

Epigeal arthropod diversity in conservation agriculture and the ecosystem services it provides

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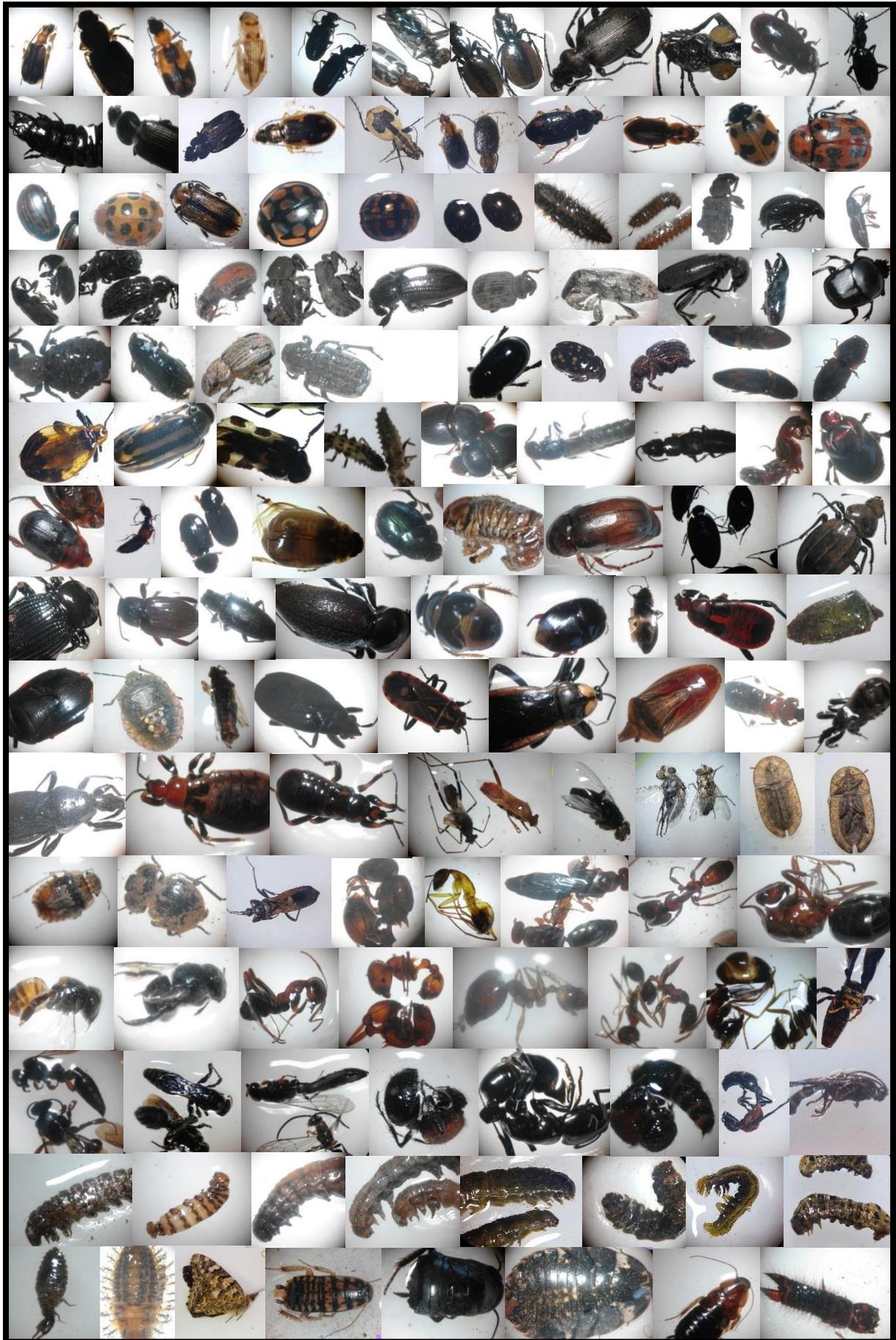


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Abstract

Conventional agricultural practices, for example, deep ploughing and continuous tillage loosens the soil, disrupts soil structure and leaves the soil surface relatively bare without plant residues to protect it. Soil erosion and degradation are of major concern for most farmers. It is especially the loss of fertile top soils that results in reduced soil productivity in conventional farming systems. Conservation agriculture (CA) is a practice used to manage agro-ecosystems to enhance and sustain productivity while increasing profits and conserving the environmental resources. Farmers started to adopt CA by implementing minimum soil disturbance, crop rotation and retention of crop residues on the soil surface to combat soil deterioration brought on by conventional cultivation practices. One major threat that farmers perceive in adopting CA is the possibility that it may support pest populations by providing different habitats. Due to the lack of knowledge of the effect of CA on arthropod communities in South Africa, this study was conducted to generate information regarding the adoption of CA in the North-West and Free State areas. The aim of this study was to compare arthropod biodiversity and ecosystem services between CA and conventional farming systems. A passive sampling method, dry pitfall traps, were used to collect soil dwelling arthropods during each of the 2014/15, 2015/16 and 2016/17 cropping seasons. There was higher abundance and diversity of arthropods in CA systems and a positive relationship was observed between ecosystem services in terms of seed and pest predation and increased predator diversity in CA fields. CA systems therefore supported natural enemies by creating a more stable system that provided improved habitat conditions and necessary resources, compared to conventionally tilled fields.

Keywords: Conservation agriculture, conventional agriculture, epigeal arthropods, ecosystem services.

Chapter 1: Literature review

1.1. Introduction

Agriculture is essential to ensure the production of food, feed, fibre and fuel resources and it is important to humankind's survival and economic thrive (Connor *et al.*, 2011). Since the ultimate goal of agriculture is to reach a sustained economic crop yield, it is of critical importance to comprehend the effect of insect pest populations on subsequent yields. The total number of interacting factors responsible for determining crop yield is overwhelming, and any decision regarding the effect of a single factor, for instance the population of one insect pest species on crop yield, is problematic (Hill, 1987).

According to predictions the world's human population will be 50% higher than the current level by 2050 and it is obvious that food security will only be guaranteed through a large increase in agricultural crop productivity and yield. According to Macfadyen and Bohan (2010), ecosystem services is the outcome product of species interactions which directly enhance crop productivity and yield. Examples of ecosystem services include beneficial services such as predation on crop pests by natural enemies, nutrient recycling by detritivores and pollination.

Arthropods are known to be one of the most successful groups of all living biota and along with other invertebrates, contribute about 80% of the total number of species in the animal kingdom (Frost, 1959). In the natural world, insects are considered as one of the most important groups which can affect the life and welfare of humans in many different ways. Although some insects are referred to as pests, others are beneficial to humans, *i.e.* insects may serve as natural enemies of harmful species, or as producers of valuable materials such as honey and silk. There are many of insect species known for being either harmful or beneficial, and in many cases their role in nature is unknown. However, insects are quite important as essential components of both modified and natural ecosystems (You *et al.*, 2005). The biodiversity of an agro-ecosystem is not only essential for its intrinsic value, but also because it affects ecological functions that are important for crop production sustainability (Hilbeck *et al.*, 2006).

Life on earth depends on various good functional large-scale ecological processes, many of which provide humanity with irreplaceable benefits and resources, commonly referred to as ecosystem services (Daily *et al.*, 1996) and biodiversity loss threatens these beneficial services. However, the exact type and richness and abundance of biodiversity necessary for unimpaired, sustained ecological functioning and productivity is still unknown (Loreau *et al.*, 2002).

E.O Wilson, an American biologist, quoted the following, to give perspective to the importance of arthropods (Roberts, 2014):

“If all mankind were to disappear, the world would regenerate back to the rich state of equilibrium that existed ten thousand years ago. If insects were to vanish, the environment would collapse into chaos”

“So important are insects and other land-dwelling arthropods that if all were to disappear humanity probably could not last more than a few months.”

To completely understand, exploit and manage biodiversity in agro-ecosystems, the changes to the underlining structure of communities that result from interactions between species and in what way these changes influence overall system productivity must be understood first of all. In South Africa, the identification of species assemblages most beneficial to soil processes and crop yield have been highlighted by Louw *et al.* (2014).

1.2. Conventional and conservation agriculture

Farming practices have shifted over time to eliminate unsustainable components of conventional agriculture, an approach which is critical for future productivity gains while conserving natural resource sustainability (Bhan and Behera, 2014). Conventional tillage systems use cultivation as the major means of seedbed preparation and to control weeds. This approach includes soil tillage (ploughing) which leaves the soil surface relatively bare without cover protection for relatively long periods after cultivation (Figure 1.1) (Aina, 2011).

Non-sustainable agricultural systems are characterized by soil erosion, soil organic matter decline and salinization (Bhan and Behera, 2014). The latter are caused primarily by intensive tillage, soil structural degradation, induced soil organic matter

decline, reduced water infiltration rates, water and wind erosion, surface sealing and crusting, soil compaction, insufficient return of organic material, and mono-cropping (Bhan and Behera, 2014). The target of conventional agriculture is to focus on maximizing crop yield through the application of synthetic chemicals and pesticides, cultivation of genetically modified crops and in most cases the planting of monocrops without proper crop rotation. Across the world many farmers have adopted the conservation agriculture (CA) concept in order to respond to the concerns regarding sustainable agriculture and the negative environmental impacts associated with modern-day agriculture (Figure 1.1) (FAO, 2015). CA is described as an approach for resource-saving agricultural crop production that aims to achieve acceptable profits and reach high and sustained production levels while concurrently preserving and maintaining the environment (FAO, 2015). Thus, it is a concept to manage agro-ecosystems in order to improve and sustain productivity, increase profits and food security while protecting and enhancing the resource base and the environment. In other words, CA conserves and builds up the organic matter content in soils, improves the soil quality and fertility as well as minimizing soil erosion. Other benefits, such as provision of ecosystem services by organisms in CA crop fields, remain largely unknown.

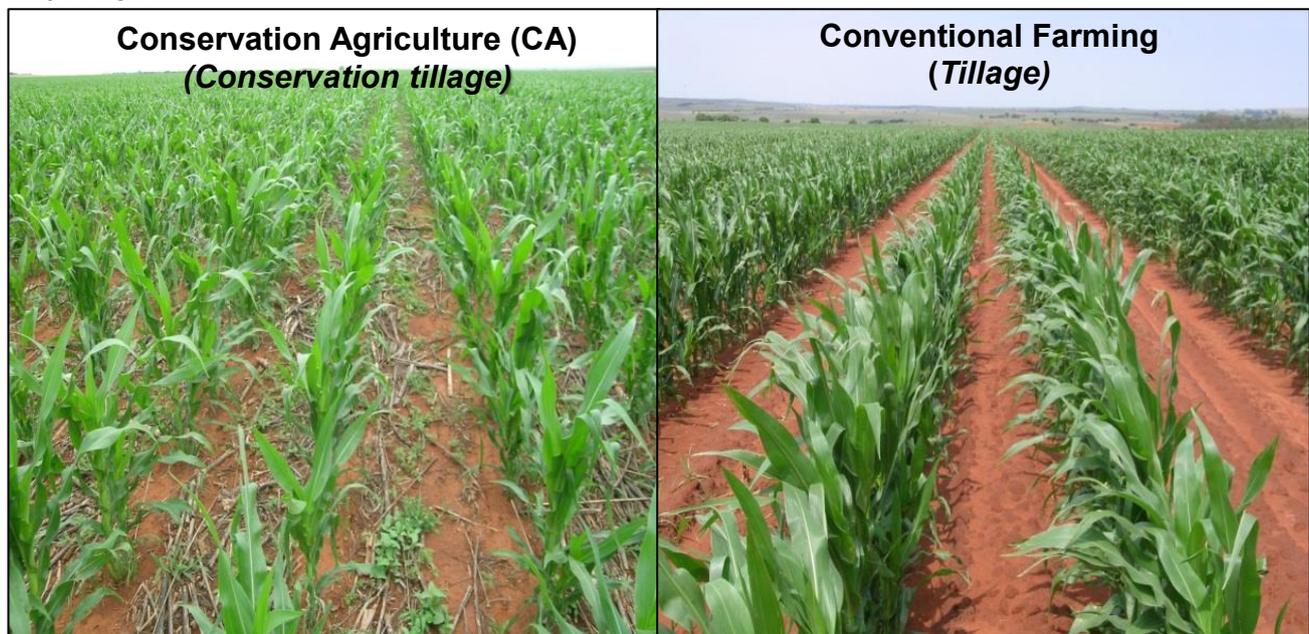


Figure 1.1. A comparison of maize fields subjected to CA (left) and conventional farming (right) practices. Higher organic content and the presence of other plant species are visible in the CA system compared to the conventional system. – Photo: A. Erasmus.

Soil is a sensitive and living resource and in a time span of 2000 years only approximately 10 cm of fertile soil is produced (Habig and Swanepoel, 2015). Soil has also been described as one of the most necessary resources held by South Africans due to it being an important and critical component of the pedosphere which sustains life (Louw *et al.*, 2014). In South Africa, soil is a highly neglected research focus in ecosystem service delivery. According to Habig and Swanepoel (2015), soil quality determines sustainable agriculture, environmental quality and ultimately plant, animal and human health. Soil quality can be described as the integration of the chemical, biological and physical characteristics of the soil for productivity and environmental quality. Fertile and high quality soil will sustain long-term agriculture production by supporting the production capacity of the system. According to Ella *et al.* (2016), the ability to sustain upland crop production systems depends largely on soil quality which can be influenced by the implementation of different farming practices. For example, ploughing activities can cause loss of soil organic carbon largely due to the exposure of soil particles to microbial activity. The loosening of soil particles in conventional farming systems may also cause a decrease in the soil residual water retention capacity. Topsoil organic matter increases with the implementation of CA and improved soil properties and processes can reduce erosion and run-off and increase soil moisture indices (Palm *et al.*, 2013).

Conventional farming (plough-based) systems increase agricultural crop production cost in the medium and the long-term due to higher levels of fertilizer inputs, soil amendments and other inputs that are necessary to compensate for the degradation of soil quality (Ella *et al.*, 2016). Conventional agricultural practices are also a reason for the diminishing soil productivity which causes depletion of nutrients in many agriculture soils, rendering these soils unable to naturally sustain crops (Habig and Swanepoel, 2015).

CA practices are based on ecological principles that make land use more sustainable. Adopting this practice requires a high level of integrated management to ensure resource efficiency and crop productivity (Du Toit, 2012). CA relies on three principles, which are interconnected and must be considered together for appropriate design, planning and implementation processes, since in combination, these principles are more effective and supports one another. These three important principles of CA are briefly discussed below.

- Minimum soil disturbance

South African soils are highly vulnerable to degradation. Soil degradation is increased by mismanagement and a lack of knowledge on general soil importance and appropriate management practices. According to van Zyl *et al.* (1996), 300-400 million tons of soil is lost annually in South Africa under conventional tillage systems, which implies approximately 20 tons/ha/annum. Since conventional practices is largely unsustainable, the principle of conservation agriculture is to disturb the soil as little as possible in order to contribute towards sustaining natural resources. Ploughing can also ruin soil structure and cause loss of organic matter and soil organisms due to the bare soil that becomes exposed and unprotected from rain, wind and heat (Du Toit, 2007).

In CA systems, primary soil cultivation is not conducted anymore and the only 'cultivation' that really takes place is when the crop is planted. Soil should preferably not be disturbed at all and at most, controlled tilling should be conducted so as not to disturb more than 20-25% of soil surface (ARC, 2015). Furthermore, if soil is cultivated or disturbed, the area which is disturbed should be less than 15 cm wide per row (ARC, 2015). Techniques to accomplish minimum tillage include direct seeding of crops by penetrating the soil cover only where the seed is planted, without disturbing the surrounding soil.

In conventional farming, ploughing is used to control weed and improve the soil structure (Kassam and Friedrich, 2011). However, in the long-term these practices may result in decreased soil fertility and poor soil structure. CA can reduce tillage by reducing the ripping of planting lines, which then protects the soil against erosion by water and wind. The ideal scenario is therefore a no-till farming system where the soil is only disturbed within the plant furrow. While minimum soil disturbance contributes to provide greater concentrations of respiration gases in the plant rooting-zone, moderate organic matter oxidation, porosity for water movement, retention and release, it also inhibits the re-exposure of weed seeds and their germination (Kassam and Friedrich, 2011).

- Soil cover

The North-West province is situated within the summer rainfall area of South Africa and receives between 400-600 mm of rainfall annually. During winter precipitation is very low (Du Toit, 2007). In this province, CA is practiced on many farms, and largely done under dry land conditions since there is no access to major rivers or dams from which to irrigate crops. Conservation of water is therefore very important, especially in low precipitation areas.

