Transitioning to organic agriculture: the changes in arthropod biodiversity and pests over time

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Declaration

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Abstract

The Greater Cape Floristic Region (GCFR) is a unique area known for its incredible biodiversity. It is also the largest wine-grape producing area in South Africa. However, agriculture and more specifically viticulture, poses a threat to biodiversity in the GCFR. Alternative and environmentally sustainable agricultural practices, such as organic farming, could ensure the conservation of biodiversity and the continued provision of important ecosystem services. In this study, I investigated the benefits organic agriculture has for both conservation and production. I looked at how arthropod biodiversity and pest control change over time since transitioning to organic agriculture. I did so by comparing vineyards at different stages in the transition process i.e. a conventional vineyard, 1-year in transition to organic (1-year transition), 5-year and a 15-year organic vineyard.

Arthropod biodiversity was sampled in December 2016 and January 2017 on the vines and in the non-crop inter-row vegetation using vacuum sampling. Species richness and abundance was determined for each vineyard treatment. The lowest species richness and abundance was found in the conventional vineyard and the highest in the 1-year transition vineyard. After the initial increase, the richness and abundance seems to decrease under organic management practices, where it then stayed constant over time, at higher levels than in the conventional vineyard. Arthropod assemblage structure was also analysed and a significant difference was found between the vineyard treatments. It does seem as if the assemblages stabilized over time, with the most similarity found between the 5- and 15-year organic vineyards.

Spider and parasitoid (natural enemies) species richness and abundance showed a similar trend to overall arthropod biodiversity, with a general influx of natural enemies in the 1-year transition vineyard, from where it seems to decrease over time under organic management practices. Despite the influx of natural enemies in the 1-year transition vineyard, the proportion of natural enemies of the total arthropods sampled, was quite low compared to the other vineyards. Over time under organic management practices, the proportion of natural enemies seems to increase.

Pest counts and damage were determined using a pest monitoring system, alongside the biodiversity sampling. Monitoring focused on the pests *Phlyctinus callosus* (Coleoptera, Curculionidae) and *Plangia graminea* (Orthoptera, Tettigoniidae). Visual inspection of 20 plots consisting of 5 vines per plot was done for every hectare. A trapping method supplemented the pest counts for *Phlyctinus callosus* in the vineyards. The pest counts did not

show any discernible pattern and it did not relate to the pest damage. Pest damage was generally higher in the 1-year transition vineyard compared to the other vineyards. The overall damage decreased over time under organic managements practices, which indicates that the pest control ecosystem services does establish over time in organic vineyards.

This study shows that the stabilisation time is an important consideration in organic agriculture. Although significant changes occur rapidly with the change in management practices, it does take time for the arthropod biodiversity and the pest control ecosystem services to return and for the agroecosystem to stabilize after conventional agriculture. Given time, these systems stabilise and become biologically resilient agricultural systems.

Opsomming

The Kaapse Floristiese Ryk (KFR) is ‘n unieke area bekend vir die besonderse hoë biodiversiteit. Dit is ook een van die grootste wyndruif-produserende areas in Suid-Afrika. Landbou en meer spesifiek wingerdbou, bedryg egter die biodiversiteit in die KFR. Alternatiewe en volhoubare landbouproduksie, soos organiese landbou, kan die bewaring van biodiversiteit, asook die bewaring van belangrike ekosisteem-dienste beteken. In hiedie studie, ondersoek ek die voordele wat organiese landbou inhou vir beide bewaring en vir produksiedoeleindes. Ek ondersoek hoe die geleedpotige biodiversiteit en pesbeheer verskil oor tyd onder organiese bestuurspraktyke. Ek vergelyk wingerde, wat in verkillende stadiums in die transisie proses is, naamlik: ‘n konvenstionele-, 1-jaar in transisie na organies (1-jaar transisie), 5-jaar organies en ‘n 15-jaar organiese wingerd.

Monsters van die geleedpotige biodiversiteit is in Desember 2016 en Januarie 2017 in die wingerde asook in die plantegroei tussen die wingerde geneem, deur gebruik te maak van die stofsuier metode. Die spesierykheid en getalrykheid is bereken vir elke wingerd. Die laagste spesierykheid en getalrykheid was in die konvenstionele wingerd en die hoogste in die 1-jaar transisie wingerd gevind. Na die aanvanklike toename, het die spesierykheid en getalrykheid afgeneem en afgeplat, by hoër vlakke as die konvenstionele wingerd. Die geleedpotige gemeenskapsamestelling was ook ondersoek en het ‘n beduidende verskil gewys tussen die behandelings. Dit lyk egter asof die gemeenskapsamestelling gestabiliseer het oor tyd, met die grootste ooreenstemming wat voorgekom het tussen die 5- en die 15-jaar organiese wingerde.

Spinnekoppe en parasitoïede (natuurlike vyande) se spesierykheid en getalrykheid het dieselfde tendens as die algemene geleedpotige biodiversiteit getoon, met ‘n instroming van natuurlike vyande in die 1-jaar transisie wingerd, waarna dit afgeneem het en afgeplat het onder organiese bestuurspraktyke. Ten spyte van die instroming van natuurlike vyande in die 1-jaar transisie wingerd, was die proporsie natuurlike vyande van die totale geleedpotiges, relatief klein vergelyking metdie ander wingerde. Die proporsie natuurlike vyande het toegeneem oor tyd onder organiese bestuurspraktyke.

