31	0.47	0.92	0.29
Cheilomenes lunata	204	6	1.34	0.56	0.96	0.27	51	3	1.16	0.76	0.80	0.34	133	4	1.37	0.61	0.98	0.26
Proplylea dissecta	387	6	1.36	0.51	0.98	0.26	61	3	0.01	0.0	1.00	1.00	115	5	1.33	0.63	0.95	0.28
Stethorus punctum	78	6	1.30	0.59	0.92	0.30	3	1	0.01	0.01	1.00	1.00	96	2	1.26	0.65	0.88	0.31
Coccinella septempunctata	151	6	1.26	0.69	0.88	0.31	33	2	1.35	0.73	0.96	0.27	101	5	1.24	0.66	0.86	0.31
Lioadalia flavomaculata	135	6	1.35	0.61	0.96	0.27	2	3	1.03	0.86	0.70	0.42	109	6	1.07	0.64	0.73	0.38

APPENDIX C: SUMPLEMENTARY FIGURES AND TABLES RELATING TO CHAPTER 5



Appendix C.1. Biomass range for (A) Coccinellid and (B) Carabid in organic, conventional and intercropped systems
*Blue (0.0001-0.009 g): Small, *Yellow (0.01-0.04 g): Medium * Red (0.05-0.1 g) Large
(Body size range with the x-axis representig individual biomass from the mentioned systems)

Appendix C.2. Calculations of mean individual biomass for Coccinellidae beetles in organic, conventional and intercropped systems

ORGANIC					CONVENTIONAL				ORGANIC INTERCROPPED			
Species	**Dry Biomass (DY) g**	**Abundance (N)**	**DY x N**	**DY x N /Biomass**	**Dry biomass (DY) g**	**Abundance (N)**	**DY x N**	**DY x N /Biomass**	**Dry biomass (DY) g**	**Abundance (N)**	**DY x N**	**DY x N /Biomass**
H. variagata												
	0.4	57	22.8	0.0228	0.1	4	0.4	0.0004	0.3	89	26.7	0.0267
	0.2	43	8.6	0.0086	0.2	6	1.2	0.0012	0.4	104	41.6	0.0416
	0.3	64	19.2	0.0192	0.1	11	1.1	0.0011	0.3	189	56.7	0.0567
	0.4	88	35.2	0.0352	0.1	32	3.2	0.0032	0.2	242	48.4	0.0484
C. lunata												
	0.3	31	9.3	0.0093	0.2	2	0.4	0.0004	0.6	27	16.2	0.0162
	0.6	44	26.4	0.0264	0.2	9	1.8	0.0018	0.4	34	13.6	0.0136
	0.5	58	29	0.029	0.3	18	5.4	0.0054	0.5	29	14.5	0.0145
	0.3	71	21.3	0.0213	0.1	22	2.2	0.0022	0.3	44	13.2	0.0132
P. dissecta												
	1.5	22	33	0.033	0.4	1	0.4	0.0004	1.2	19	22.8	0.0228
	1.3	66	85.8	0.0858	0.3	4	1.2	0.0012	1.4	23	32.2	0.0322
	1.6	37	59.2	0.0592	0.5	9	4.5	0.0045	1.1	45	49.5	0.0495
	1.7	30	51	0.051	0.3	19	5.7	0.0057	1	28	28	0.028
S. punctum												
	0.1	22	2.2	0.0022	0	0	0	0	0.4	9	3.6	0.0036
	0.1	66	6.6	0.0066	0	0	0	0	0.4	19	7.6	0.0076
	0.2	37	7.4	0.0074	0	0	0	0	0.2	31	6.2	0.0062
	0.1	30	3	0.003	0	0	0	0	0.4	42	16.8	0.0168
C. septempunctata												
	0.2	12	2.4	0.0024	0.1	9	0.9	0.0009	0.3	6	1.8	0.0018
	0.4	9	3.6	0.0036	0.2	15	3	0.003	0.2	22	4.4	0.0044
	0.3	24	7.2	0.0072	0.1	17	1.7	0.0017	0.4	28	11.2	0,0112
	0.4	33	13.2	0.0132	0.3	20	6	0.006	0.5	39	19.5	0.0195
L. flavomaculata												
	1.4	19	26.6	0.0266	0	0	0	0	1.2	3	3.6	0.0036
	1.6	35	56	0.056	0	0	0	0	1.4	13	18.2	0.0182
	1.5	39	58.5	0.0585	0	0	0	0	1	41	41	0.041
	1.3	42	54.6	0.0546	0	0	0	0	1.5	52	78	0.078

Appendix C.3. Calculations of mean individual biomass for Carabidae beetles in organic, conventional and intercropped systems