Farmers that do not follow CA practices usually remove or burn crop residues, whereas in CA systems, residues of crops are left on fields to limit soil erosion (ARC, 2015). In order to practice effective CA, a general requirement is that the soil surface must at least be 30% covered with organic material to prevent the soil from washing away during heavy rains and to encourage a microclimate that benefits soil organisms and to conserve soil moisture levels (ARC, 2015).

Plant residues protect the soil against erosion and in many instances may have a favourable effect on water infiltration rate from rain or irrigation. Water run-off and the associated environmental impact thereof are consequently reduced. Crop residues and soil cover also serve as a slow-release source of food for soil organisms (ARC, 2015). It also suppresses weed germination and growth and improves recycling of nutrients.

- Crop rotation

In conventional farming systems the same crop is planted each season, which may allow certain pests to survive due to host plants always being present (ARC, 2015). In CA, crops are rotated over seasons to maintain soil fertility and in many cases to suppress pest populations. The ideal crop rotation system in a CA farming system requires at least three different crops that should follow each other, for example forage sorghum, legumes and maize (ARC, 2015).

Soil microbe activity and diversity usually thrive in CA systems, especially when a legume crop is included in the rotation. Crop rotations that involve legumes and maize suppress build-up of pest populations through life cycle disruption and have environmental benefits such as enhancing biodiversity, off-site pollution control and biological nitrogen fixation (Dumanski *et al.*, 2006). Grain yield and grain quality are usually higher in crop rotations cultivations.

1.3. History of conservation agriculture

CA has its origin in conservation tillage, which was developed to react to the drastic degradation of agricultural production resources caused by wind and rain (Friedrich and Kienzle, 2007). Tillage, especially in fragile ecosystems, was questioned for the first time during the 1930s, when dustbowls devastated large areas of the mid-west United States. During the 1940s, Edward Faulkner elaborated theoretical concepts resembling today's CA principles in his book "Ploughman's Folly". It was however, only during the 1960s that the concept of no-tillage was effectively introduced into farming systems in the USA. In the early 1970s no-tillage farming as a strategy also commenced in Brazil, where farmers together with scientists transformed the technology into the system which is today commonly referred to as CA (Friedrich *et al.*, 2012). Reduced forms of tillage research and experiments started gaining momentum during the late 1960s and early 1970s (Du Toit, 2007).

A total of nearly 95 million hectares are currently being cultivated worldwide according to the principles of CA (FAO, 2015). The United Nations' Food and Agriculture Organization (FAO), who has promoted the CA concept during the past decade, reported that CA has great potential in Africa and that it is the only truly sustainable production system for the continent (FAO, 2015).

The CA experience in the USA contributed largely to the establishment of the CA movement in South Africa (Du Toit, 2007). During the past 15 years, successful adoption of CA took place among grain and sugarcane farmers in KwaZulu-Natal, as well as among grain farmers in the Western Cape and Free State provinces. The adoption of CA farming has, however, remained rather slow in other crop production areas of South Africa. CA has also gained acceptance over the past couple of years in the North-West province, which is one of the most important grain producing areas in South Africa (Du Toit, 2007). The general lack of knowledge and little experience with regard to CA is, however, a barrier to adoption of the approach (Jat *et al.*, 2014). CA has gained acceptance in South Africa over the past couple of years (Du Toit, 2007) but adoption is largely limited to a few summer grain producers in the Free State province, winter grain farmers in the Western Cape, and grain and sugar cane farmers in KwaZulu-Natal.

1.4. Adoption of conservation agriculture

A large number of African farmers are resource-poor and practice farming on farm sizes of less than 1 ha in size (Nyagumbo *et al.*, 2017). Farming systems in Africa are characterised by drought and variable rains, food insecurity, degradation of soil fertility, as well as lack of human power for agricultural labour. CA systems are highly suitable for addressing these old as well as emerging challenges, such as environmental degradation climate change and high energy costs. CA is also promoted in South Africa as providing a valuable set of principles that could contribute towards advancing resilience to climate variability and change (Nyagumbo *et al.*, 2017). According to Nyagumbo *et al.* (2017), some of the key constraints faced by small-holder farmers in southern Africa include highly variable rainfall, the high cost and poor availability of agricultural inputs, as well as a lack of draught power and labour.

CA systems have many benefits that could address the above mentioned constraints. CA can notably lead to the continuous build-up of soil organic matter over time, as illustrated in protocols that have successfully been tested and applied by farmers in many parts of the world over the past 40 years (Friedrich *et al.*, 2009). CA enables fields to be cropped more effectively without risk of degradation, and is attractive to farmers since it leads to increased crop yields and reduced soil erosion and water run-off. It also results in savings in terms of reduced tractor use, fuel and production costs. Modern agriculture is dependent on sustainable food production regimes and CA is one of the most promising practices to ensure sustainability and environmental safety (Bajaw, 2014).

Since 2005 South Africa has experienced only a modest growth in the areas under no-tillage (Derpsch *et al.*, 2010). It is important that the South African farming industry strengthen their efforts to promote no-tillage systems in order to overcome erosion problems and the challenges provided by limited rainfall in many regions. The farming system environment in South Africa provides ideal conditions for applying no-tillage technologies and while interest groups such as no-till clubs and government programs do exist, these need to be better exploited (Derpsch *et al.*, 2010).

According to Derpsch *et al.* (2010), barriers to adopt CA include the mind-set, knowledge, availability of adequate implements, availability of appropriate herbicides

and adequate policies to promote adoption of CA as policy by politicians, public administrators, farmers and researchers.

In the South African agricultural systems producers have access to sufficient equipment and technology to plant an array of different crop seeds (Du Toit, 2007). The progress in biotechnology with the development of herbicide tolerant crops and improvement of herbicides allow farmers to cultivate crops, such as maize, without ploughing. The use of glyphosate which is a broad spectrum herbicide, is one of the most important factors contributing to the feasibility of CA in South Africa.

According to Du Toit (2007), it is estimated that reduced tillage is practiced on approximately 34.6% (1 522 718 ha) of South Africa's total cultivated land area (4 402 255 ha) and that 8.6% (377 169 ha) is under no-tillage. In the North-West province, reduced tillage is practiced on approximately 32.4% (392 289 ha) of the province's arable lands and no-tillage on 5.2% (62 960 ha).

The FAO's strategy in South Africa has been to formulate a national strategy to accelerate the adoption of CA. Grain SA has undertaken the task of promoting CA, especially amongst small holder farmers, and is supported by the Agricultural Research Council (ARC, 2015).

1.5. Advantages and disadvantages of conservation agriculture

According to Knowler and Bradshaw (2006), there are important costs and benefits to the adoption of CA.

Benefits

- Reduced farming costs, *i.e.* saving time, labour and mechanized machinery
- Increase soil moisture retention and fertility, resulting in long-term yield increase and greater food security
- Stabilization of soil and protection from soil erosion, leading to reduced downstream sedimentation
- Reduction in contamination of surface and ground water with agro-chemicals
- Recharging of aquifers as a result of better water infiltration
- Reduction in air pollution resulting from reduced use of soil tillage machinery
- Conservation of terrestrial and soil-based biodiversity

Cost implications

- Application of additional herbicides
- New management skills required
- Short-term pest problems due to the change in crop management practices
- Purchasing of specialized planting equipment

1.6. The importance of arthropod biodiversity

Biodiversity refers to all species of plants, animals and micro-organisms existing and interacting within an ecosystem (Altieri, 1999). As such biodiversity is the most valuable working component of natural and agro-ecosystems. It contributes to maintaining ecological processes, has a moderating effect on the climate, recycles nutrients, degrades waste, controls diseases and above all, provides an index of health of an ecosystem (Solomou and Sfourgaris, 2016).

Arthropods are one of the most diverse group of organisms in most ecosystems and many species are well adapted to provide ecosystem services. According to Hawksworth and Ritchie (1993), arthropods can also be used as indicators to observe changes such as habitat disturbance, effects of pollution and climate change. The abundance and diversity of terrestrial arthropods can provide a rich base of valuable information to aid achieving biodiversity and improve planning and management of nature reserves (Kremen *et al.*, 1993).

Farmers can manage or enhance the ecosystem services provided by biodiverse communities in order to work towards sustainable agricultural production by using improved farming practices (FAO, 2016). According to the FAO (2016), to conserve and enhance arthropod biodiversity in cropping systems both above and below ground role players are part of the foundation of sustainable farming practices. Biodiversity is also important in sustaining key functions in the ecosystem, which in turn contributes in optimizing agricultural production by enhancing ecosystem services. A higher biodiversity can also result in increased natural pest control within agricultural systems (Gurr *et al.*, 2012). Since biodiversity can ultimately contribute to improved management and conservation of both agricultural and natural ecosystems, it is of great value to understand the effect of agricultural activities on biodiversity.

1.7. Ecosystem services

The concept nature's services (ecosystem services) was initially developed to draw attention to the benefits that ecosystems generate for society and to raise awareness for biodiversity conservation (Birkhofer *et al.*, 2015). Ecosystem services in terms of arthropods are ecological functions that are provided, such as decomposition (by detritivore arthropods), pollination (by pollinator species) and biological control of crop pests (predators and parasitoids), all of which contribute to increased agricultural yield. According to Isaac *et al.* (2008), ecosystem services contribute to the maintenance of agricultural productivity and decreased pesticide inputs.

Changes in landscape structure can result in changes in insect abundance and community composition, which in turn, may influence the ecosystem services provided by arthropods (Birkhofer *et al.*, 2015). Humans, and especially their agricultural activities, are known to be the main drivers of changes in ecosystems and landscapes (Birkhofer *et al.*, 2015). Since ecosystem services depend on the movement of arthropods across landscapes at different scales, as well as the abundance and diversity of the arthropods that provide these services (Mitchell *et al.*, 2014), agricultural activities, especially large scale conventional mono-cropping systems, may adversely affect ecosystem services (Botha *et al.*, 2015; 2016).

Arthropods pollinate about 80% of the flowering plants on earth and approximately a third of the world's crop production depends indirectly or directly on pollination (Saul, 1999). Furthermore, certain groups of arthropods are responsible for nutrient cycling, conditioning and aeration of the soil, while natural pest control services may be provided by predators, parasites and parasitoids (Saul, 1999).

Ecosystem services therefore benefit humans in terms of pest regulation and sustaining agricultural productivity. Improving ecosystem health contributes towards the resilience of agriculture as it intensifies to meet the impact of growing demands for food production (FAO, 2016).

1.8. Problem identification

In South Africa soil erosion is a serious environmental problem confronting water and soil resources. Despite the fact that soil erosion is a natural process, it is generally

increased by human activities such as soil tillage and clearing of vegetation which involves the loss of fertile topsoil and reduction of soil productivity (Le Roux, 2014).

Sand and dust storms (Figure 1.2) are dangerous and unpredictable weather events that may cause great agricultural and environmental problems in many parts of the world. These storms move forward like an overwhelming tide and strong winds transport drifting sands to bury farmlands or blow away top soil (WMO, 2015). The process of land degradation is aggravated during this process, resulting in serious environmental disturbance and destruction of ecological networks, as well as damage to crops through loss of nutrients and organic matter. Globally, soil degradation is one of the main reasons for low yields in subsistence agriculture, which significantly contributes to food insecurity (Rivers *et al.*, 2016).



Figure 1.2. Dust storm sweeping through the Hoopstad district in the Free State province of South Africa. (Top) Dust storm on maize farm during planting, (Bottom) dust storm in Hoopstad. (Photo: P. Roux, 13 January 2016).

South African soils are very sensitive to degradation and have low recovery potential. When small mistakes occur in land management, it can cause devastation and limit the chances of recovery. Approximately 25% of South Africa's soils are extremely

susceptible to wind erosion, which include the sandy soils of the North-West and the Free State provinces (Goldblatt, 2015).

Associated with the changes in farming practices to reduce water and wind erosion, are the possible concomitant changes in pest species and populations. According to Power (2010), management practices may also influence the potential for 'disservices' from agriculture, including loss of habitat for conserving biodiversity, nutrient run-off, sedimentation of waterways, and pesticide poisoning of humans and non-target species. At the community level, invertebrates are more vulnerable to habitat changes than plants and vertebrates (Burel *et al.*, 1998). CA practices in maize production systems provide different habitats for hosting and supporting pests and may also influence beneficial insect populations (Ogg *et al.*, 1999). Very high arthropod diversity inside maize fields in South Africa have been reported by Botha *et al.* (2015; 2016), who also indicated that the presence of large numbers of predators and parasitoids inside and adjacent to maize fields could be exploited in terms of pest management.

One major constraint associated with the adoption of conservation systems is the possibility of pests and diseases of which the off season survival inside or under crop residues, may increase, especially when no crop rotation is practised (Fowler, 1999). CA involves the retention of crop residues on the soil surface and according to Van den Berg *et al.* (1998) maize crop residues in the form of stubble and stalks, form the primary source of infestation of the African maize stem borer, *Busseola fusca* (Lepidoptera: Noctuidae) and *Chilo partellus* (Lepidoptera: Crambidae), which spend the dry season inside crop residues.

According to Rivers *et al.* (2016), reduction of tillage and retaining of crop residues on the soil surface may lead to an increase in the incidence of herbivorous insects, some of which may be crop pests. An increase in the prevalence of insect pests may be a risk factor associated with CA, but arthropod natural enemies, such as generalist predators, may also contribute to suppress the insect pests. CA also changes soil properties and processes compared to conventional agriculture thus these changes can, in turn, influence the delivery of ecosystem services by arthropods (Derpsch *et al.*, 2010).

There is a general lack of statistical and recorded data concerning CA in South Africa and little information is available on the effect of CA on biodiversity of pests and

beneficial arthropods in maize. Biodiversity in general in agricultural systems in South Africa (Louw *et al.*, 2014) and especially in maize ecosystems (Botha *et al.*, 2015; 2016) have not been sufficiently addressed in terms of research. With the move of many farmers from conventional agriculture to CA, it is important to investigate the following:

- the arthropod biodiversity supported by CA.
- ecosystem services provided by certain arthropod species inside CA systems.

1.9. Aims and objectives

The main objective of the study was to compare arthropod biodiversity in maize fields where conventional and CA farming practices are followed.

Specific objectives were:

- to compile a list of morpho-species that occur in conventional and CA fields.
- to compare the arthropod diversity between conventional and CA maize fields.
- to determine the potential ecosystem services provided by an increased arthropod diversity.

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Chapter 2: Comparison of epigeal arthropod community composition in conservation and conventional tillage systems

Abstract

Although arthropods are sensitive to alterations in vegetation composition, they play an important role in the functioning of ever-changing agro-ecosystems. Arthropod communities in agricultural systems can be influenced by mechanical changes of soil, modification of quantity and location of plant residues and changes in weed communities. The aim of the study was to compare epigeal arthropod communities in conservation (CA) and conventional (Conv) tillage systems. Arthropods were sampled over three cropping seasons using dry pitfall traps. Sampling was done at 6 localities namely: Ottosdal, Vredefort, Hartbeesfontein, Sannieshof, Kroonstad and Bothaville. At each of these localities, a CA and Conventional maize production system (site/farm) was selected. Sampling commenced one month after planting and continued for four months during the growing season. Trapping was done for a period of two weeks per month, giving to 10 080 trap samples for the whole study. Trap catches were identified to morpho-species level and diversity indices (Simpson, Shannon, Margalef richness and Pielou's evenness) were calculated. A total of 40 000 arthropod individuals, comprising 197 morpho-species from 14 orders were collected during this study. There was a significant difference in the abundance and species richness between CA and conventional farming systems, with CA systems supporting a healthier biodiversity and more diverse communities. To effectively manage and exploit biodiversity in agro-ecosystems, the changes in farming practices must first be understood, together with the underlining structure of communities that result from interactions between species, and secondly the effect of these changes on the overall system productivity must be further investigated.

Keywords: Biodiversity, conventional and conservation agriculture, diversity indices, epigeal arthropods, pitfall traps.

2.1. Introduction

Agriculture is one of the major contributors to the loss of biodiversity due to large areas of land designated for this purpose (Brennan *et al.*, 2005). Biodiversity loss is related to increased management intensity and a decrease in environmental diversification. Biodiversity includes all micro-organisms and plant and animal species that interact inside ecosystems. In agricultural systems arthropods provide ecosystem services, such as nutrient recycling, regulation of pest populations and hydrological processes (Altieri, 1999). Agricultural practices can alter biological diversity that regulates and supports these ecosystem services, with some practices that may lead to decreases in ecosystem services while others may enhance or maintain (Palm *et al.*, 2013). According to Altieri *et al.* (2006), the more diverse the plant, animal and soil-borne organism communities are that inhabit farming systems, the more diverse the communities of beneficial organisms are that can provide ecosystem services.