Pestellings en -skade was bepaal deur gebruik te maak van ‘n pesmoniteringstelsel, wat tesame met die biodiversiteit monsters geneem is. Monitering was gefokus*Phlyctinus callosus* (Coleoptera, Curculionidae) en *Plangia graminea* (Orthoptera, Tettigoniidae). Visuele inspeksie van 20 persele, wat bestaan uit 5 wingerdstokke per perseel, is gedoen vir elke hektaar. ‘n Lokvalmetode was ook gedoen as aanvulling vir die pestellings vir die spesie

Phlyctinus callosus. Die pestellings het nie enige tendense gewys nie en dit het ook nie ooreengestem met die pes skade nie. Die pesskade was oor die algemeen die hoogste in die 1-jaar transisie wingerd. Die pesskade het afgeneem oor tyd onder organiese bestuurspraktyke, wat aandui dat die pesbeheer ekosisteem-dienste vestig oor tyd onder organiese bestuurspraktyke.

Hierdie studie wys dat die stabiliseringstyd belangrik is in organiese bestuurspraktyke. Alhoewel daar beduidende verskille waarneembaar is onmiddelik na die oorskakeling in bestuurspraktyke, neem dit tyd vir die geleedpotige biodiversiteit en die pesbeheer ekosisteem-dienste om te vestig. Dit lyk dus asof organiese sisteme stabiliseer oor tyd, wat aandui dat die biologiese veerkragtigheid versterk.

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1. Introduction

1.1 Agriculture: the present, past and future

As the human population grows, so does the demand for agricultural produce. By 2050, agricultural production would have to increase by 70% to sustain a population of 9.1 billion people (FAO 2009). The annual production rate of major crops is however, not enough to meet the demands by 2050 (Ray 2013). Furthermore, agriculture as a sector is facing many environmental challenges such as climate change, loss of biodiversity, pollution and land degradation, which dampens the prospects of feeding a growing population.

The world has seen a substantial increase in agricultural production in the past. During the mid to late 20th century, technological advances such as the development of high yielding crop varieties and chemical inputs allowed for an increase in agricultural productivity. This period, known as the Green Revolution, resulted in global cereal production to consequently triple (Mulvaney 2009). Technology that gave rise to the Green Revolution also shaped much of modern agriculture as we know it today.

The high productivity associated with the Green Revolution and modern agriculture comes at an environmental cost (Wilson & Tisdell 2001). The loss of biodiversity is one of these environmental costs (Tilman 1999). Although species extinction is a natural phenomenon that has occurred throughout the history of life on earth, the current rate of species extinction far outpaces the natural background or pre-human extinction rate (Dirzo *et al*. 2014; May 2010). Not only are we experiencing great losses in biodiversity, but also changes in the distribution, composition and abundance of species (Pereira 2012).

Habitat change and degradation are some of the leading causes responsible for the loss and the changes in biodiversity (Vitousek 1997; Pereira 2012) and agriculture is largely to blame. Diverse natural habitat is transformed into vast areas of simplified land with a selected few animal, crop, weed and pest species. It is estimated that one billion hectares of natural habitat will be lost to the conversion of agricultural land by 2050 (Tilman 1999). Intensive agricultural practices contribute to the degradation of the agricultural landscape, which further contributes to the loss of biodiversity (Benton *et al*. 2003; Butler 2007). The dependence on external inputs, which characterizes intensive agricultural practices, is also growing. By 2050, a doubling to trebling of nitrogen inputs, phosphorous inputs, water usage and pesticide usage is expected (Tilman 1999).

Some scientists believe that of all the environmental challenges that faces humanity, the loss of biodiversity poses the greatest threat (Cardinale 2012; Hooper 2012). This is because biodiversity plays a pivotal role in the functioning of life supporting ecosystems (Altieri 1999; Cardinale 2006). Humans depend on ecosystem functions to produce ecosystem services, which are "the conditions and the processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life" (Daily 1997). Agroecosystems produce a variety of essential ecosystem services, aside from food production. These include provisioning- (e.g. fresh water and genetic resources), supporting- (e.g. soil formation and nutrient cycling) and regulating ecosystem services (e.g. climatic regulation and pollination) (Millennium Ecosystem Assessment 2005).

1.2 Conserving biodiversity and ecosystem services

Two strategies have been proposed to limit the impact agriculture has on biodiversity namely, "land sparing" and "wildlife-friendly" or "land sharing" strategies (Green 2005). Land sparing advocates for the intensive use of agricultural land, to maximize the yields and economic efficiency (Green 2005). This allows for more untransformed land to be set aside for conservation purposes. This strategy typically creates a highly uninhabitable agricultural landscape with high chemical inputs, low crop diversity and with biodiversity consequently restricted to protected areas (Fisher 2008).

On the other hand, wildlife-friendly strategies advocate for larger areas of land to be farmed in a less intensive manner, which would benefit biodiversity within farmlands (Green 2005). Wildlife-friendly farming strategies typically use less intensive management practices within the production areas. It also aims to enhance biodiversity throughout the farmland mosaic by conserving fragments of natural and semi-natural vegetation. These patches provide important habitat and resources to the remaining biodiversity (Benton *et al*. 2003). Other forms of non-cropped habitat like hedgerows, are also found in the landscape, which act as stepping-stone habitats and conduits, which allows for organisms to move more easily between natural habitats (Benton *et al.* 2003).

There has long been a debate on whether land sparing or wildlife-friendly strategies would benefit biodiversity the most (Green 2005). Both approaches have been shown to be effective in different types of agroecosystems (Cunningham 2013). However, Fischer (2008) suggests that we should not consider these as two strategies as mutually exclusive. The problem is, so far much of the focus in biodiversity conservation has been on conserving pristine or semi-natural habitat (Tscharntke *et al*. 2005) and not on addressing the land management practices per se.

The focus has more recently shifted towards the agricultural matrix for biodiversity conservation (Driscoll 2013). Many authors now suggest that the best way forward for biodiversity conservation within farmlands, lies with sustainably intensifying agricultural production (Godfray 2010; Foley 2011; Tilman 2011; Kremen 2015). Conserving farmland biodiversity and harnessing the important ecosystem services that it provides, is an important part of sustainable intensification (Bommarco *et al*. 2013).