ORGANIC					CONVENTIONAL				ORGANIC INTERCROPPED			
Species	**Dry Biomass (DY) g**	**Abundance (N)**	**DY x N**	**DY x N /Biomass**	**Dry Biomass (DY) g**	**Abundance (N)**	**DY x N**	**DY x N /Biomass**	**Dry Biomass (DY) g**	**Abundance (N)**	**DY x N**	**DY x N /Biomass**
P. madidus												
	0.8	5	4	0.004	0.3	1	0.3	0.0003	0.8	3	2.4	0.0024
	0.5	11	5.5	0.0055	0.2	6	1.2	0.0012	0.6	11	6.6	0.0066
	0.7	22	15.4	0.0154	0.5	3	1.5	0.0015	0.5	13	6.5	0.0065
	0.8	27	21.6	0.0216	0.1	11	1.1	0.0011	0.9	21	18.9	0.0189
P. aethiops												
	1.1	9	9.9	0.0099	0.1	0	0	0	1.2	8	9.6	0.0096
	1.2	26	31.2	0.0312	0.1	0	0	0	1.4	17	23.8	0.0238
	0.8	15	12	0.012	0.2	0	0	0	0.9	10	9	0.009
	0.7	25	17.5	0.0175	0.3	0	0	0	0.8	25	20	0.02
P. aterrimus												
	0.8	17	13.6	0.0136	0.2	0	0	0	0.7	5	3.5	0.0035
	0.8	21	16.8	0.0168	0.6	2	1.2	0.0012	0.6	22	13.2	0.0132
	0.5	25	12.5	0.0125	0.4	1	0.4	0.0004	0.6	18	10.8	0.0108
	0.4	35	14	0.014	0.5	5	2.5	0.0025	0.9	26	23.4	0.0234
A. gracilipes												
	0.5	12	6	0.006	0.1	0	0	0	0.2	7	1.4	0.0014
	0.3	19	5.7	0.0057	0.1	0	0	0	0.2	15	3	0.003
	0.4	29	11.6	0.0116	0.2	0	0	0	0.1	26	2.6	0.0026
	0.4	28	11.2	0.0112	0.1	0	0	0	0.2	19	3.8	0.0038
A. vidum												
	1.2	4	4.8	0.0048	0.2	1	0.2	0.0002	0.4	3	1.2	0.0012
	1.1	10	11	0.011	0.3	4	1.2	0.0012	0.6	11	6.6	0.0066
	0.9	19	17.1	0.0171	0.2	3	0.6	0.0006	1	10	10	0.01
	1	21	21	0.021	0.2	4	0.8	0.0008	0.5	20	10	0.01
B. lampros												
	1.5	6	9	0,009	0.6	1	0.6	0.0006	0.9	11	9.9	0.0099
	1.5	33	49.5	0,0495	0.4	2	08	0.0008	0.8	19	15.2	0.0152
	1.4	22	30.8	0,0308	0.6	3	1.8	0.0018	0.9	27	24.3	0.0243
	1.5	15	22.5	0,0225	0.5	3	1.5	0.0015	1	31	31	0.031
B. properans												
	1	15	15	0.015	0.5	0	0	0	0.9	1	0.9	0.0009

	0.9	22	19.8	0.0198	0.2	2	0.4	0.0004	1.1	3	3.3	0.0033
	0.8	18	14.4	0.0144	0.5	4	2	0.002	0.6	16	9.6	0.0096
	0.9	14	12.6	0,0126	0,6	6	3.6	0.0036	0,5	25	12.5	0,0125
C. caminara												
	2.5	36	90	0.09	1.9	1	1.9	0.0019	2.5	39	97.5	0.0975
	1.9	34	64.6	0.0646	1.7	2	3.4	0.0034	2.7	48	129.6	0.1296
	2	54	108	0.108	2	4	8	0.008	2.4	50	120	0.12
	2.7	42	113.4	0.1134	1.6	7	11.2	0.0112	1.9	59	112.1	0.1121
A. eanea												
	0.9	24	21.6	0.0216	0.3	1	0.3	0.0003	2.1	11	23.1	0.0231
	0.6	31	18.6	0.0186	0.3	3	0.9	0.0009	0.6	18	10.8	0.0108
	0.6	44	26.4	0.0264	0.1	5	0.5	0.0005	0.5	21	10.5	0.0105
	0.6	36	21.6	0.0216	0.1	3	0.3	0.0003	0.5	38	19	0.019
G. auratiacus												
	2.1	1	2.1	0.0021	0	0	0	0	0	0	0	0
	1.8	0	0	0	0	0	0	0	1.3	0	0	0
	0.9	3	2.7	0.0027	0	0	0	0	0	0	0	0
	1	5	5	0.005	0	1	1	0.001	0	1	0	0
T. homoplatum												
	4.3	0	0	0	0	0	0	0	4.8	1	4.8	0.0048
	4.1	4	16.4	0.0164	0	0	0	0	3.9	2	7.8	0.0078
	3.2	2	6.4	0.0064	0	0	0	0	4.5	1	4.5	0.0045
	4.5	7	31.5	0.0315	0	0	0	0	3.2	3	9.6	0.0096

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BIODIVERSITY OF PREDATORY BEETLE GROUPS, CARABIDAE AND COCCINELLIDAE AND THEIR ROLE AS BIOINDICATORS IN WHEAT AGROECOSYSTEMS

by

MARIA MAMSHOLAWA MAKWELA

Submitted in accordance with the requirements for the degree of

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in the subject

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at the

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