According to Kabirigi (2017), biophysical limitations to agricultural productivity include land degradation, depletion of soil fertility and weather variability. Land degradation caused by conventional agricultural practices, such as crop residue removal and tillage, is a major factor that contributes to low yields and subsequent food insecurity (Rivers *et al.*, 2016). CA, which implies minimum soil disturbance, planting of cover crops and polycultures, crop rotation as well as retention of the soil surface and crop residues on the soil surface, can enhance biodiversity and lead to an increase in diversity of natural enemy abundance which lead to lower pest population densities (Altieri, 1999). CA practices therefore also indirectly provide desirable habitats for beneficial soil-dwelling organisms that may provide improved pest control (Rivers *et al.*, 2016). Retention of crop residues on the soil surface reduces soil erosion, as well as the variation in soil moisture levels and temperatures, which in turn enhances soil quality and crop performance (Altieri *et al.*, 2011). CA also contributes to maintaining high soil organic matter which enhances the diversity of soil macro- and microbiota, which promotes an environment that improves plant health (Altieri and Nichols, 2003). In CA systems where no-tillage is implemented, no disturbance of soil food webs is caused which contributes to an increasing soil microbial diversity and activity which is important to drive in ecosystem process functioning (Habig and Swanepoel, 2015). Crop residues generate more complex biological systems and develop more stable microclimatic conditions, including increased soil humidity and more stable

temperatures which can create more suitable habitats for supporting soil fauna (Rodríguez *et al.*, 2006).

It is important to improve food security, while conserving agro-biodiversity and soil and water resources. A case study in Madagascar showed that the yield benefit/profit that realized in CA plots increased in terms of the number of years under this practice (Altieri *et al.*, 2011). According to Altieri *et al.* (2011), yields are generally higher when cover crops and crop rotation are implemented. Improved crop production can be achieved with better conservation of soil and water management, *i.e.* reduced run-off water and improved water infiltration (Altieri *et al.*, 2011). As such, CA increases water use efficiency through conservation of soil moisture (Kabirigi *et al.*, 2017).

Arthropods are sensitive to alteration in vegetation and they react to a range of conditions around them (Rodríguez *et al.*, 2006; Pryke *et al.*, 2013). Abiotic (*i.e.* temperature, soil, water) and biotic factors can have major impacts on the seasonal activity patterns of insects. For example, arthropod communities are influenced by mechanical changes of the soil, modification in quantity and location of plant residues, as well as changes in weed community composition (Rodríguez *et al.*, 2006). Altieri (1999) reported decreased abundance and diversity of natural enemies and an increase in pest populations in monoculture agro-ecosystems where chemical fertilization and pesticides were applied and conventional tillage practices were followed. Conventional tillage is known for disturbing the soil surface physically and can negatively affect soil biotic activity and species diversity due to the loss of soil microhabitat which is critical for nutrient recycling and the balance between organic matter, soil organisms and plant diversity (Altieri, 1999). Conventional tillage has been reported to lead to changes in arthropod communities but the degree of these changes depends on the intensity and reiteration of tillage practices (Rodríguez *et al.*, 2006).

According to Fowler (1999), one of the major constraints to the adoption of CA is the possible survival of pests and diseases inside crop residues. All (1988) conducted field experiments to compare infestations of Fall armyworm, *Spodoptera frugiperda*, between no-tillage and plow-tillage systems and reported reduced pest damage during early growth stages of maize in no-tillage fields. According to All (1988), *S. frugiperda* moths laid fewer eggs on maize during early plant growth stages in CA fields (up to 3rd leaf stage) since seedlings remained within the mulch. However, after the 4th leaf

stage, the number of eggs and plant damage were similar in no-tillage and conventional tillage systems. According to Meagher *et al.* (2004), planting cover crops such as cowpea and sunhemp that are less attractive to fall armyworm has the potential to reduce populations by lengthening developmental time and increasing larval mortality.

Conservation tillage and cover crops therefore promote agro-ecosystem stability which promote habitats for beneficial insects and increase natural enemy and pest species interactions by providing alternate prey or hosts (Tillman *et al.*, 2004). The Fall armyworm invaded South Africa in January 2017 and established in some maize cropping systems (Erasmus, 2017). The presence of Fall armyworm in South Africa is a concern to CA farmers since, other than the stem borer species during the season, this pest goes into a pupal stage inside the soil, which, in CA systems provides ideal pupation sites. The benefit in terms of ecosystem services such as predation on pupae, provided in CA systems still needs to be determined.

Arthropods fulfil many important roles within an ecosystem where they act as predators, pollinators, detritivores, herbivores and parasitoids (Boehme, 2014). They are efficient indicators of ecosystem functions and ideal to use as indicators of habitat quality. According to Altieri (1999), the key is to identify the type of biodiversity that is beneficial and desirable to support and provide ecological services and then to determine agricultural practices that contribute to enhance biodiversity components. It is therefore important to encourage agricultural practices which promote an increase in abundance and richness of both above- and below-ground organisms.

2.2. Diversity indices

Diversity indices are mathematical equations used to describe diversity in a community. According to Morris *et al.* (2014), the aim of indices is to describe general characteristics of communities which can assist in comparison of diversity between different regions, taxa and trophic levels. Diversity indices provide more information regarding community composition than mere species richness (number of species present), since these indices also take into account relative abundance of the different species. Quantification of diversity is an important tool in the study of composition of communities and the impact that management practices may have on communities.

Several indices are used to describe evenness diversity in communities. These include the Margalef, Pielou, Shannon and Simpson indices which are further described below.

S= Total number of species

$P_i = N_i/S$

ln= Natural logarithm

CA= Conservation Agriculture

N= total number of individuals

Conv= Conventional tillage

N_i = Total number of organisms of species

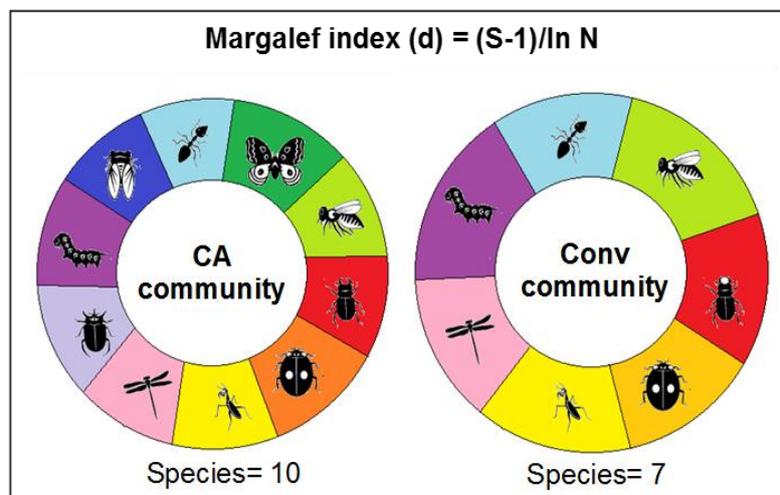


Figure 2.1. The Margalef index (d) describes both species richness and abundance of a particular species (total number of species in a given ecosystem).

The simplest measure of species diversity is the number of species (S), or the species richness. Richness is an indicator of the relative wealth of species in a community (Peet, 2003). An example is provided in figure 2.1 where the CA system has a total of 10 species and the Conventional farm (Conv) 7 species, which indicate that the CA community has a higher species richness. In case of the Margalef index, the richness will depend on the total number of individuals in the sample (sampling size) (Gamito, 2010). The Margalef index measures the number of species present in communities, making some allowance for the number of individuals.

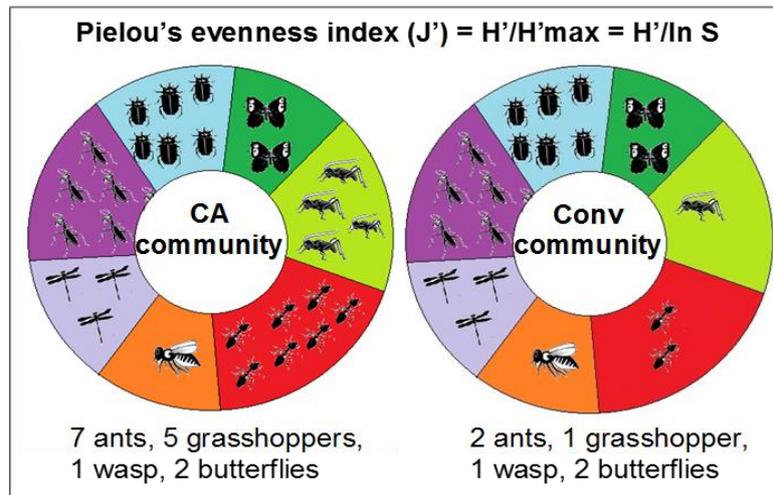


Figure 2.2. Pielou's evenness index (J') describes the evenness of species in a community (compares the similarity of the population size of each species present).

According to Morris *et al.* (2014), evenness represents the degree to which individuals are split among species and where low values (closer to zero) signify that one or a few species dominate and high values (closer to 1) signify that numbers of individuals are relatively equal between species. For example, in figure 2.2, the ant and grasshopper species may be more dominant in the CA system than the Conv system due to the higher number of individuals while other species such as wasps and butterflies are more evenly spread among the total number of individuals between these systems. Pielou's index measures how evenly the individuals are distributed among the different species in the different communities. Realistic measures of biodiversity should not only reflect the relative abundance of species, but also the difference between them (Leinster and Cobbold, 2012).

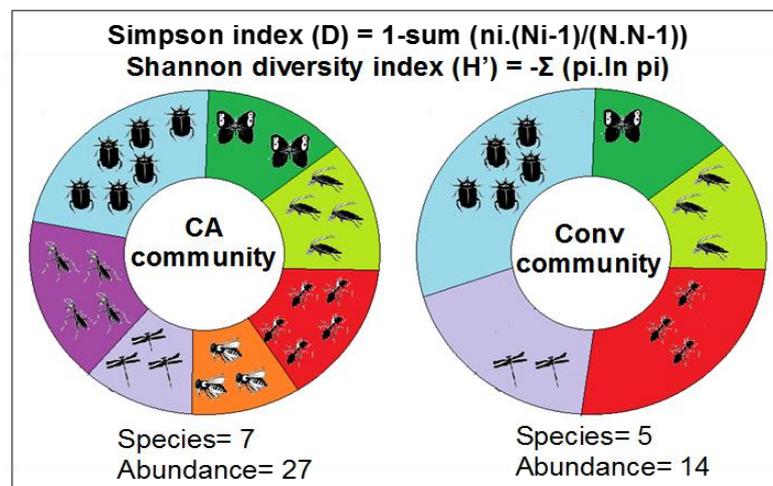


Figure 2.3. Shannon diversity indices measure diversity and accounts the number of species present and abundance of each species (richness and evenness).

The Simpson's diversity (D) and Shannon's diversity (H') indices differ in their theoretical foundation and interpretation (Morris *et al.*, 2014). According to Levin (2009), both Simpson and Shannon diversities increase as richness increases, for a given pattern of evenness, and increase as evenness increases, for a given richness, although they do not always rank communities in the same order.

Simpson diversity is less sensitive to richness and more sensitive to evenness than Shannon diversity, which, in turn, is more sensitive to evenness than a simple count of species (Levin, 2009). In the example provided in figure 2.3, the Simpson's and Shannon diversity indices indicate calculation of the diversity scores for a community in a CA and Conv system, accounting for both the number of species and the number of individuals present in the community. The aim of the study was to compare epigeal arthropod communities in conservation agriculture (CA) and conventional (Conv) tillage systems, using the indices described above.

2.3. Materials and methods

2.3.1. Sampling method

This study was conducted during each of three growing seasons (2014/15, 2015/16 and 2016/17), with sampling commencing during January and ending at the end of April of each season. The distance between replicates was 15 m and traps were 5 meters apart (Figure 2.4). Traps were put out 2 weeks after planting. There were 3 replicates per site with 10 pitfalls per replicate (Figure 2.4). The number of traps per site per season was 420. Tapping was done for a period of two weeks per month for four months during the active growing season, which means that for the whole study there were 10 080 trap samples (420 traps x 2weeks x 4 months x 3 years= 10 080 samples).

Since the focus of this study was on epigeal arthropods, pitfall traps were used which is a passive sampling method and the most appropriate method for this type of study (Zou *et al.* 2012). Pitfall traps are convenient and the least expensive method for use to determine diversity of terrestrial and litter arthropods (Greenstone, 2015).

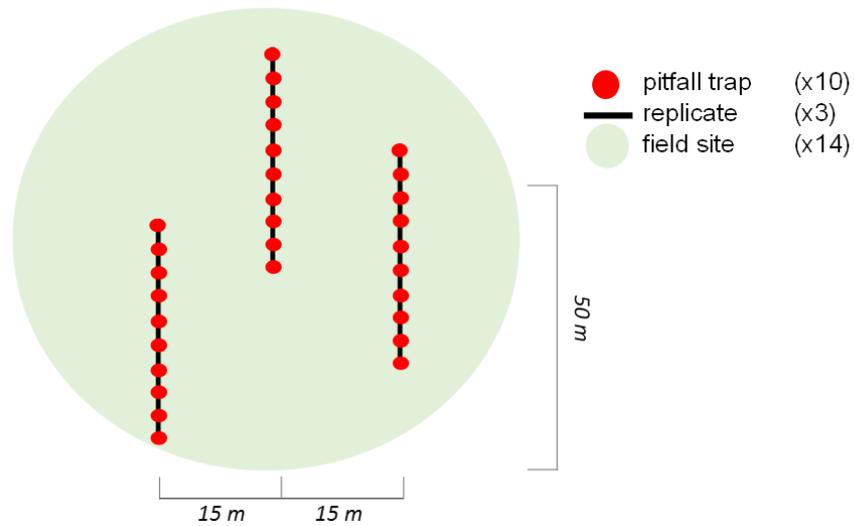


Figure 2.4. Layout of pitfall traps at a single field site.

Traps were 12 cm in deep and 5.5 cm in diameter and consisted of a plastic and metal container with fine mesh wire beneath to help with drainage of rainwater (Figure 2.5). The traps were supported within a larger plastic container inserted into the soil prior to sampling each season to support the pitfall traps and to have easy access to traps. The mouth of the traps and container were level with the soil surface. No alcohol was put into traps since traps had to be out for a prolonged period and were often out during rainy periods. For this reason the trap were fitted with wire mesh at the bottom for rainwater drainage.



Figure 2.5. The burying of traps and marking of trap positions in the field, as well as the components of the trap.

2.3.2. Morpho-species identification and data recording

After the arthropods were removed from pitfall traps, they were sorted and placed in 70% ethanol in 40 ml bottles. All arthropods were identified to morpho-species level and numbers of each morpho-species were determined for each trap, as illustrated in Figure 2.6. The term morpho-species in this context implies organisms that are classified as the same species based on the use of morphological criteria.



Figure 2.6. Identification of arthropods was done by means of a light microscope (left) and 40 ml bottles with 70% ethanol were used to preserve arthropods for record keeping (right).

2.3.3. Site selection

Sampling of arthropods was done at six localities near Ottosdal, Hartbeesfontein, Sannieshof, Vredefort, Kroonstad and Bothaville where well-established CA and conventional farming systems have been implemented for a number of years (Figure 2.7). Information regarding the individual trial sites is provided in table 2.1. These sites were selected on the basis of these farmers practicing CA for more than 5 years and using crops and tillage systems that are recommended for CA systems in the region.

A total of 14 field sites were selected of which eight were CA and six conventional farming sites. The Conv sites, which served as a control treatment at each locality, were not less than 20 km away from the CA site at the respective localities.