Within the current study area of the Cape Floristic Region (CFR), wine farms have collectively conserved over 140 000 ha of fragments of remnant vegetation within the production area (WWF 2017). Conserving these natural fragments are considered an effective tool for biodiversity conservation (Attwood *et al*. 2008) and a valuable source of natural pest enemies to farmers (Bianchi *et al*. 2006). A study by Gaigher *et al*. (2015) compared the parasitoid diversity within the natural fragments and in the vineyards of the CFR. They found that there was a higher parasitoid diversity within the remnant fragments compared to the vineyards, however there was limited “spill-over” of parasitoids from the fragments into the vineyards. The study concludes by emphasizing the importance of increasing the permeability between the fragments and the vineyards. This can be achieved by reducing the impact of agricultural practices and by softening the agricultural matrix.

In this study, I specifically focus on organic agriculture, because it has the potential to address many of the environmental concerns relating to conventional agriculture, including the loss of biodiversity (Hole *et al*. 2005). In addition, studies done in the CFR have also shown that surface-active arthropods (Gaigher & Samways 2010), spiders (Gaigher & Samways 2014) and monkey beetles (Kehinde & Samways 2011) benefit from organic agriculture.

1.3 Differences in management practices

To understand how organic agriculture differs from conventional agriculture, I contrast the two sets of management practices. Even though conventional and organic farmers operate within specific management programmes, individual management practices often vary from one farmer to the next (Trewavas 2004). I specifically focus on the impact management practices have on the biotic component of agroecosystem and therefore, only the relevant environmental impacts are discussed.

Conventional agriculture uses synthetic chemical inputs and mechanization with the goal of maximizing productivity and profitability (FAO 2009). Water soluble inorganic fertilizer, consisting of mineral nitrogen and phosphate, which are plant limiting factors in the natural environment, are supplied in excess resulting in a nutrient rich environment (Tilman 1999). The high concentration of nutrients is often leached out of the soil and into water bodies, leading to the pollution and the loss of aquatic and marine biodiversity (Tilman 1999). Inorganic fertilizer has also been shown to adversely impact the soil fauna community and diversity (Wang *et al*. 2016).

Tillage is mainly performed to loosen and prepare the soil, control weeds and to oxygenate the soil, which increases the short-term fertility of the soil. Tillage however, disrupts the top 15 - 25 cm of the soil and transforms a stratified soil into a homogenized till zone (Altieri 1999). Tillage disrupts the soil habitat and changes the physical and chemical properties of the soil (Thiele-Bruhn *et al.* 2012). Tillage can affect the survival of organisms directly, by either killing or injuring them, or indirectly, by exposing them to predation (Thiele-Bruhn *et al*.2012) and by altering their habitat conditions. In the long term, excessive tillage results in a loss of organic matter, soil erosion, soil compaction, crust formation and loss of biodiversity (e.g. Mäder *et al.* 2002; Montgomery 2007).

Biocides (fungicides, insecticides, rodenticides and herbicides) are not only detrimental to pests, but to other non-target organisms as well. Biocides impact organisms directly, through toxicity and indirectly, through a process known as bioaccumulation, which is the accumulation of residues in organisms. Biocides impact pollinators in agroecosystems, which results in reduced pollination and an overall decrease in vegetable and fruit yields (Pimentel 2005). Biocides also impact natural enemies, such as predatory and parasitoid arthropods, which are beneficial to farmers, because they prey on herbivorous pests (Zhender 2007). In many regions, there has been increase in pest pressure due to pesticide-linked declines in natural enemies (Geiger *et al*. 2010).

Organic agriculture on the other hand, is a more holistic approach to farming, where management practices aim to promote and enhance the health of agroecosystems (FAO 2007). The organic certification standards differ around the world however, it is fundamentally based on improving the biological function in the agroecosystems (Letourneau & Bothwell 2008). Organic farmers try to create a more suitable environment to biodiversity by having minimal chemical and mechanical disturbances. Organic farming uses organic matter, such as compost and manure to enhance soil fertility (Briar 2007). For arthropod pest control, organically approved natural insecticides (mostly plant-based) and biological control is used (Gomeiro 2011). Other cultural practices, such as intercropping and cover crops enhances the soil fertility and creates a more suitable environment to beneficial organisms (Zehnder 2007).

1.4 Current knowledge on organic agriculture

Organic agriculture is one of the fastest growing food sectors in agriculture (Raynolds 2004). The supply of organic produce is however, not able to keep up with the growing demand (Jin & Constance 2010). A few studies have investigated the barriers to the adoption of organic agriculture amongst conventional farmers and the lack of knowledge on organic farming is identified as one of the hindrances (e.g. Khaledi *et al*. 2010; Jin & Constance 2010).

The transition period refers to the time it takes for conventional farms to be certified organic. Research on the transition period is scarce and consequently, little is known about this period (Lamine & Bellon 2009). This is however, an important time for potential organic farmers, because not only is it costly, but also a risky period. Farmers not only experience low yields, but the crops are generally more susceptible to pests and diseases (Zinati 2002). It generally takes a few years to complete the transition period, before the produce can be labelled and considered as organic. For example, the organic certification for the United States Department of Agriculture (USDA), requires at least a three-year transition period (Menalled *et al.* 2012). According to Lockeretz (2007), the initial reasoning behind the period was thought to be the time it takes for pesticide residues to leave the system. Since then, many other reasons are given and these often relate to soil-related properties and yields and rarely is the above-ground biodiversity and the ecosystem services mentioned.