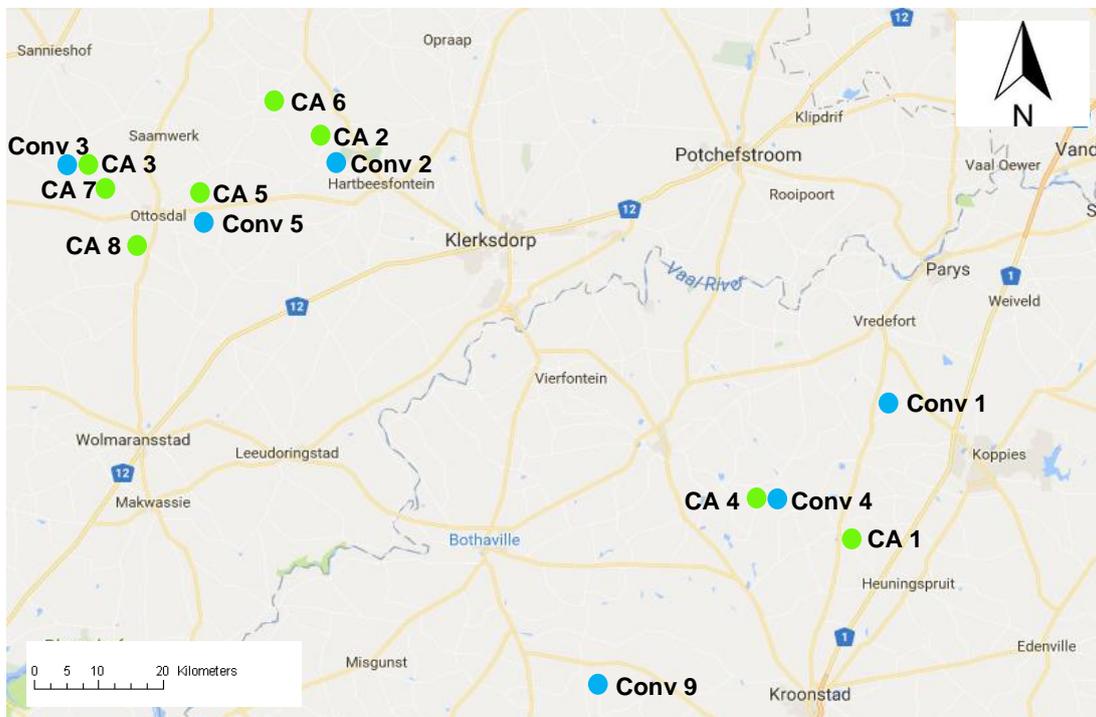


Figure 2.7. Localities of the 14 field sites. Green dots indicate conservation (CA) farming sites and blue dots indicate conventional (Conv) farming sites.

Table 2.1. The location coordinates of sites and crops that were planted over the three growing seasons.

Location	Site no.	Farmer	GPS Coordinates	Crop Planted		
				2014/15	2015/16	2016/17
Vredefort	CA 1	Flip Van der Merwe	27°21'44.6"S 27°17'30.6"E	Soybeans	Maize	Maize
	Conv 1	Johan Bronkhorsts	27°09'01.0"S 27°20'57.3"E	Sorghum	Maize	Soybeans
Hartbeesfontein	CA 2	Frik van Siter	26°41'10.3"S 26°19'46.7"E	Maize	Sunflower	Maize
	Conv 2	Frikkie Lemmer	26°45'12.9"S 26°22'33.0"E	Maize	Maize	Maize
Ottosdal – Sannieshof	CA 3	Magnus Theunissen	26°45'09.7"S 25°48'53.6"E	Maize	Sunflower	Maize
	Conv 3	(Neighbour)	26°45'09.7"S 25°48'53.6"E	Maize	Sunflower	Maize
Kroonstad	CA 4	Kobus van Coller	27°19'08.0"S 27°08'34.4"E	Maize	Sunflower	Soybeans
	Conv 4	Kobus van Coller	27°19'08.0"S 27°08'34.4"E	Maize	Sunflower	Soybeans
Hartbeesfontein - Ottosdal	CA 5	Hannes Otto	26°48'33.8"S 26°04'56.4"E	Maize	Sunflower	Maize
	Conv 5	(Neighbour)	26°48'33.8"S 26°04'56.4"E	Sunflower	Sunflower	Sunflower
Ottosdal - Colingy	CA 6	Koos Vorendyck	26°38'00.6"S 26°11'14.1"E	Sunflower	Sunflower	Maize
Ottosdal – Sannieshof	CA 7	George Steyn	26°46'51.5"S 25°53'16.4"E	Maize	Sunflower	Maize
Ottosdal - Wolmaransstad	CA 8	Hannes Otto	26°49'45.2"S 26°00'02.1"E	-	Soybeans	Sorghum
Bothaville	Conv 9	Martin Slabbert	27°37'16.9"S 26°48'38.6"E	-	Maize	Groundnut

Vredefort (Conv 1; CA 1):

The altitude at Vredefort is 1 425 m above sea level a.s.l. and the long term average rainfall is 487 mm per year, with most rainfall occurring during mid-summer. The average midday temperatures for Vredefort range between a low of 17.1 °C in June to 28.1 °C in January. The region is the coldest during July when temperatures decrease to 0 °C on average during the night (SAexplorer, 2015).

Hartbeesfontein (Conv 2; CA 2; CA 6):

The altitude at Hartbeesfontein is 1 459 m a.s.l. and the long term average rainfall is 471 mm per year, with most rainfall occurring mainly during mid-summer. The average midday temperatures range between a low of 17.2 °C in June to 29.1 °C in January. The region is the coldest during July when the temperature decreases to 0 °C on average during the night (SAexplorer, 2015).

Ottosdal (Conv 5; CA 5; CA 7; CA 8):

The altitude at Ottosdal is 1 459 m a.s.l. and the long term average rainfall is 447 mm per year, with most rainfall occurring mainly during mid-summer. Ottosdal receives the lowest rainfall (0 mm) in June and the highest (98 mm) in January. The average midday temperatures range between a low of 17 °C in June to 29.7 °C in January. The region is also the coldest during June when the temperature decreases to 0 °C on average during the night (SAexplorer, 2015).

Sannieshof (Conv 3; CA 3):

The altitude at Sannieshof is 1 031 m a.s.l. and the long term average rainfall is 398 mm per year, with most rainfall occurring mainly during mid-summer. The average midday temperatures range between a low of 18 °C in June to 31 °C in January. The region is the coldest during June when temperature often decrease to 0 °C during the night (SAexplorer, 2015).

Kroonstad (Conv 4; CA 4):

The altitude at Kroonstad is 1 343 m a.s.l. and the long term average rainfall is 468 mm per year, with most rainfall occurring during mid-summer. Kroonstad receives the lowest rainfall (2 mm) during June and the highest (76 mm) in January. The average daily midday temperatures range between a low of 17 °C in June to 28.7 °C in January.

The region is the coldest during June when the mean temperature is 0 °C during the night (SAexplorer, 2015).

Bothaville (Conv 9):

The altitude at Bothaville is 1 276 m a.s.l. and the long term average rainfall is 429 mm per year, with most rainfall occurring during mid-summer. Bothaville receives the lowest rainfall (0 mm) during June and the highest (76 mm) in January. The average midday temperatures range between a low of 18 °C in June to 30 °C in January. The region is the coldest during July with a mean of 0.2 °C during the night (SAexplorer, 2015).

2.3.4. Data analysis

Data were analysed to compare diversity and abundance between conventional and conservation tillage fields. The four most abundant orders of epigeal arthropods collected during three growing seasons in CA and conventional systems were compared. Data were pooled for the three replicates per farm or site and species richness and abundance were calculated for each site during each of the 3 seasons. T-tests were conducted, calculated in Excel. The mean number of morpho-species and individuals per site, Margalef (d), Pielou's evenness (J'), Shannon (H'), and Simpson (1-lambda) indices were also calculated to determine diversity of soil-dwelling arthropods between the two different systems for each season, as well as for the 3 seasons combined. Non-metric multi-dimensional scaling (NMDS) plots were created using presence and abundance data per treatment to detect differential clustering and to compare arthropod communities between treatments. The NMDS ordination uses Bray-Curtis dissimilarity to calculate clustering of treatments in Primer 6 (Version 6.1.15).

2.4. Results and discussion

A total number of 40 000 soil-dwelling arthropods of 197 morpho-species from 30 different families and 14 different orders were collected during this study.

Table 2.2. The four most abundant orders of arthropods collected during three growing seasons in conservation (CA) and conventional (Conv) farming systems.

Order	Species richness		Number individuals	
	CA	Conv	CA	Conv
Coleoptera	69	63	19 294	10 059
Carabidae	18	13	3 240	1 399
Coccinellidae	4	5	22	37
Scarabaeidae	9	10	1 939	725
Tenebrionidae	10	8	10 693	6181
Hymenoptera	22	21	981	541
Aphididae	3	2	8	4
Mutillidae	11	11	719	347
Formicidae	2	2	101	59
Vespidae	4	4	31	33
Araneae	16	16	448	128
Hemiptera	20	11	228	85
Reduviidae	8	5	161	54
Pyrrhocoridae	3	3	24	11
Pentatomidae	4	0	8	0

The total number of coleopteran morpho-species as well as the number of individuals of Carabidae, Scarabaeidae and Tenebrionidae were much higher in the CA community than in conventional fields (Table 2.2). The Coleoptera is the largest order in the animal kingdom and it includes 40% of all insects and nearly 30% of all animal species (Tom and Kaippallil, 2016). In this study Coleoptera was one of the most abundant orders with 40.1% of all morpho-species collected during this study (Table 2). During this study predatory coleopteran families such as Carabidae (e.g. *Harpalus* spp.) and Coccinellidae were common. Both the Scarabaeidae and Tenebrionidae families included pests and beneficial organisms and these were also abundant in trap catches during this study. Tom and Kaippallil (2016), amongst others, reported that beetles play an important role in ecosystems as predators, pests, scavengers and vectors that transmit plant diseases.

The species richness and abundance of Hymenoptera in the CA arthropod communities were higher than in conventional farming fields. The most common Hymenoptera were the Vespidae, Mutillidae and Formicidae families (Table 2.2). According to Van Noort (1992), Hymenoptera is one of the most species rich groups of insects along with beetles. Africa houses a rich diversity of ants, bees and wasps which represent 65 of the 85 hymenopteran families in the world. The Hymenoptera also plays an important ecological role in terms of pollination and pest control and can act as one of the beneficial components in an arthropod community in agro-ecosystems.

A total of 9% of all the arthropod morpho-species sampled belonged to the Araneae. Although the abundance of spiders in CA communities was generally higher than in conventional farming communities, the number of morpho-species was similar (Table 2.2). Spiders are one of the most diverse and abundant terrestrial invertebrate groups within arthropods with more than 40 000 described species and 60 families worldwide. They are predacious during all life stages and they provide important ecological functions in many ecosystems (Dippenaar-Schoeman, 2011). According to Rajeswaran (2005), species abundance in spider communities in agricultural and horticultural ecosystems can be as high as in undisturbed natural ecosystems. Habitat diversity and natural vegetation that surrounds crop fields may benefit spider community structures, allowing them to migrate into crop fields where they may feed on pests, as such providing essential ecosystem services (Nagrare *et al.*, 2015). Midega *et al.* (2006; 2008) reported significant increases in abundance of spiders as well as in predation on pests, in cropping systems with increased plant species diversity. The latter authors reported increased predation on immature stages of stemborers in cropping systems where maize was intercropped with *Desmodium uncinatum*.

The Heteroptera or true bugs is a suborder of the Hemiptera which worldwide include about 37000 described species, many of which feed on plants. Some Heteroptera are specialized for feeding on ants, millipedes and fungi (Schaefer and Panizzi, 2000). The Heteroptera sampled in this study included families such as the Reduviidae that prey on other arthropods and phytophagous Pyrrhocoridae and Pentatomidae. Hemiptera abundance and species richness were higher in the CA community (Table 2.2).

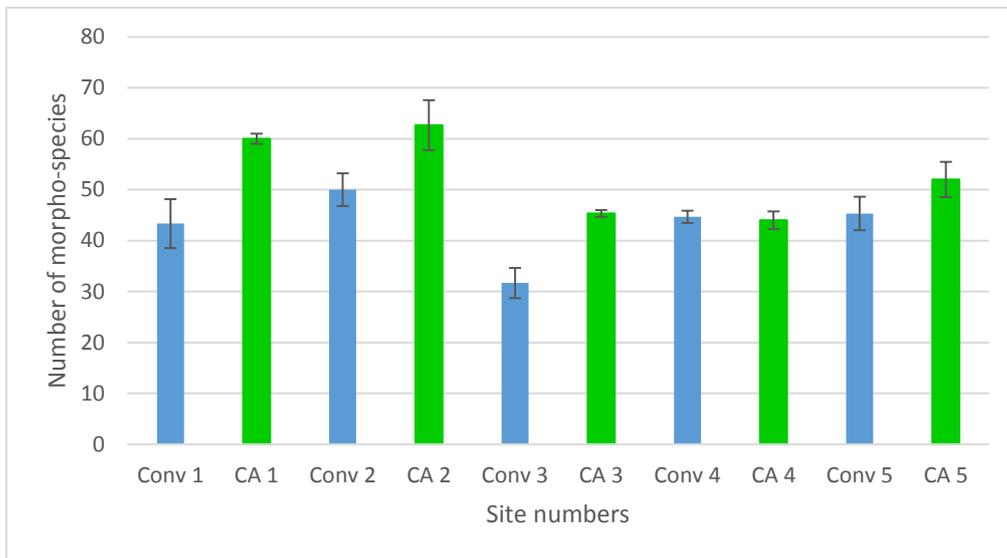


Figure 2.8. Mean arthropod species richness in CA systems compared to conventional tillage systems over a 3-year period (2015-2017). Conv = conventional farming sites; CA = conservation farming sites. Bars = standard errors.

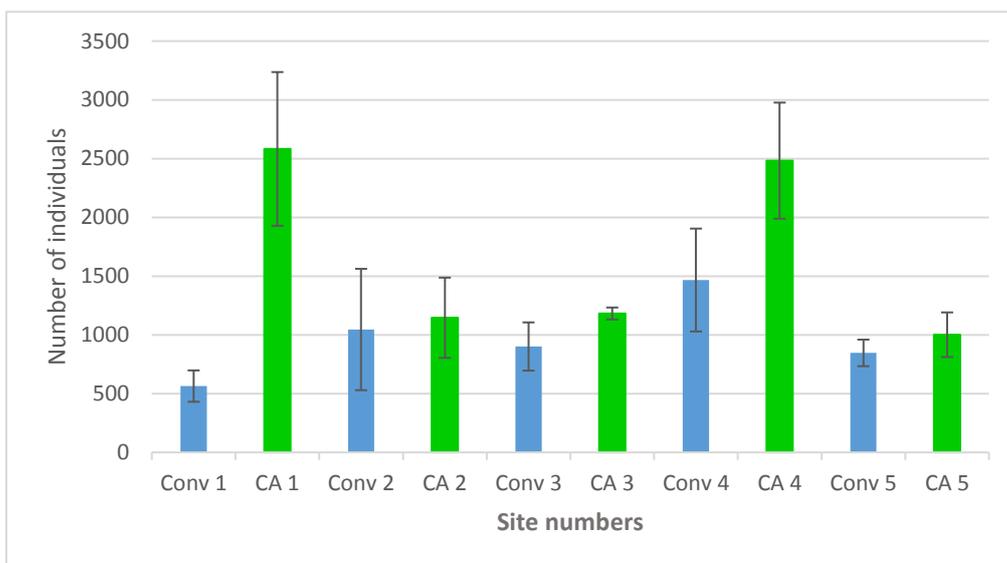


Figure 2.9. Mean arthropod abundance in pitfall traps in CA and conventional tillage systems over a 3-year period (2015-2017). Conv = conventional farming sites; CA = conservation farming sites. Bars = standard errors.

Monitoring the diversity of epigeal arthropods provides general biodiversity information which may indicate overall environmental benefits based on the increased biodiversity in CA. Species richness ($P= 0.027$) as well as abundance ($P=0.03$) were significantly higher in the CA fields than in conventional fields (Figures 2.8 and 2.9). At site number 4 the number of individuals was relatively higher in the CA system, although the species richness was similar. A possible explanation for this small difference could be

that the same crop rotation was implemented or the same amount of crop residues were present in the conventional and conservation agricultural fields (Table 2.1). Sites 2, 3 and 5 showed that there was an increase in arthropod abundance and species richness in CA systems, compared to conventional systems (Figures 2.8 and 2.9).

Table 2.3. Species richness and diversity index values comparison between conservation agriculture (CA) and conventional (Conv) systems over three seasons and for three different seasons in each treatment.