It has been shown numerous times that arthropod biodiversity benefits from organic management practices (Bengtsson 2005; Hole *et al*. 2005), but how does the arthropod biodiversity react to the changes in management practices during the transition period? In a review by Hole *et al.* (2005), the authors proposed that biodiversity could show a multiple-year time lag in response to the changes in management practices. This could mean that the biodiversity and associated ecosystem services that the biodiversity provides, could only return a few years after transitioning. This time lag in response to changes in management practices could substantiate the reasoning behind the lengthy and costly transition period. However, so far, studies have contradicted a multiple-year time lag and instead, show a rapid increase in species richness after transitioning. For example, a study by Jonason (2011) looked at how plant and butterfly species richness change over time under organic management practices. They found that the plant and butterfly species richness increased rapidly after transitioning to organic agriculture. In another study, Andersson *et al*. (2012) also showed a rapid increase in pollinators in strawberry crops after transitioning.

Ecological principles could help explain this rapid increase in species richness with the changes in management practices. Disturbances and the level of disturbances have been shown to be important factors in determining biodiversity and in shaping communities (Connell 1978). Ecosystems with high levels of disturbances, such as conventional crops, would typically have a low species richness, because only a few hardy species survive the frequent and intensive disturbances. An ecosystem with low levels of disturbances, such as organic crops, is also characterized by low species richness, due to competitive exclusion by dominant species. Connell (1978) proposed that the highest diversity is typically found at intermediate levels of disturbances, known as the Intermediate Disturbance Hypothesis (IDH). It could therefore be, that transition crops experience intermediate levels of disturbances, resulting to a higher species richness.

Alternatively to a rapid increase in biodiversity, we can expect either a delayed or a gradual increase in arthropod biodiversity over time under organic management practices. A delayed reaction in pest control ecosystem services and an increase in pest damage is generally expected in the transition period (Zinati 2002). In terms of pest management, during the transition period chemical sprays are reduced or completely stopped so that it can be replaced by natural enemies instead. However, the natural enemies take time to establish, which would explain why there is an increase in pest damage.

Pest control ecosystem services does seem to increase and stabilize over time under organic farms. A study by Letourneau (2001) compared the arthropod biodiversity and pest control between certified organic and conventional farms in the central valley of California. They found no significant difference in the pest damage between the conventional and organic farms. They also found a higher arthropod biodiversity and natural enemy diversity on the organic farms. One reason they suggest, for the equal effectiveness in pest control between the farms, is that the biological control by the natural enemies could be taking over the function of the synthetic insecticides on the organic farms.

The following questions still needs to be studied: what trends do the overall arthropod biodiversity and natural enemy diversity follow, after transitioning to organic practices? Additionally, how does this correspond to pest control ecosystem services?

1.5 Aim and objectives

In this study, I assess how the arthropod biodiversity and pest control ecosystem services change over time under organic management practices. To achieve this, I compare the arthropod biodiversity, natural enemies, pest counts and pest damage over a gradient of time since transitioning from conventional to organic management practices. This study takes place in the Greater Cape Floristic Region of South Africa within a conventional-, 1-year in transition to organic, 5-year organic and 15-year organic vineyards. The study objectives are to:

1. Compare the arthropod species richness, abundance and assemblage structure over time since transitioning to organic management practices.
2. Compare the species richness, abundance and assemblages of key natural enemies over time since transitioning to organic management practices.
3. Compare the pest counts and pest damage over time since transitioning to organic management practices.
4. Determine whether there is a link between the overall arthropod biodiversity, natural enemy diversity, pest counts and pest damage over time since transitioning to organic management practices.

I expect to see greater pest damage soon after transition, with lower damage levels in more established vineyards. This would be due to more established natural enemy communities in the vineyards that have been organically managed for longer. Studying how time since transitioning to organic farming affects arthropod biodiversity and pest control is of practical importance. This study will allow farmers to know what to expect from the changes in management practices, so that they can facilitate the transition process. From an agro-ecological point of view, the knowledge can help us better understand the changes in the agroecosystem dynamics when there is a change in management intensity.

2. Materials and methods

2.1 Study area

The Greater Cape Floristic Region (GCFR) is one of the smallest floristic regions in the world, located on the most southern tip of Africa. The GCFR is identified as an area with exceptionally high levels of species richness and endemism for both plants and vertebrates (Myers 2000). There is an estimate of 9000 vascular plant species of which 69% are endemic (Goldblatt & Manning 2000). The arthropod diversity is not as well studied as the plant diversity however, there is a close relationship between arthropod- and plant diversity (Procheş & Cowling 2006) and the arthropod diversity could therefore resemble the high plant diversity.

The GCFR is identified as an area of high conservation priority and a global hotspot of biodiversity (Myers 2000). Agriculture, specifically viticulture, poses a great threat to biodiversity in the GCFR (Fairbanks *et al*. 2004) and the need for sustainable wine-grape production has been recognized. Conservation and environmental sustainability initiatives and schemes, such as the Integrated Production of Wine (IPW) and WWF Conservation Champions (formerly known as the Biodiversity Wine Initiative), have become very popular over recent years (IPW 2017; WWF 2017). These initiatives aim to conserve natural habitats, as well as to reduce the impact agricultural practices has on the environment.

2.2 Study sites

This study was conducted on two neighbouring wine-grape producing farms near Stellenbosch. The one is an alternative farm, consisting of certified biodynamic and organic vineyards (from here on, collectively referred to as organic) and the other farm, is a conventional farm. The organic farm expanded over the years and the farmer gradually converted neighbouring conventional farms into organic farms. Today, the organic farm consists of organic vineyards, with vineyards at different times since the transitioning to organic management practices.

There are four treatments in this study: conventional vineyards, 1-year in transition to organic, 5-year organic and a 15-year organic vineyard. All the treatments are within a two-kilometer radius from each other, which makes this a unique study area with limited environmental variation.

2.3 Site description

2.3.1 Organic farm

The organic vineyards were all managed the same, regardless of the time since transitioning (Figure 1). No form of insecticides or herbicides were used in the vineyards. Instead, the farmer relies on natural predators, such as ducks for the predation of snails and arthropod natural enemies to control arthropod pests. A combination of organically approved and non-systemic fungicides (sulphur- and copper based) were used, together with fungi metabolite (Trichoderma) as a biological control agent.