Year		2014/15		2015/16		2016/17		Combined data	
Treatment		Conv	CA	Conv	CA	Conv	CA	Conv	CA
Number of morpho-species per site	(S) mean	27.6	34.5	26.4	33.5	27.2	33.4	43.2	53.0
	F and P values	$F_{(1;28)}= 9.62$; P= 0.004		$F_{(1;28)}= 11.55$; P= 0.002		$F_{(1;28)}= 5.59$; P= 0.0025		$F_{(1;28)}= 9.62$ P= 0.002	
Number of individuals per site	(N) mean	221.5	434.1	332.5	711.1	418.2	533.6	964.2	1678.8
	F and P values	$F_{(1;28)}= 13.57$; P= 0.0001		$F_{(1;28)}= 8.44$; P= 0.007		$F_{(1;28)}= 3.41$; P= 0.075		$F_{(1;28)}= 6.38$; P= 0.017	
Margalef diversity index	(d) mean	4.99	5.68	4.56	5.17	4.42	5.21	6.28	7.16
	F and P values	$F_{(1;28)}= 2.37$; P= 0.138		$F_{(1;28)}= 2.18$; P= 0.150		$F_{(1;28)}= 3.99$; P= 0.055		$F_{(1;28)}= 3.74$; P= 0.060	
Pielou's Evenness	(J') mean	0.73	0.65	0.61	0.59	0.64	0.61	0.61	0.57
	F and P values	$F_{(1;28)}= 6.76$; P= 0.014		$F_{(1;28)}= 0.08$; P= 0.778		$F_{(1;28)}= 2.29$; P= 0.142		$F_{(1;28)}= 1.12$; P= 0.298	
Shannon diversity Index	(H') mean	2.401	2.299	2.008	2.103	2.105	2.126	2.87	2.59
	F and P values	$F_{(1;28)}= 0.53$; P= 0.472		$F_{(1;28)}= 0.25$; P= 0.620		$F_{(1;28)}= 0.05$; P= 0.829		$F_{(1;28)}= 0.02$; P= 0.864	
Simpson diversity index	(D) mean	0.85	0.82	0.73	0.78	0.81	0.79	0.80	0.80
	F and P values	$F_{(1;28)}= 1.71$; P= 0.202		$F_{(1;28)}= 1.1$; P= 0.301		$F_{(1;28)}= 1.87$; P= 0.182		$F_{(1;28)}= 0.004$; P= 0.950	

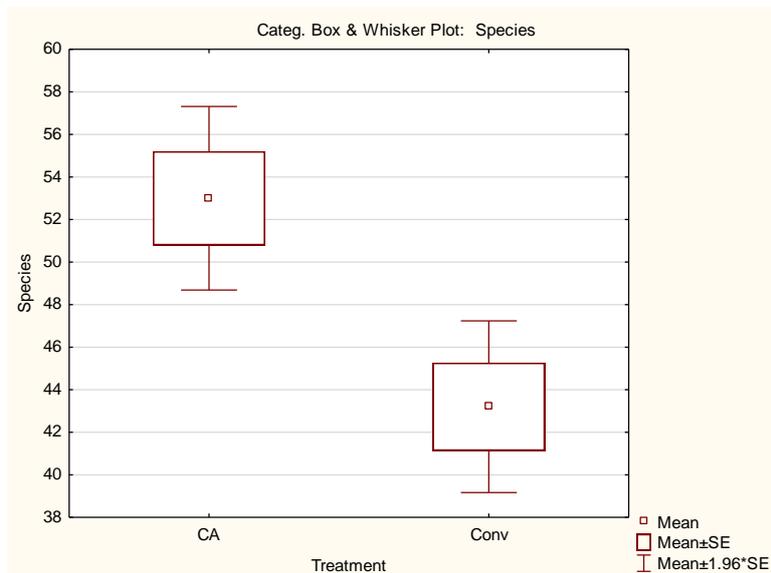


Figure 2.10. Overall species richness recorded in conservation agriculture (CA) and conventional (Conv) farming systems over three years (2015-2017) ($F= 10.568$; $P= 0.003$).

Analyses of combined data over the three growing seasons showed that species richness was significantly ($P=0.003$) higher in the CA systems than conventional systems (Figure 2.10). An average of 53 morpho-species were collected in CA systems over the 3-year period compared to the 43 morpho-species in the conventional systems (Table 2.3). Over each season the total average number of morpho-species was also higher in a given CA than conventional system (Table 2.3).

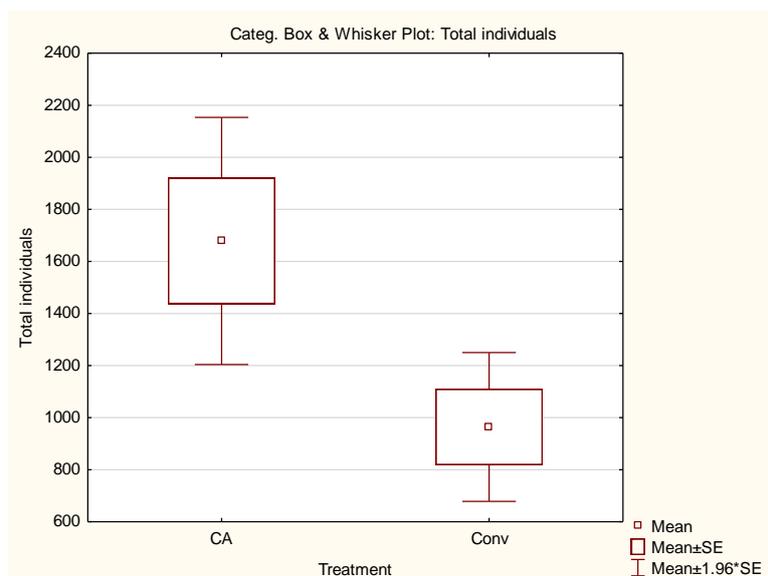


Figure 2.11. Overall abundance of arthropods trapped in conservation agriculture (CA) and conventional (Conv) farming systems over a 3-year period (2015-2017) ($F= 6.386$; $P= 0.017$).

Overall abundance was significantly ($P= 0.017$) higher in the CA system than conventional farming system (Figure 2.11). Over the three seasons, the average number of individuals collected in traps in CA systems was almost twice as many as that in the conventional systems. The lowest abundance in a CA system was during the 2014/15 season when only 434 individuals were sampled, which was, however still higher than the abundance in conventional systems (Table 2.3). CA therefore contributed to higher arthropod abundance (Figure 2.11). The abundance of arthropods was also significantly higher in CA systems during the 2014/15 ($P= 0.0001$) and 2015/2016 ($P= 0.007$) seasons (Table 2.3).

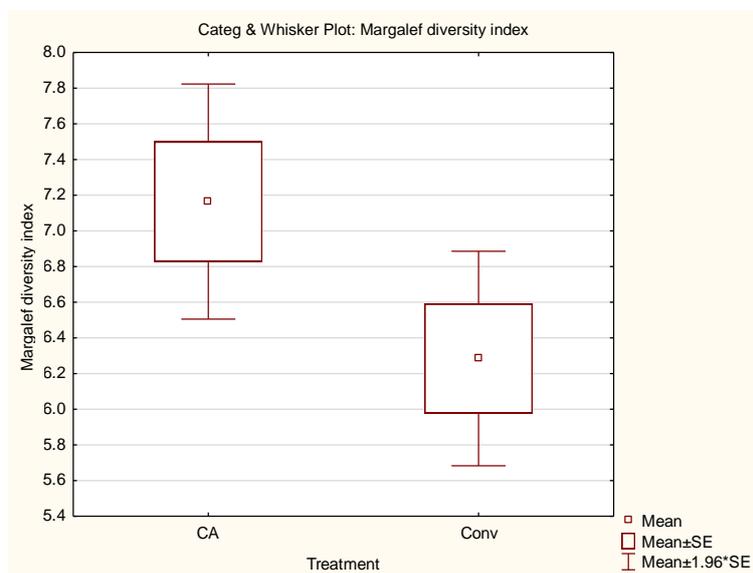


Figure 2.12. Margalef index values comparing diversity of arthropods between conservation (CA) and conventional (Conv) farming systems over a 3-year period (2015-2017) ($F= 3.738$; $P= 0.06$).

Although there was a tendency for Margalef diversity index values to be higher in CA than the conventional tillage farming systems for each of the seasons, these differences were not significant (Table 2.3). The mean overall Margalef index value for the 3-year period was, however, significantly higher for the CA systems at a level of $P= 0.06$ (Figure 2.12). These results indicate that the practice of CA can lead to increased arthropod species richness in a given ecosystem.

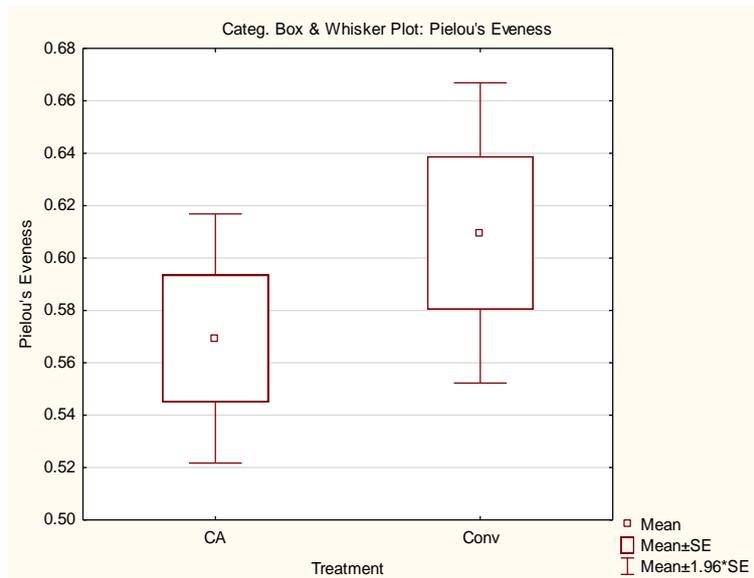


Figure 2.13. Pielou's evenness index values comparing evenness of arthropods between conservation (CA) and conventional (Conv) farming systems over a 3-year period (2015-2017) ($F= 1.125$; $P= 0.298$).

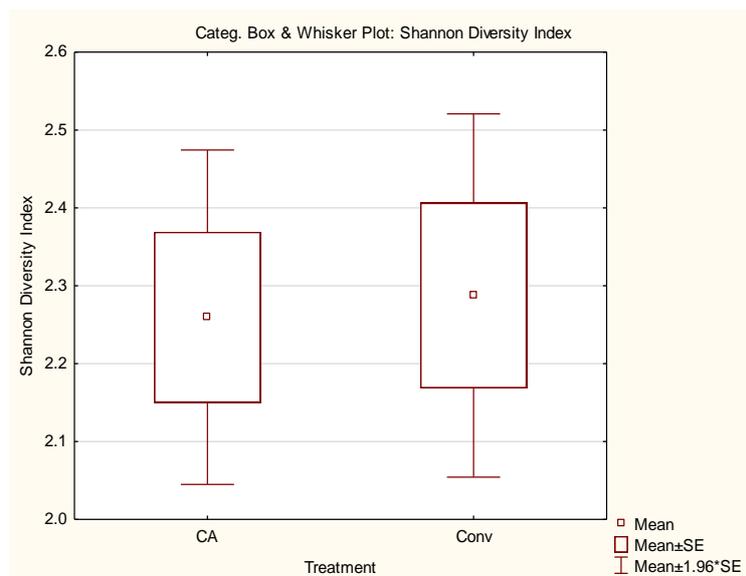


Figure 2.14. Shannon diversity index values comparing arthropod community diversity between conservation (CA) and conventional (Conv) farming systems over a 3-year period (2015-2017) ($F= 0.028$; $P= 0.864$).

The Pielou's evenness index values were significantly lower in CA than in conventional systems during the 2014/15 season ($P = 0.014$) (Table 2.3) (Figure 2.13). For the Pielou's evenness index, low values signify that one or a few species dominated while high values signify that numbers of individuals were relatively similar between species. The arthropod community in the CA system during the 2014/15 seasons was therefore dominated by one or two species and the community was therefore considered to be

less even than in the conventional system in which several different species had similar abundances. These dominant species in the CA system were Carabidae and Tenebrionidae of which large numbers of morpho-species with high abundances were recorded (Table 2).

Over the whole 3-year period no significant difference in arthropod community diversity was observed. Neither the Shannon ($P = 0.864$), nor the Simpson diversity ($P = 0.950$) indices differed between the CA and conventional farming systems (Figures 2.14 and 2.15; Table 2.3). According to Levin (2009), the Shannon diversity index, is more sensitive to evenness and less so to the number species.

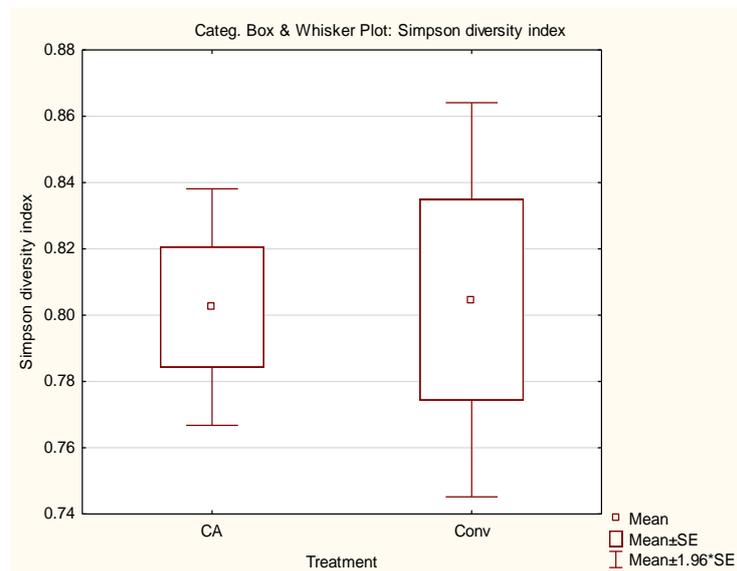


Figure 2.15. Simpson diversity index values comparing diversity of arthropods between conservation (CA) and conventional (Conv) farming systems over 3-year period (2015-2017) ($F = 0.004$; $P = 0.951$).

The Simpson diversity index showed that there was no significant difference in arthropod biodiversity between CA and conventional systems (Figure 2.15). In table 2.3 the mean Simpson diversity index value over three seasons was the same for both conventional and CA treatments ($D = 0.8$), indicating that the mean diversity remained similar over the seasons.

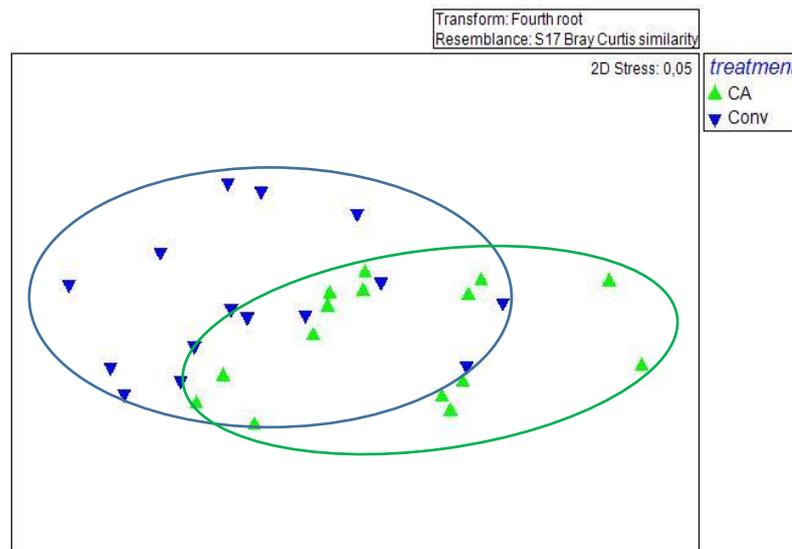


Figure 2.16. Non-metric multi-dimensional scaling (NMDS) plot of arthropod community composition in conservation (CA) and conventional farming systems over the 3-year period (2015-2017). Blue and green indicate species composition in conventional tillage and CA systems respectively.

NMDS analysis represents the composition of arthropod communities between treatments based on species richness and evenness. The composition of arthropod communities in conventional and CA fields differed (Figure 2.16). The habitat type can be the main factor influencing both taxonomic and trophic community structure.

According to Rivers *et al.* (2017), biodiversity in agricultural systems evolves in an ascending line over many years after the development of new topsoil management methods. Although there were no significant differences observed in the diversity indices between the two agricultural systems evaluated in this study, diversity of arthropods was slightly higher CA systems, which indicates that this practice may eventually lead to improved arthropod community diversity over time. The benefit of CA in this regard is further supported by the higher abundance and species richness in the CA systems.

Biodiversity type and abundance can vary across agro-ecosystems that differ in age, overall diversity, structure and management (Altieri, 1999). According to Altieri (1999), biodiversity in agroecosystems depend on diversity of vegetation, different crops and management intensity. According to Altieri *et al.* (2011), high levels of biodiversity play important roles in regulating ecosystem functioning and providing ecosystem services.