The cover crops in the organic vineyards consisted of grazing vetch (*Vicia* spp.), Bur Medic (*Medicag*o spp.) and Clover (*Trifolium* spp.). Nutrients is put back into the systems by planting legumes (as part of the cover crop plant species mixture), by applying a foliar biodynamic preparation and by applying organic compost every second year. Tillage is done twice a year using a disc with a ghrop implement: first in autumn, to sow the cover crops and again in spring, to manage the weeds.

Figure 1. The organically managed vineyards with the 1-year transition vineyard (left), 5-year organic vineyard (middle) and the 15-year organic vineyard (right).

2.3.2 Conventional farm

The conventional farm is registered to the Integrated Production of Wine (IPW). Oats (*Avena flatula*) is sown annually as a cover crop, but various other weeds and plant species are found in the conventional vineyards (Figure 2). A range of insecticides, fungicides and herbicides are used, throughout the year. Chemical fertilizer is applied every second year and it was last applied in the year 2016. Tillage with a disc implement, is performed twice a year, in spring and in late summer.

Figure 2. A typical row in the conventional vineyard.

2.3.3 Major arthropod pests in the area

By consulting both farmers, it was determined that both farms experience two major arthropod pests, namely vine snout weevil (*Phlyctinus callosus*) and katydids (*Plangia graminea*).

2.3.3.1 Phlyctinus callosus

The species *Phlyctinus callosus* (Coleoptera: Curculionidae) is commonly known as the vine snout weevil or the banded fruit weevil. This is an indigenous insect species to South Africa and it causes severe damage to grapes and apples, but they also infest other crops such as strawberries, plums, peaches and pears (de Villiers & Pringle 2008). The pest is of phytosanitary importance and importing countries reject infested consignments (de Villiers & Pringle 2008).

The weevil lays its eggs close to the surface of the soil in summer and autumn. The larvae hatch when there is sufficient moisture in the air and soil. The larvae then live and feed off the roots of the vines (Nel 1983). When they are fully grown, they pupate in the soil from where the adults emerge (Nel 1983). The adults feed at night and in day they hide under bark, between the fruit, leaves or in the ground. Early in the season the adults attack the leaves and young shoots (Ferreira & Venter 1996). The damage is typically in the form of holes in the leaves, characterized by stringy filaments and crescent shaped bite marks on the leaf edges (Figure 3) (Ferreira & Venter 1996). The adults also feed on the stems, shoots, rachides and berries later in the season (Figure 3).

Figure 3. *Phlyctinus callosus* or the vine snout weevil (left) and the leaf damage (middle) and bunches damage (right) caused by the pest (Photos by: Piet Goussard).

2.3.3.2 Plangia graminea

Plangia graminea (Orthoptera: Tettigoniidae) is commonly known as katydids or the long-horned grasshoppers (Figure 4). Little is known on the biology of the species. The immature stages of the insect appear early in the season between September and October, where they feed on the young leaves of the vines. Later in the season, they feed on the bunches (Ferreira & Venter 1996). The damage caused by katydids is like that of the vine weevils (Ferreira & Venter 1996). The main difference is the vine weevil feed from the edges inward, where katydids starts feeding from anywhere on the leaf (Allsopp 2012).

Figure 4. *Plangia graminea* or a katydid (left), immature stage of the insect and the leaf damage it caused (middle) and the bunch damage caused by the pest (right) (Photos by: Piet Goussard).

2.4 Experimental layout

In each treatment, two one-hectare blocks were measured out, wherein all the sampling was done (Figure 5). The two blocks were at least 10 meters apart to capture as much of the environmental variation within each treatment as possible, and at least 8 meters from the edge of the vineyard, to limit the edge effect. The experimental layout within the blocks, for the environmental variables and the arthropod sampling, is different to the layout used for the pest sampling.

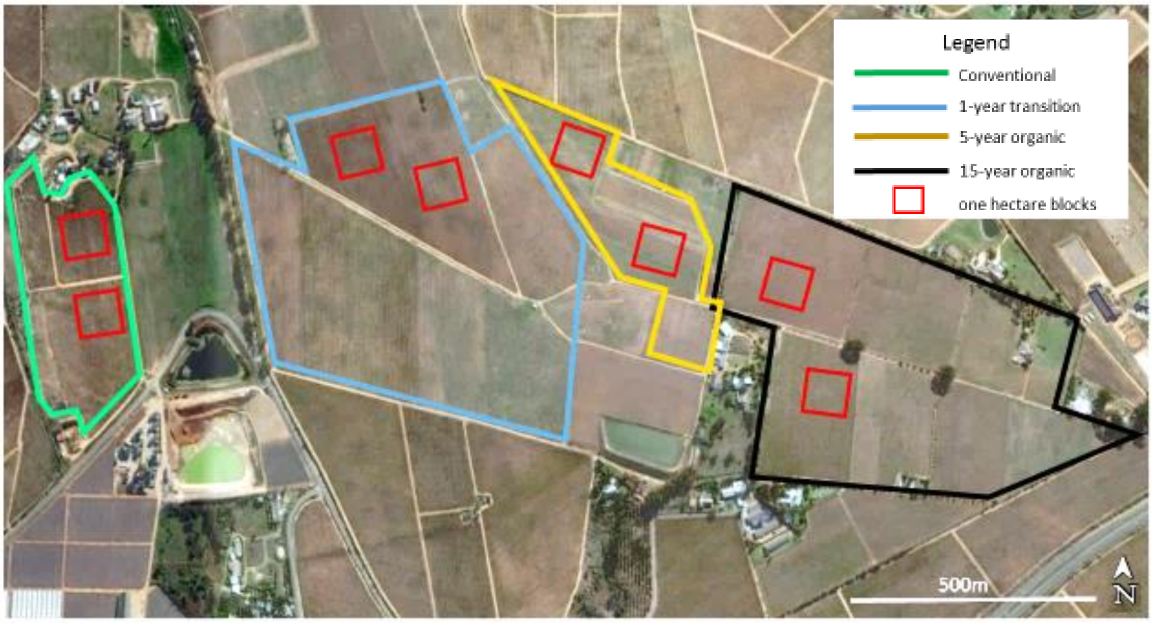

Figure 5. The map of the study site with the different stages in the transition process demarcated. All the sampling was done in the one-hectare blocks (red).