The key strategy in order to obtain production sustainability is to enhance functional biodiversity (Altieri, 1999). According to Palm *et al.* (2013), higher biodiversity in CA systems implies increased ecosystem services, which include pollination and pest regulation. CA, as practiced in the systems that were evaluated during this study, increased crop diversity through rotations, minimized tillage that reduces erosion. According to Rivers *et al.* (2016) this will lead to stabilization of crop yields which will provide a more complex and desirable habitat for soil-dwelling organisms. Studies have shown that an increase in structural diversity in agro-ecosystems leads to a greater diversity of both pest and beneficial insects, which usually result in reduced overall pest damage to crops (Marino and Landis, 1996).

2.5. Conclusions

CA can contribute to sustainable farming by conserving natural resources, enhancing biodiversity, providing ecosystem services and preventing of land degradation. Both plant and arthropod community diversity can be enhanced over time through crop rotation, intercropping, cover crops and agroforestry (Altieri, 1999).

It is evident that crop residues and minimum soil disturbance contribute to higher arthropod abundances and that the CA strategies have potential positive effects on the diversity of arthropods. Increased soil cover, provided by cover crops and crop residues on fields improves environmental conditions for epigeal arthropods by protecting their habitats against water and wind erosion. It further limits local variations in humidity and temperature, increases organic matter as a food source and provides a more stable environment for soil and litter dwelling invertebrates (Blanchart *et al.*, 2006). The conventional cropping environment may be stressful to arthropods due to the continued disturbance of the environment, as well as the fact that there may be comparatively fewer ecological niches. CA has the potential to increase the abundance of beneficial arthropod species such as Carabidae beetles and Araneae which can provide vital ecosystem services.

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Chapter 3: Arthropod feeding on weed seed and lepidopteran larvae in conservation agriculture systems

Abstract

Conventional agricultural practices such as continuous tillage lead to the disruption of soil structure and loss of fertile top soil, resulting in a reduction of soil productivity. Conservation agriculture (CA) is recognised as a way to combat soil deterioration brought on by conventional cultivation. Although CA practices in crop production systems may provide different habitats for hosting and supporting pests, it may also influence beneficial insect populations and underlying biodiversity that supports many ecosystem services. Insects have many important functions within ecosystems, including their roles as predators, pollinators, detritivores, herbivores and parasitoids. As such they are efficient indicators of ecosystem habitat and community structure and health, they provide meaningful information regarding habitat comparison studies. There is a general lack of information on the effect of CA on arthropod diversity, and the potential ecosystem services they provide in South Africa. Understanding the impact of landscape structures on the diversity and abundance of beneficial and harmful arthropods, pest regulation and ultimately crop yield can contribute significantly to improving the management of agricultural landscapes. The aim of this study was to determine the potential ecosystem services provided by an increased arthropod diversity. The predation on *Chilo partellus* and consumption of the seeds of the weeds *Urochloa panicoides* and *Setaria pallide-fusca*, by beneficial arthropods were compared between CA and conventional systems. This study was done during the 2016/17 growing season at the Ottosdal, Hartbeesfontein and Sannieshof localities. Ultimately it was recorded that the CA approach contributed to increased diversity and abundance of beneficial arthropods that provided an valuable ecosystem services.

Keywords: Arthropods, conservation agriculture and conventional tillage, ecosystem services and functional groups.

3.1. Introduction

Soil biota provide a wide range of key ecosystem functions such as nutrient cycling, bioturbation, decomposition of organic pollutants, decomposition of organic matter, purification of ground water, directly interaction with plants, and suppression of soil borne diseases and pests (Brussaard, 1997). According to Brussaard (1997), given these ecological services, soil organisms are essential to agroecosystem sustainability and can be negatively disturbed by human activities such as agricultural tillage practices. While soil dwelling groups form an abundant and essential portion of total biodiversity indices which are important for bioremediation, food security and sustainable land use practices, the majority of soil diversity is still unknown (Janion-Scheepers *et al.*, 2016).

Although conservation agriculture (CA) was originally introduced to manage wind and water erosion, it is now considered to contribute significantly to the delivery of multiple ecosystem services (Palm *et al.*, 2013). Ecosystem services are benefits provided to humans by the complete change of environmental resources into important goods and services that are essential to human well-being, health, livelihood and survival (Costanza *et al.*, 2014). The alteration of agricultural landscape structures has the potential to change ecosystem services provided by arthropods (Mitchell *et al.*, 2014). The intensive agricultural practices that are implemented to increase crop production can affect ecosystem components and processes such as ecosystem services that involve nutrient cycling, climate regulation, regulation of water quality and quantity, pollination and pest control (Palm *et al.*, 2013). Increased pest and disease pressure in agro-ecosystems is caused by changes in agricultural practices such as increased use of fertilizer and pesticides and expansion of monocultures (Altieri and Nichols, 2003). According to Altieri (1999), most insect pest problems are related to extensive crop monocultures which decrease local habitat diversity. Polycultures support lower herbivore numbers than monocultures, because they have more stable natural enemy populations and provide a variety of available food resources and micro habitats for all arthropods (Altieri, 1999). Cultivation activities such as conventional tillage, weed removal, pesticide spraying and harvesting can damage habitats and destroy food resources and micro-niches on which beneficial organisms depend (Altieri *et al.*, 2006).

According to Palm *et al.* (2013), CA, when compared to conventional practices, has more pronounced and adverse effects on soil properties and processes and these changes can in turn affect the delivery of ecosystem services. CA practices where crop residues are left on the soil surface after harvest can support predaceous ground beetles and other natural enemies with a permanent habitat for overwintering and create a more stable environment that promotes more diverse communities of decomposers (Altieri *et al.*, 2006). With an increased abundance and efficiency of predators and parasitoids in CA systems, a decrease in insect pest incidence can be expected (Altieri, 1999).

Ecosystem services resulting from the practice of CA may differ between systems due to climate, soil types and crop rotation sequences. There is however insufficient information to support a predictive comprehension of where CA provides better ecosystem services compared to conventional practices (Palm *et al.*, 2013). According to Altieri (1999), soil organisms such as microbes, nematodes, mites, millipedes and arthropods are important regulators of soil ecosystems which provide essential functions such as decomposing litter and nutrient cycling, converting atmospheric nitrogen into organic forms, suppressing soil-borne pathogens and altering soil structure. Encouraging agricultural practices such as CA is important because soil organisms are the key to sustainability in agro-ecosystems and this CA may therefore enhance abundance and diversity of soil organisms (Altieri, 1999). According to Palm *et al.* (2013), CA practices aim to increase crop yields by enhancing several regulating and supporting ecosystem services.

CA systems may affect the underlying biodiversity that support ecosystem services, which depend on arthropod movement, abundance and diversity across agricultural landscapes at different scales. Arthropod biodiversity has also been reported to be higher in CA systems than in systems where conventional tillage is practiced, and a higher diversity can often be related to a potential increase in ecosystem services (Palm *et al.*, 2013).

3.2. Beneficial arthropods

Not all arthropods are pests and farmers can profit from beneficial insects, since they help to control, problem insects. CA can be regarded as a form of conservation

biological control which is a very important component of integrated pest management (IPM). According to Bale *et al.* (2008), biological control is described as the use of certain organisms that feed on or parasitize pest organisms with the resulting effect of decreased pest and weed populations. These beneficial organisms are used to suppress pest populations and in the process render them less damaging than they would otherwise be (Eilenberg *et al.*, 2001). Most pests have natural enemies that suppress their numbers in most situations. An example of a biological control agents are certain ladybird species (Coccinellidae), which have been widely used as natural enemies of pests such whiteflies, aphids and mites. Beneficial carnivorous arthropods prey on other arthropods such as spider mites, are essential in the natural biological control programme, since they feed on all stages of the prey species.

Conservation biological control is a process during which the environment is made more favourable for natural enemies of pests by identifying factors that limit their effectiveness and then introducing strategies to address these factors and enhance their ability to attack the pest (Klemm, 2007). According to Thomas and Waage (1996), the most common action taken to conserve natural enemies is to reduce pesticide use. The conservation of natural enemies is perhaps the most cost-effective and universal form of conservation biological control to enhance beneficial arthropod abundance or activity (Thomas and Waage, 1996; Bale *et al.*, 2008).

The habitats of beneficial insects must also be protected and maintained, such as by leaving crop residues on the ground, in the case of CA to support natural enemy populations. According to Altieri *et al.* (2006), cover crops can attract beneficial insect, suppress weed growth, enhance soil quality, and provide moisture conserving mulch. CA is a therefore a natural strategy that can be used to reduce pest numbers in a healthier manner by enhancing populations of beneficial insects.

3.3. Agricultural pests and their management

Managing insects, weeds, nematodes and disease pathogens is a particular concern and challenge for growers that adopt organic management practices (Rivers, 2016). A wide diversity of arthropods functioning as predators, parasitoids and entomopathogens provide valuable ecosystem services by acting as natural biological control agents of agricultural pests (Bale *et al.*, 2008). Some pests can be of greater

concern than others, depending on geographical area, environmental conditions, and production practices. Commonly harmful insects can be categorized into the leaf feeding guild, fruit and flower feeding guild and root feeding guild, or combinations of these. Guild analysis can be of great economic importance when pest and weed pressure result in crop loss (Pretorius, 2014). According to McErlich and Boydston (2013), weeds are present annually and some degree of management is necessary for optimum crop yield and profitability. Weeds hinder the growth of crop plants when they are in the same field, competing for nutrients, water, light and can serve as alternate host for insect and disease pest (Quinn *et al.*, 2016). Weed species become of critical importance when their characteristics include rapid initial growth, strong competitiveness, high seed viability, rapid seed emergence and high seed production. Herbivorous insects and mites have generally been used in the biological control of weeds (Bale *et al.*, 2008).

Tillage practices are often used to suppress weed populations. Since this practice is cost and labour intensive and there is a potential for reducing soil quality, farmers need alternative practices (Rivers, 2016). The practise of cover crop-based rotational no-till management is increasingly being adopted to reduce tillage and to retain organic mulches on soil surfaces. More complex crop rotation practices in CA build up stress points against weeds and make it difficult for weeds to become a dominant factor (McErlich and Boydston, 2013). According to Chauhan *et al.* (2012), due to minimal soil disturbance in CA, most of the weed seeds remain on the soil surface after crop planting. Such circumstances may then be more favourable for granivore fauna, such as ants and other seed-feeding insects. Shallow distributed weed seeds present on soil surfaces in CA systems are most vulnerable to soil-dwelling seed predators, because weed seed predation increases with vegetation cover, due to the provision of favourable habitats for weed seed foragers (Quinn *et al.*, 2016). Seed predators have preference for certain kinds of seeds, for example, *Solenopsis geminata* (Hymenoptera: Formicidae) prefers grass seeds over broadleaf weed seeds (Chauhan *et al.*, 2012). Selectivity in seed consumption by these seed feeders may result in shifts in weed populations which suggest that seed predation can reduce the size of weed seed banks. Various approaches, including the use of crop residue as mulches, intercropping with competitive crop cultivars, herbicide-tolerant cultivars and

herbicides application are needed to manage weeds in CA-systems (Chauhan *et al.*, 2012).

According to Quinn *et al.* (2016), ground beetles (Carabidae) and crickets (Gryllidae) provide ecosystem services in terms of weed seed feeding and insect pest mortality in agricultural systems. Beneficial omnivorous crickets are promoted as a large consumer of weed seeds in temperate agricultural systems, *e.g.*, a recent study in North American crop fields concluded that predation on *Setaria faberi* seeds is highly correlated with the activity of *Gryllus* and *Allonemobius* cricket species (Lundgren, 2009). Efficient production of maize depends on the crop being able to grow free from weed competition (Rodríguez *et al.*, 2006). According to Menalled *et al.* (2007), under both laboratory and field conditions, Carabidae beetles play a valuable role as predators in annual row-crop agricultural systems since they consume a large numbers of weed seeds. It is of critical importance to understand the dynamics of Carabidae communities and their weed seed feeding services because they have the potential to suppress weeds in agricultural systems (Menalled *et al.*, 2007). According to Altieri *et al.* (2011), cover crops not only minimize soil erosion but suppress weed growth. CA systems do not depend on herbicides to control weeds but rather on summer and winter cover cropping, which also results in thick layers of crop residues where directly planted crops are not significantly affected by weed interference.

3.4. Functional groups of arthropods

According to Eilenberg *et al.* (2001), natural enemies or beneficial insects fall into a variety of categories, namely pathogens, predators and parasitoids that function as biological control agents to manage certain pests (Herzfeld, 2011). Functional groups are an essential asset in studying the role of soil biota in maintaining ecosystem services (Brussaard, 1997).

3.4.1. Herbivores

Not all herbivorous arthropods are crop pests and not all crop pests will cause economic damage to a crop Rivers (2016). There are several insect pest species that are major constraints to maize, sorghum and sugarcane production in southern Africa, *e.g.* the stem borers *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae), *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae), *Sesamia calamistis* Hampson (Lepidoptera:

Noctuidae) and *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (Moolman *et al.*, 2013). *Chilo partellus* is an important pest of maize and grain sorghum in South Africa, especially in the warm, low-altitude regions (Kfir, 1997). Conventional tillage seems to be an obvious method to control stem borers during their overwintering stages inside crop residues on top of or below the soil surface. However, the benefits of leaving crop residues on the field, on the other hand, may include better water retention in soil, decreased soil erosion, improved weed control and soil structure and eventual savings in production costs (Kfir *et al.*, 1989). There are many aspects that could influence the potential of an herbivorous insect to become pestiferous, but in many agroecosystems and organic systems, generalist predatory arthropods have the potential to suppress pests numbers (Rivers, 2016).

3.4.2. Predators

The natural enemy hypothesis suggests that a more diverse system where there is an increase of crop or non-crop resources can result in an increase of predators and parasitoids which in turn increases pest control (Rivers, 2016). A diverse habitat that include practices such as crop rotation, no-till, cover crops and mulch on soil surfaces can augment generalist arthropod predator numbers which may reduce potential pest populations and through time increase stability of the system (Rivers, 2016). According to Rivers (2016), predators depend on their presence in the field which in turn relates to increased habitat availability and complexity in agroecosystems. Although predatory species occur in most arthropod orders, they are most abundant in the Coleoptera, Neuroptera and Hemiptera (Altieri *et al.*, 2006).

Centipedes (Chilopoda) are widely distributed in moist habitats and they occur commonly in woodlands and grasslands. Generally they are active predaceous species that consume soil-inhabiting arthropods, aphids, Collembola and mites. Certain centipede species can contribute to biological control of crop pests, e.g. *Scolopendra* spp. (Bagyaraj *et al.*, 2016).

Ants (Hymenoptera: Formicidae) are beneficial and act as predators of other many other arthropod species. For example, *Pachycondyla tarsata* (Formicidae), also known as the African stink ant, is widespread in sandy savanna habitats where they are predators of termites, millipedes and beetles (Picker *et al.*, 2004). According to

Janion-Scheepers *et al.* (2016), ants act as ecosystem engineers through their nest construction activities which also provide macropores for water infiltration.

Larvae of antlions (Neuroptera: Myrmeleontidae) are ferocious predators of mainly small arthropods (Boehme, 2014). Most Carabidae beetles are omnivorous predators which may feed on both arthropod prey and plant seeds (Kotze *et al.*, 2011). According to Kotze *et al.* (2011), Carabidae beetles have a variety of food items beside prey which include leaves, fruits, pollen, seeds and fungi. Some Carabidae species feed on plant material or seeds, for example *Harpalus* spp. and *Amara* spp. These species are essential biological control agents for weeds in no-till management systems. Most predaceous ground beetles hide under plant litter and rocks during the day and at night they hunt their prey (Altieri *et al.*, 2006).

3.4.3. Detritivores

Many soil insects are associated with fragmentation and decomposition of dead organic material as well as nutrient recycling (Janion-Scheepers *et al.*, 2016). Soil beetles provide important functions as detritivores, e.g. Cetoniinae, Dynastinae, Melolonthinae and Elateridae (Janion-Scheepers *et al.*, 2016). According to Boehme (2014), darkling beetles (Coleoptera: Tenebrionidae) are mostly detritivores and common throughout the world in almost every type of environment. According to Bagyaraj *et al.* (2016), the Diplopoda are widely distributed, tend to be more abundant and diverse in calcareous soils, and mostly occur in adequately moist habitats and usually in the upper soil horizons. Millipedes are detritivores which improve the soil system and by acting as agents of decomposition by feeding on dead plant matter (leaf debris, wood and fungal mycelia) which can enhance nutrient release (Bagyaraj *et al.*, 2016).

3.4.4. Pollinators

Three quarters of all food crops in the world especially vitamin rich crops, depend on pollen-gathering insect pollinators (Boehme, 2014; Chaudhary *et al.*, 2013). Most of the organisms in this functional group are bees, moths, flies, wasps and beetles. Studies have reported that agricultural crop yields can on average be improved by approximately 20% by native pollinators near forests (Chaudhary *et al.*, 2013). According to Samways (1994), insects are a key driver of flower diversity and many crops, as well as flowering plants are under threat because their wild pollinators are

declining. According to Chaudhary *et al.* (2013), the environmental problem of pollination in food crops is that in a monoculture cropping system greater concentrations of pollinators are required, and pollinator populations are declining due to intensive chemical use in agriculture. Many South African crops also need pollination services which are unfortunately adversely affected by environmental issues, such as habitat transformation, fragmentation, climate change and loss of floral resources (Menlin *et al.*, 2014). It is therefore important to conserve biodiversity in agricultural landscapes and CA may contribute to this issue.

3.5. Aim and objectives

The main objective of the study was to determine the potential ecosystem services provided by an increased arthropod diversity. Specific objectives were:

- to compare different functional group abundance and species richness between CA and conventional farming fields.
- to compare predation on lepidopteran larvae and consumption of weed seed between different farming practices.
- to determine the relationship between predation, arthropod abundance and species richness in different farming practices.

3.6. Materials and methods

3.6.1. Site selection

This study was done on three well-established CA field sites and three conventional farming field sites at Ottosdal, Hartbeesfontein and Sannieshof (Figure 3.1). The epigeal arthropod species richness and abundance (see Chapter 2) and functional groups were all monitored at these field sites.

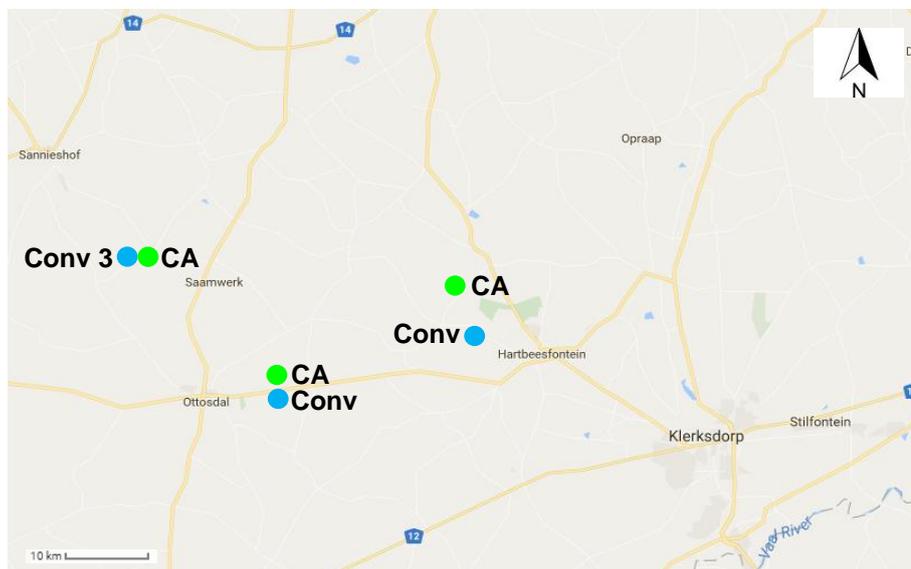


Figure 3.1. The localities of the 6 field sites. Green dots indicate CA fields and blue dots indicate conventional (Conv) fields.

3.6.2. Experiment 1: Weed seed removal by beneficial arthropods

This experiment was conducted during March and April of 2017. The weed spectrum was identified at three localities after which two dominant grass species were chosen, *i.e.* *Urochloa panicoides* and *Setaria pallide-fusca*. Seeds from each of these species were collected and fixed to the inner base of modified petri dishes using double-sided sticky tape. Each petri dish contained 50 seeds of the respective weed species. Fine gravel was then added onto the seed and sticky tape to coat the remaining sticky surface to prevent arthropods from becoming trapped. Petri dishes were placed into specially constructed vertebrate exclusion cages, and then buried so that the petri dishes were level with the soil surface (Figure 3.2).



Figure 3.2. Vertebrate exclusion cage with Petri dishes containing *Setaria pallide-fusca* and *Urochloa panicoides* seed (left). Each Petri dish contained 50 seeds of the respective weed species (right).

Five exclusion cages were used at each field site. Cages were randomly placed between the rows in the maize field. There was a total of 15 cages in CA fields and 15 cages in conventional fields (Figure 3.3). The seed dishes were left in the field for ten consecutive days after which the number of damaged and missing seeds were enumerated. The experiment was repeated twice, once in March and once in April.

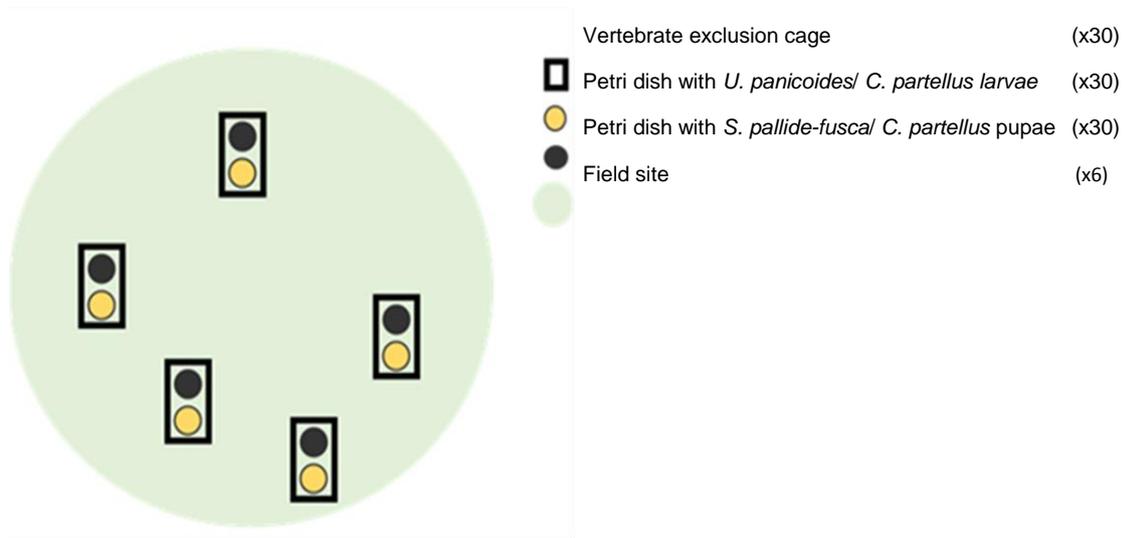


Figure 3.3. Layout of exclusion cages with petri dishes at a single field site.

3.6.3. Experiment 2: Pest removal by beneficial arthropods

The prey items that were provided to potential predators were pupae and larvae of *Chilo partellus* (Lepidoptera: Crambidae). Each cage contained one petri dish with two live, final instar *C. partellus* larvae and one petri dish with two pupae (Figure 3.4). Larvae and pupae were pinned onto agar covering the bottom of a petri dish to prevent their escape after which they were placed into the cages and in the field (Figure 3.4). This experiment was also conducted during April and March of 2017 and at the same localities and field sites as indicated in experiment 1. The same number of vertebrate exclusion cages were used. Damage to or removal of pupae and larvae were recorded after 24 hours. Larvae that were removed or damaged were recorded as preyed upon. The experiment was repeated twice, once in March and once in April.

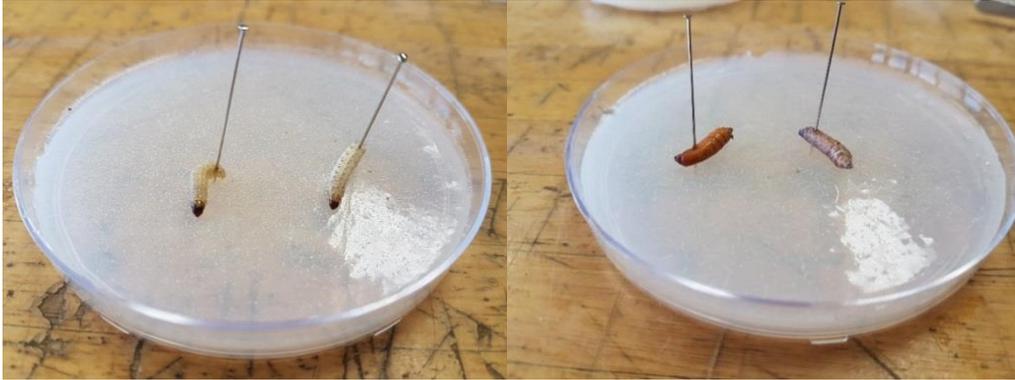


Figure 3.4. Chilo-borer larvae (left) and pupae (right) pinned on a petri-dish prior to placement in cages for recording of predation.

3.7. Data analysis

The data used in *Chapter 2*, to compare arthropod abundance and biodiversity between CA and conventional systems were also used in this study, with the difference that morpho-species were grouped into functional groups in the chapter.

These data were pooled for the three replicates per farm and species richness and abundance of organisms within the different functional groups were calculated for each site during each of the three growing seasons (2014/15, 2015/16 and 2016/17). Data were used to calculate the average species richness and abundance in different functional groups and to compare conventional and conservation tillage systems, using T-tests in Excel. The percentage predation on *C. partellus* larvae and pupae and the percentage consumption of *U. panicoides* and *S. pallide-fusca* by beneficial arthropods for 2016/17 growing season were also calculated and compared with T-tests. Regression analyses were done to compare the seed or *C. partellus* removal from the different treatments.

3.8. Results and discussion

There were no significant differences between the mean numbers of arthropods in the different functional groups collected at conventional and CA sites (Table 1). However, CA promoted a higher abundance in numbers of herbivores, predators, detritivores and pollinators compared to conventional systems (Table 3.1 and Figure 3.5).

Table 3.1. The mean numbers of arthropods and numbers of morpho-species of the different functional groups collected during three growing seasons in conservation (CA) and conventional (Conv) farming systems.

Functional group	Treatment	Mean number of individuals (\pm SE)	t-value(df); P-value	Mean number of morpho-species (\pm SE)	t-value(df); P-value
Herbivores	Conv	1743 (\pm 371)	-1.491 (8); 0.174	27.8 (\pm 1.9)	-1.208 (8); 0.261
	CA	3218.8 (\pm 917.4)		31.6 (\pm 2.4)	
Predators	Conv	853 (\pm 177.1)	-1.149 (8); 0.283	37.8 (\pm 2.4)	-2.831 (8); 0.022
	CA	1114.4 (\pm 142.5)		47.8 (\pm 2.4)	
Detritivores	Conv	290 (\pm 137.1)	-1.394 (8); 0.201	4.8 (\pm 0.3)	-1.5 (8); 0.172
	CA	695.2 (\pm 256.3)		6.0 (\pm 0.7)	
Pollinators	Conv	4.8 (\pm 1.1)	-1.49 (8); 0.173	2.6 (\pm 0.2)	-0.784 (8); 0.455
	CA	7.2 (\pm 1.1)		3.0 (\pm 0.4)	
Parasitoids	Conv	1.8 (\pm 1.8)	0.651 (8); 0.533	0.2 (\pm 0.2)	-0.894 (8); 0.397
	CA	0.6 (\pm 0.4)		0.6 (\pm 0.4)	

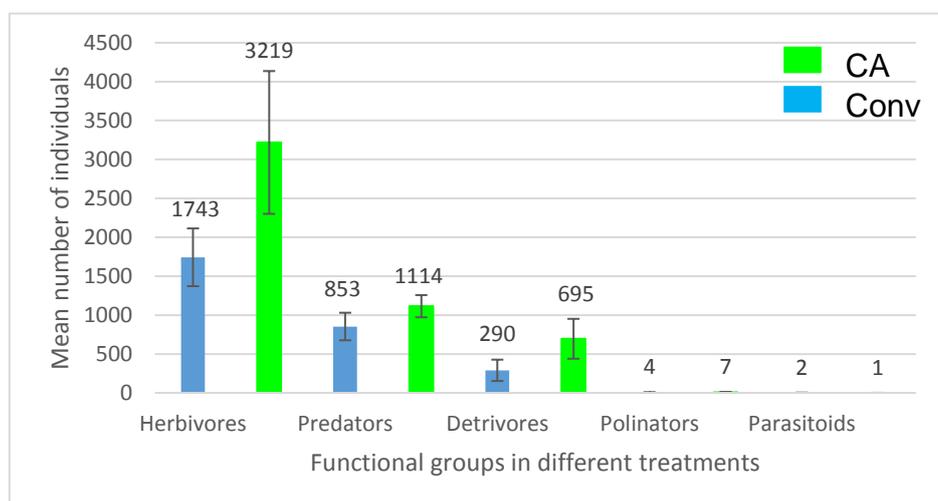


Figure 3.5. Mean arthropod abundance in functional groups in conservation (CA) systems compared to conventional tillage systems over a 3-year period between in 2015-2017. Conv = conventional farming sites; CA = conservation farming sites. Bars = standard errors.

No significant differences were observed between the species richness within functional groups in the conventional and conservation agriculture systems (Table

3.1). Although not always significant, the numbers of arthropod species were always higher in the CA system (Figure 3.6). Only predator species richness was significantly higher in CA treatments ($P= 0.022$) (Table 3.1; Figure 3.6).

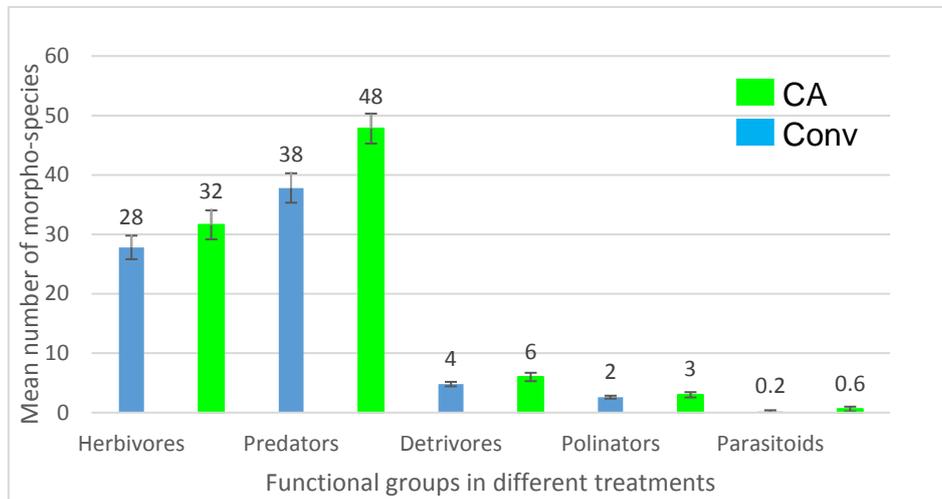


Figure 3.6. Mean arthropod species richness in functional groups in conservation (CA) systems compared to conventional tillage systems over a 3-year period between in 2015-2017. Conv = conventional farming sites; CA = conservation farming sites. Bars = standard errors.

No significant differences were observed in the percentage consumption of *S. pallide-fusca* seeds by arthropods between CA and conventional systems. However, in contrast to this, the percentage consumption of *S. pallide-fusca* seeds was higher in a CA system (Figure 3.7).

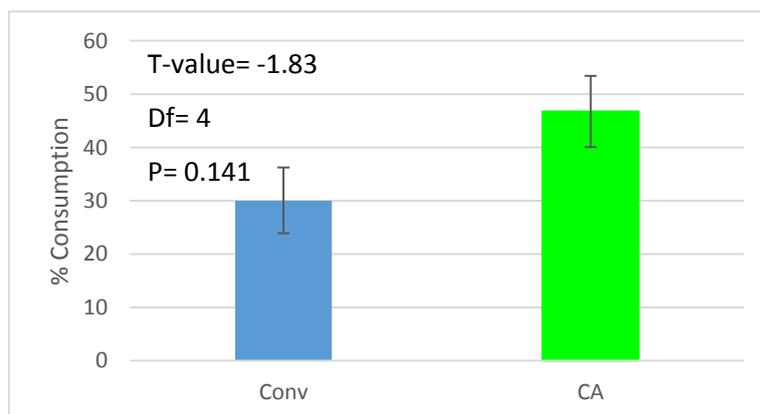


Figure 3.7. The mean percentage consumption of *Setaria pallide-fusca* seeds in conservation (CA) and conventional systems during the 2016/17 growing season.

Conv = conventional farming sites; CA= indicates conservation farming sites. Bars = standard errors.