2.4.1 Environmental and arthropod sampling

Within each block, three evenly spaced rows (about 13 meters apart) were chosen and marked. Within the chosen rows, 50-meter lines were measured out in the middle of the block, using a 50-meter measuring tape (Figure 6). Environmental and arthropod sampling were done along the 50-meter lines.

2.4.1.1 Environmental data

Two vegetation transects were performed along the 50-meter lines. A transect was performed in between two vine rows (working row) and the other underneath the vines (ridge), seeing as the non-crop vegetation differs between the working rows and ridges. The Line-Point Intercept vegetation sampling method was used to sample the vegetation along each transect (Herrick *et al*. 2005). Starting at the zero-meter mark, at every one-meter interval the stick was vertically dropped to the soil without guiding the stick. The plant species that touched the stick was recorded according to Fourie (2003), as well as the type of soil surface (bare ground, rocky or leaf litter) on which the stick landed. Plant species that could not be identified were sampled and given a pseudonym for later identification. The average plant height per transect was also recorded.

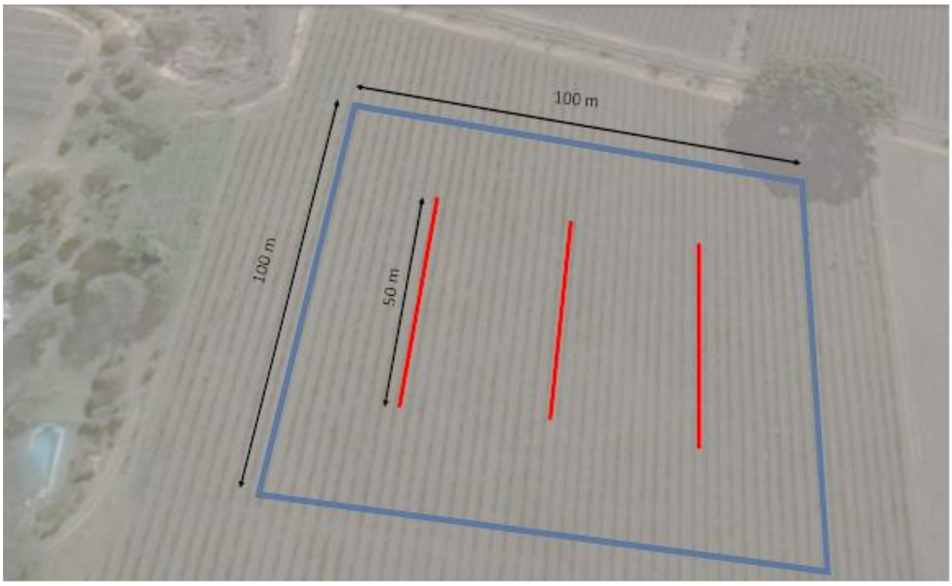

Figure 6. The 50-meter transects measured out in each of the one-hectare blocks.

The soil compaction was measured using a penetrometer. The soil compaction was measured at three evenly spaced points along the working row and the ridge transects. The information on the vineyard management practices during the period of January 2016 up to January 2017 were obtained through consultation with the farmers. The management practices include the biocide application, fertilizer application and the mechanical tillage regime.

2.4.1.2 Arthropod biodiversity

Arthropod sampling was done twice within one grape growing season, in early December 2016 and again in mid-January 2017, roughly 6 weeks apart. A leaf blower set on vacuum mode, with a mesh bag attached to the 10cm diameter nozzle, was used to catch the arthropods (Figure 7) (Gaigher *et al*. 2015). Two arthropod samples were taken along the 50-meter lines (described in section 2.4.1): one for the vines and the other for the non-crop vegetation in the working row. A sample consisted of 50 “pokes” at every one-meter interval. A poke refers to the gradual and constant insertion of the vacuum nozzle into the vegetation. After each sample, the content was emptied into a labelled Zip Lock bag (Figure 7). In total, six samples were taken per treatment: three non-crop samples and three vine samples.

Samples were stored in a minus 15-degree Celsius freezer. In the laboratory, the insects were sorted according to morphospecies (Oliver & Beattie 1996) with the use of a Leica MZ75 microscope and each specimen was identified to order level (Picker 2004). The reference collection of the arthropod specimens is kept at Stellenbosch University Entomological Museum.

Figure 7. Vacuuming and sampling arthropods on the vines with a leaf blower (left). Emptying the sample, that consists of 50 "pokes", into a labelled Ziplock bag (right).

2.4.2 Pest sampling

The arthropod pests were sampled using a generic sampling system for monitoring arthropod pests in table grapes (de Villiers 2008). The monitoring systems uses plant inspections and trapping methods to estimate the pest population levels in the vineyards[1]. The layout of the monitoring systems is in one-hectare blocks with 20 plots of five vines per plot (Figure 8).