No significant differences were observed in the percentage seed removal by arthropods between CA and conventional systems, although the percentage consumption of *U. panicoides* seeds was higher in the CA system (Figure 3.8). According to Lundgren (2009), some Carabidae larvae feed exclusively on seeds that may have higher nutritional value than insect prey, which is more suitable for larval development for species such as *Harpalus honestus*.

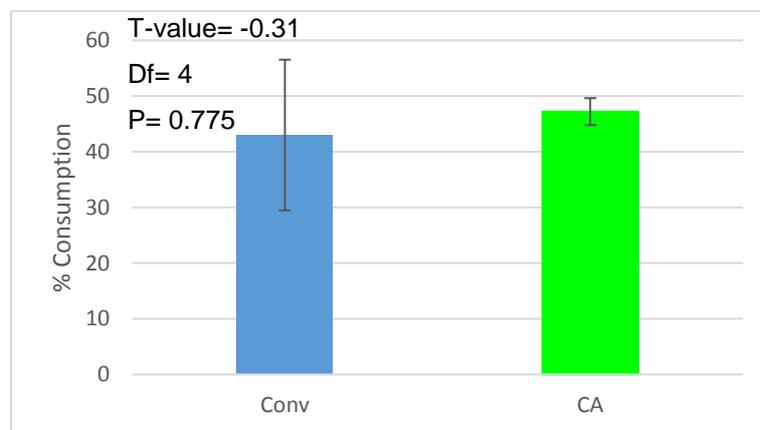


Figure 3.8. The mean percentage removal *Urochloa panicoides* seeds in conservation (CA) and conventional system during the 2016/17 growing season. Conv = conventional farming sites while CA indicates conservation farming sites. Bars = standard errors.

The percentage predation on Chilo-borer larvae differed significantly ($P= 0.003$) between CA and conventional farming fields, with the CA system contributing to a higher predation activity (Figure 3.9).

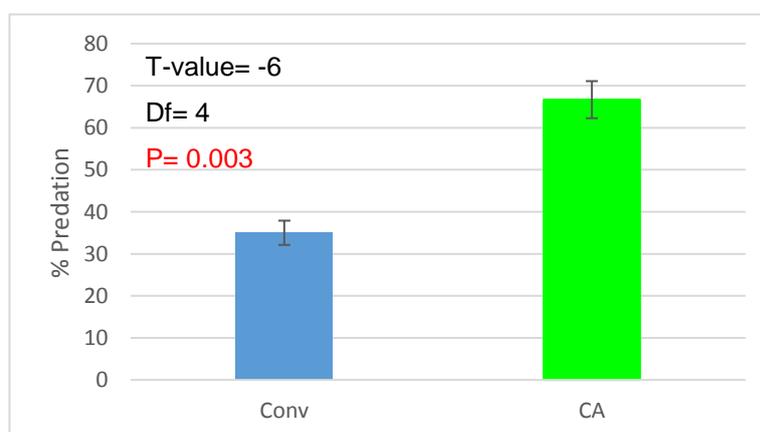


Figure 3.9. The percentage predation on *Chilo partellus* larvae in conservation (CA) fields compared to conventional fields during the 2016/17 growing season. Conv = conventional farming sites; CA = conservation farming sites. Bars = standard errors.

No significant differences were observed with the percentage predation on Chilo-borer pupae, although the predation was higher in CA compared to the conventional system (Figure 3.10).

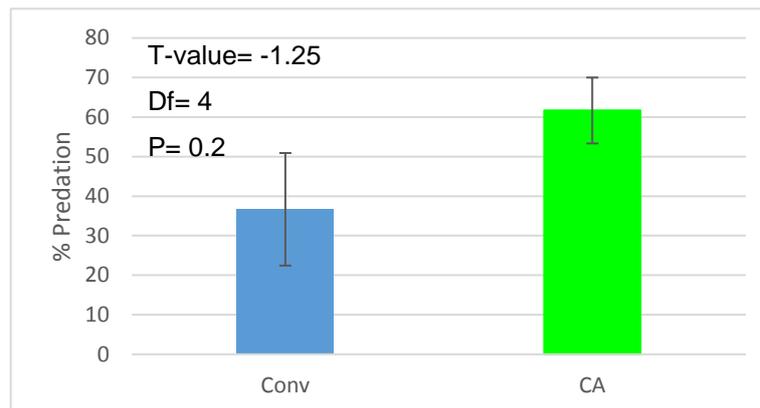


Figure 3.10. The percentage predation on *Chilo partellus* pupae in conservation (CA) fields compared to a conventional system during the 2016/17 growing season. Conv = conventional farming sites; CA = conservation farming sites. Bars = standard errors.

The percentage predation recorded in CA systems was higher than that in the conventional systems (Figure 3.11). Differences were observed in the relationship between predation on *C. partellus* larvae and the total abundance of arthropod predators in CA and conventional system (Figure 3.11). The percentage predation tended to increase with total number of predator individuals in both treatments, both correlation coefficients were high. Although when the same number of predator individuals occur in both treatments, the percentage predation tend to be much higher in CA system (Figure 3.11).

The percentage predation in the CA system was higher than that in the conventional system (Figure 3.12). A difference was observed in the relationship between predation on *C. partellus* larvae and the total arthropod predator richness in the CA and conventional systems, with significantly higher levels of predation observed in the CA system. The only significant correlation between predator species richness and predation was observed in the CA system (Figure 3.12).

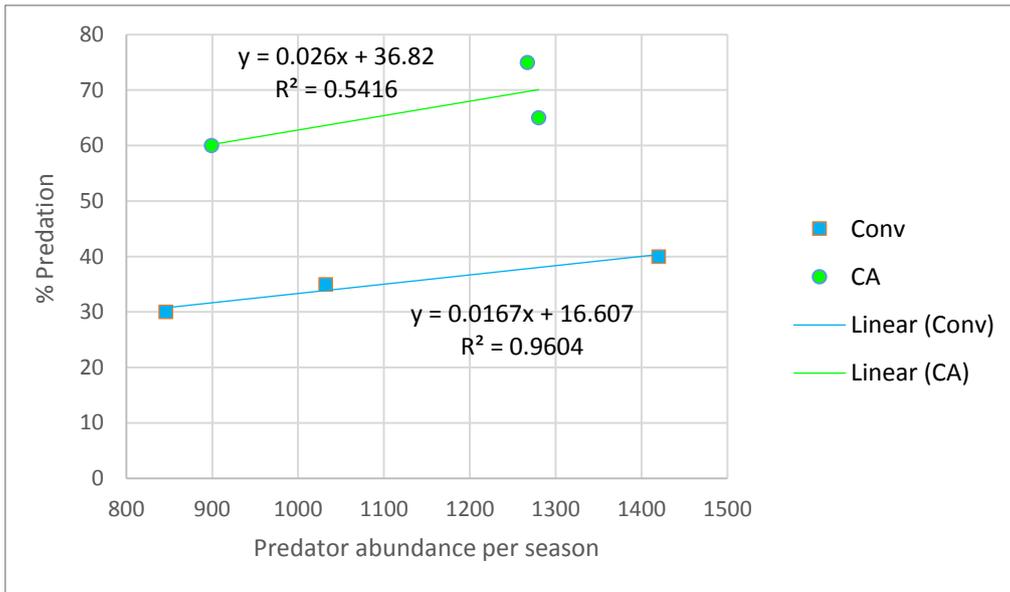


Figure 3.11. Regression lines indicating the relationship between the percentage *chilo partellus* larvae predated upon and predator abundance in conservation (CA) and conventional systems during the 2016/17 growing season per farm. Conv = conventional farming sites; CA = conservation farming sites.

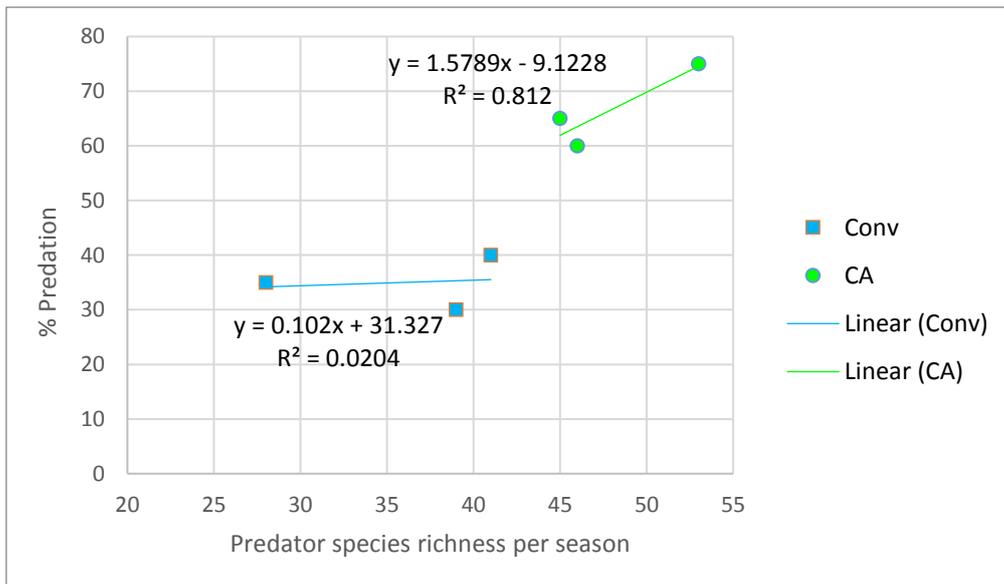


Figure 3.12. Regression lines indicating the relationship between the percentage *Chilo partellus* larvae predated upon and predator species richness in conservation (CA) and conventional systems during the 2016/17 growing season. Conv = conventional farming sites; CA = conservation farming sites.

Several species of beneficial arthropods were observed near cages during experiment 2 (Figure 3.13). Some of these species, which included the ground beetles, ants and earwigs were predated on *C. partellus* larvae. *Etrichodia crux* was not observed to feed on *C. partellus* pupae, although they are known for feeding on millipedes.

Predatory arthropods, especially Carabidae abundance and species richness was higher in CA than conventional systems. The total number of *Harpalus* spp. individuals caught during this study was 2 336 in the CA system and 1 249 in the conventional system, and 8 morpho-species in the CA system and 5 in the conventional system. This was the case for most Carabidae species, including *Graphipterus* spp. and *Thermophilum* spp.

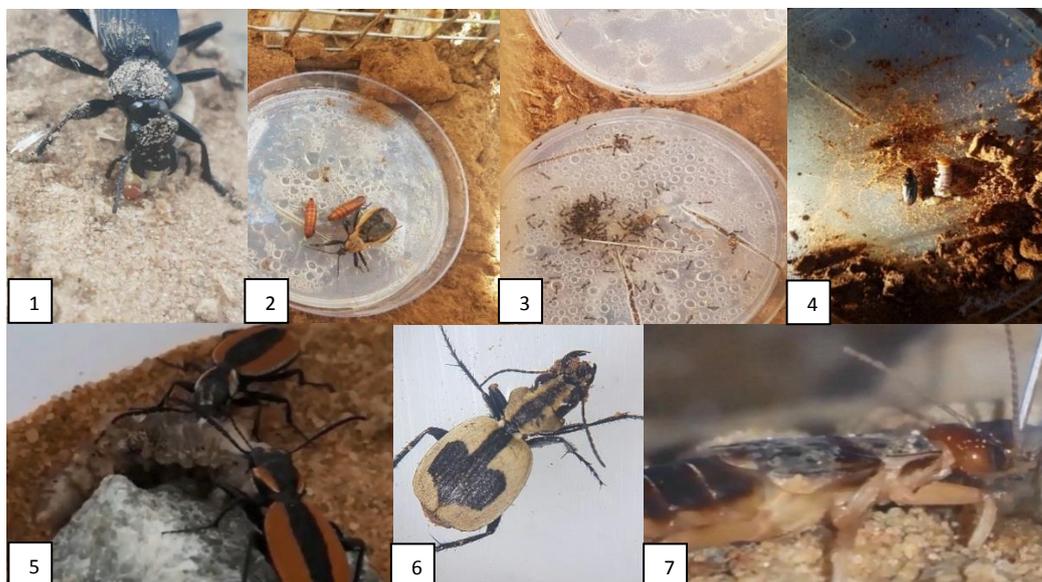


Figure 3.13. Some beneficial predator arthropods observed predated on Chilo-borer larvae during experiment 2: (1) *Thermophilum homoplatum*, (3) Formicidae species, (4) *Harpalus* species, (5) *Graphipterus atrimediatus*, (6) *Graphipterus* sp. and (7) *Labidura riparia*. (2) *Etrichodia crux* was active around Chilo-borer pupae.

Arthropods react to the conditions around them. According to Landis *et al.* (2000), many agro-ecosystems have high disturbance levels, such as conventional tillage, which create environments that are unfavourable for the support of natural enemies. CA practices lead to diversified habitats and improves the availability of resources, which can contribute towards increasing beneficial arthropod biodiversity, which is critical for ecosystem services and agricultural sustainability (Landis *et al.*, 2000). Ecosystem services also depend on arthropod mobility, abundance and diversity

across agricultural landscapes at different scales. More stable habitats result in even higher levels of weed seed removal in natural and agricultural systems (Lundgren, 2009). According to studies in Ohio, USA, it was reported that maize plants in conventional systems showed four times higher damage when predators were removed, than when predators were present in no-tillage systems (Stinner and House, 1990). Tillage therefore significantly reduced predator density and predation on cutworm larvae (Stinner and House, 1990). According to Stinner and House (1990), it will be a challenge for future research to exploit the roles that arthropods play, not only as pests and natural enemies, but as agents in regulation of ecosystem processes.

3.9. Conclusions

CA practices support the build-up of natural enemy populations that could suppress pest and weed populations. Arthropod biodiversity was higher in CA than conventional systems and this higher diversity was positively related to increased ecosystem services. The presence of predators is critical in conservation agriculture systems since they can reduce pest numbers and contribute to weed suppression by consuming weed seeds. It is important to maintain and, if necessary restore natural ecosystems and the services they provide for the sustainability of community well-being, economic prosperity and general social system efficiency.

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Chapter 4: Conclusion and recommendations

4.1. Conclusions

Conservation agriculture (CA) can contribute to sustain economic crop yields that are essential for food security, while conserving environmental resources. CA provides improved soil quality by enriching soil organic content, reducing soil erosion and creating optimal environmental conditions that support important arthropod communities. Findings suggested that epigeal arthropod communities differ between CA and conventional systems and that arthropods are sensitive to alterations in vegetation. This study showed that arthropod abundance and species richness were higher in CA fields than conventional maize fields in the North-West and Free State provinces of South Africa. CA also increased the number of arthropod individuals and morpho-species in different functional groups such as herbivores, predators and detritivores. CA resulted in increased numbers of important predators, particularly Carabidae species. These predators feed on and may suppress the numbers of pests such as Lepidoptera larvae and also weed seeds. This study showed that CA contributes to suppressing *Chilo partellus* numbers and that seed predators removed large numbers of *Urochloa panicoides* and *Setaria pallide-fusca* seed. Overall positive relationships were observed between arthropod species and abundance and percentage predation on Lepidoptera larvae.

With an increase in arthropod species richness and abundance, CA promotes ecosystem system services. Arthropod communities are important to ensure sustainability and functioning of ecosystems and they play an essential role in nutrient cycling and add economic value through ecosystem services such as predation and pollination. Conventional agriculture may make use of unsustainable practices which disturbs the soil and removes organic matter from fields, resulting in a loss of biodiversity. Through the practice of CA, farmers can respond to the degradation of agricultural production resources in South Africa and address emerging challenges such as climate change, drought and poor availability of agricultural inputs. It is important for farmers to improve ecosystem services by working towards sustainable agriculture farming practices. Up to date no new insect pests were reported on farms in South Africa where CA is practiced. Although several pest species were recorded

during this study, no major economic important pests were observed. It is still necessary to monitor pests in CA systems, for example the invasive Fall army worm, *Spodoptera frugiperda*, which pupates in the soil. CA should be promoted in South Africa as a strategy that contributes to an increase in biodiversity and as a result more stable, healthier agro-ecosystems.

4.2. Recommendations

- For further studies Arthropoda can be identified to species level. Future studies can be conducted to quantify the contribution of different functional groups, especially predators, to ecosystem services such as predation and weed seed removal.
- For further studies of this nature, additional sampling methods such as pitfall traps, sweep nets and D-Vac suction could be used to also collect alate insects and insects that occur on plants.
- Laboratory experiments can be conducted to identify specific arthropod species that consume specific weed seeds and to quantify the removal of seeds. Broad leaf weed seeds in general are smaller than that of grass species and it may be more effective to incorporate a broader weed species range in the weed seed removal experiments.