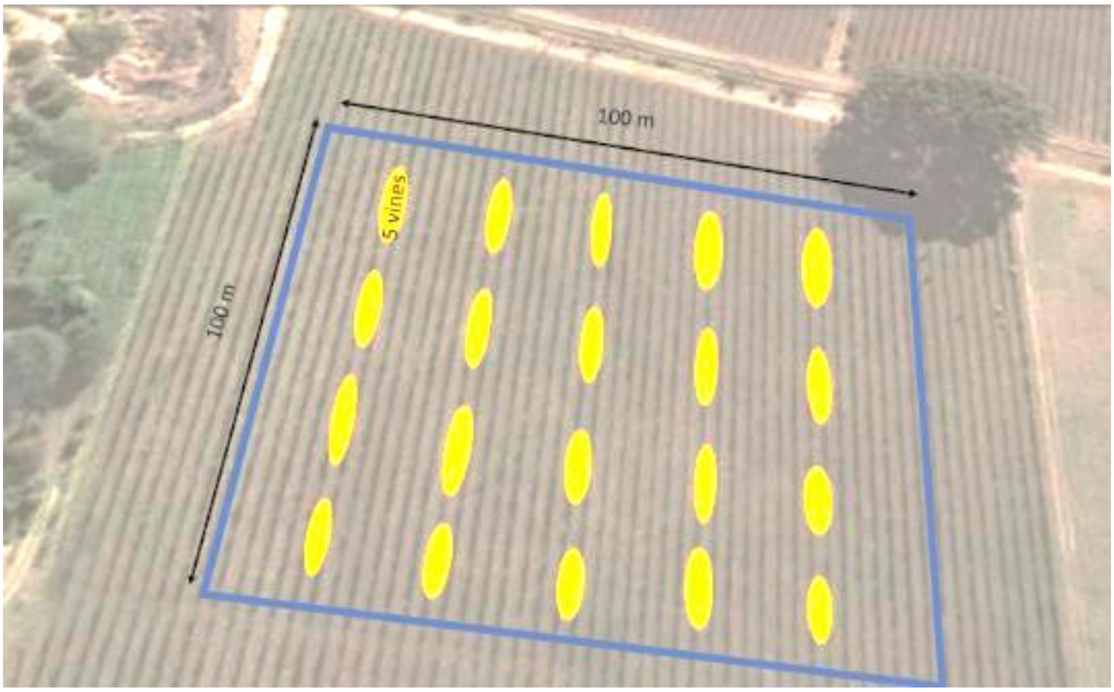

Figure 8. The layout of the monitoring system is designed for one-hectare blocks. Within each block, there are 20 evenly spaced plots, consisting of five vines per plot.

2.4.2.1 Plant inspection

The five vines in each of the 20 plots were inspected according to a set procedure. With each step in the procedure, the presence, counts and the damage of the pests were recorded. The damage caused by katydids and the vine snout weevils were recorded as a unit and I did not try to distinguish between the damage. The following steps for plant inspection were followed:

[1] There was no monitoring system for katydids at the time. The plant inspection in the monitoring system by de Villiers and Pringle (2008) was adapted for monitoring the pest.

1. The two main cordons were inspected for 30 cm from where it branches from the main stem and one young shoot was inspected for 15 cm for damage caused by the pests (Figure 9).
2. The leaves around the stem were also inspected for damage.
3. One bunch per vine was randomly chosen and inspected for the presence and damage of the pests.
4. One leaf per vine was randomly chosen and inspected for the presence and damage of the pests.
5. Depending on whether any leaf or bunch damage was found in the previous steps, the vine leaves and bunches are either recorded as damaged or not damaged.

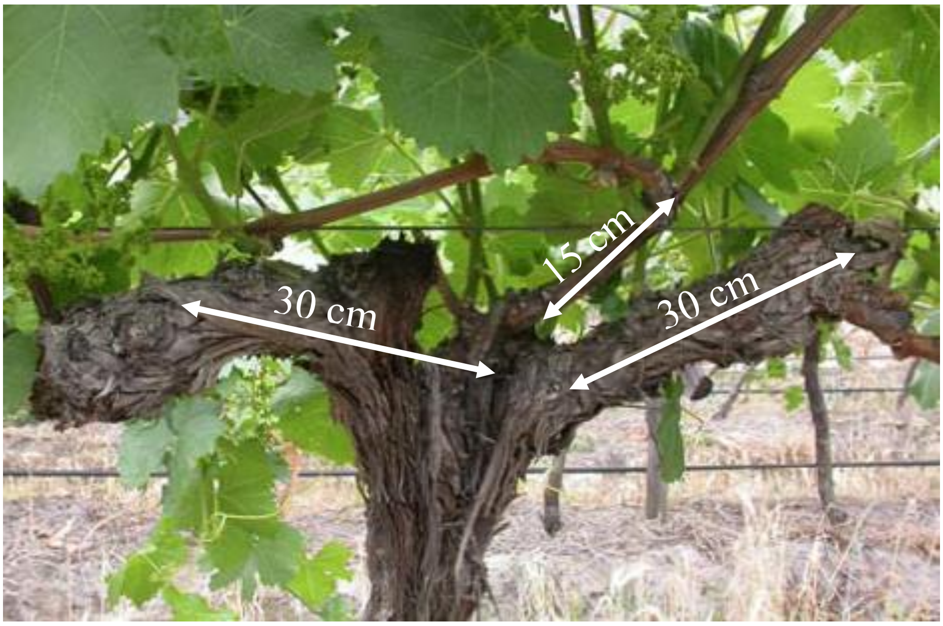

Figure 9. The vine pest inspection as described by de Villiers and Pringle (2008). Part of the procedure requires the two main cordons be inspected for 30 cm, as well as 15 cm of a young shoot (Photo by Marelize de Villiers).

2.4.2.2 Trapping method

The vine snout weevil is nocturnal species and hides underneath the bark, leaves and between the berries in the day. Cardboard bands tied around the stem acts as a hide out for the pest in the day. The cardboard bands are an effective way of estimating the population levels of the vine snout weevil within vineyards. The following steps were performed for this trapping method:

1. One vine in each plot was chosen
2. Single faced corrugated cardboard bands with a width of 10 cm, was tied around the base of the stem, with the corrugated side against the stem (Figure 10).
3. Wire was loosely tied around the cardboard band and the stem, to secure the band.
4. After six weeks, the band is carefully inspected and the number of weevils (counts) under each band was recorded.
5. After each inspection, the band was moved to next vine in the plot.
6. Inspection of the bands was done twice, together with the plant inspection.

Figure 10. Corrugated cardboard band tied around the base of the stem used for trapping *Phlyctinus callosus* (Photo by: Marelize de Villiers).

2.5 Data analysis

2.5.1 Overall arthropod species richness, abundance and assemblage structure

Generalized linear mixed models (GLMMs) were used to determine how the species richness and abundance varied between the different times since transitioning to organic farming (Bolker *et al*. 2009). Poisson distribution was specified in the model, as the data showed a Poisson distribution according to the Shapiro-Wilk tests and the likelihood ratio test. The time since transitioning and the vegetation sampled (vineyard or non-crop vegetation) was included as fixed factors. The month nested within transect was included as random variables, to reduce over dispersion in the data. The software package RStudio (RCore Team 2016) with the package *lme4* (Bates *et al*. 2017) was used to perform GLMMs. The package *multcomp* was used to perform the post-hoc Tukey test (Hothorn *et al*. 2016).

The assemblage structures for the overall treatments were determined by combining the vine and the non-crop arthropod samples. A permutational multivariate analysis of variance (PERMANOVA) was done, using PERMANOVA+ package in PRIMER 6 (PRIMER-E 2008) to determine how the assemblage structures between the treatments differed. The data was first square root transformed, to reduce the influence of very abundant species. The resemblance matrix was calculated using the Bray-Curtis similarity matrix. Pseudo-F values and p-values for the test, as well as t-values and p-values for the post-hoc comparisons, were estimated using 9999 permutations. A canonical analysis of principle coordinates (CAP) was performed in PRIMER 6 (PRIMER-E 2008) to visually represent the clustering.

2.5.2 Natural enemy species richness, abundance and assemblage structure

The spiders (Order: Araneae) and parasitoids (Order: Hymenoptera) are important natural enemies in vineyards. We analysed these two groups separately and determined the abundances and species richness for each treatment. The data was Poisson distributed according to Shapiro-Wilks and the likelihood ratio test. GLMMs with the time since transitioning and vegetation sampled was included as fixed factors. The month nested within transect was included as random variables, to reduce over dispersion in the data. A post-hoc Tukey tests was performed to determine whether there was a significant difference in the in diversity and abundance natural enemies between the treatments (Hothorn *et al*. 2016).

A PERMANOVA was done to determine the assemblage structures for the natural enemies per treatments (PRIMER-E 2008). The data was first square root transformed, to reduce the influence of very abundant species. The resemblance matrix was calculated using the Bray-Curtis similarity matrix. Pseudo-F values and p-values for the test, as well as t-values and p-values for the post-hoc comparisons, were estimated using 9999 permutations. A canonical analysis of principle coordinates (CAP) was performed in PRIMER 6 (PRIMER-E 2008) to visually represent the clustering.

2.5.3 Arthropod pest counts and percentage pest damage

For *Phlyctinus callosus* both the inspection, as well as the trapping counts were combined. The mean counts for *Plangia graminea* and *Phlyctinus callosus* per treatment was determined. Significant differences in the counts were tested, using Kruskall-Wallis non-parametric tests.

The percentage of vines with leaf and bunch damage per plot was determined, from which the percentage leaf and bunch damage was calculated per treatment. The data was Poisson distributed according to Shapiro-Wilks normality test and a likelihood ratio test. GLMMs were used to compare the leaf and bunch damage between the treatments. The random variables included in the models were the month and the block.

2.5.4 Environmental variables and vineyard management intensity

The mean percentage plant cover, mean percentage plant litter cover, mean soil compaction and the plant species richness were determined for all the vegetation transects for both monitoring sessions combined. For each variable, the data for the working- and the ridge row were first averaged per row and then averaged per treatment.

To quantify the vineyard intensity level, a system by the Integrated Production of Wine (IPW 2014) was used to calculate the intensity code associated for the biocide type. An intensity code for the fertilizer application and the tillage regime was also allocated for each treatment based on whether fertilizers were organic or inorganic and the known potential of different tillage methods for soil disturbances (Gaigher & Samways 2010). See Appendix A for the codes assigned for the vineyard management practice.

The environmental variables and the vineyards intensity levels were correlated to the arthropod species richness and the arthropod abundance. Using R Studio (RStudio Team 2016), a scatterplot with a trend line was drawn for each combination of variables, using the function "ggplot" (Wickham 2001). A non-parametric Spearman Rank-Order correlation test was performed for each combination of variables.

3. Results

3.1.1 Overall arthropod species richness, abundance and assemblage structure

A total of 1231 arthropods were sampled in this study, comprising of 172 morphospecies from 9 orders. The most abundant orders were: Hemiptera (363), Hymenoptera (341), Araneae (283), Coleoptera (76) and Diptera (70). The highest species richness was found in the following orders: Araneae (53), Hymenoptera (44), Hemiptera (34), Diptera (20) and Coleoptera (8).

The mean species richness differed significantly between the treatments (χ^2 =18.355, P<0.0001). A post hoc Tukey test showed that the only significant difference was between the conventional and the 1-year transition vineyard. The conventional vineyard had the lowest species richness of all the treatments and the highest species richness was found in the 1-year transition vineyard (Figure 11a). The 5-year and 15-year organic vineyards had medium levels of species richness.

The mean abundances between the treatments were significantly different (χ^2 = 141.39, P<0.001). A post hoc Tukey test showed that all the treatments differed significantly from each other. The mean abundance showed the same trend as the species richness (Figure 11b). The conventional vineyard had the lowest mean abundance, the 1-year transition had the highest and the organic vineyards had intermediate abundances.

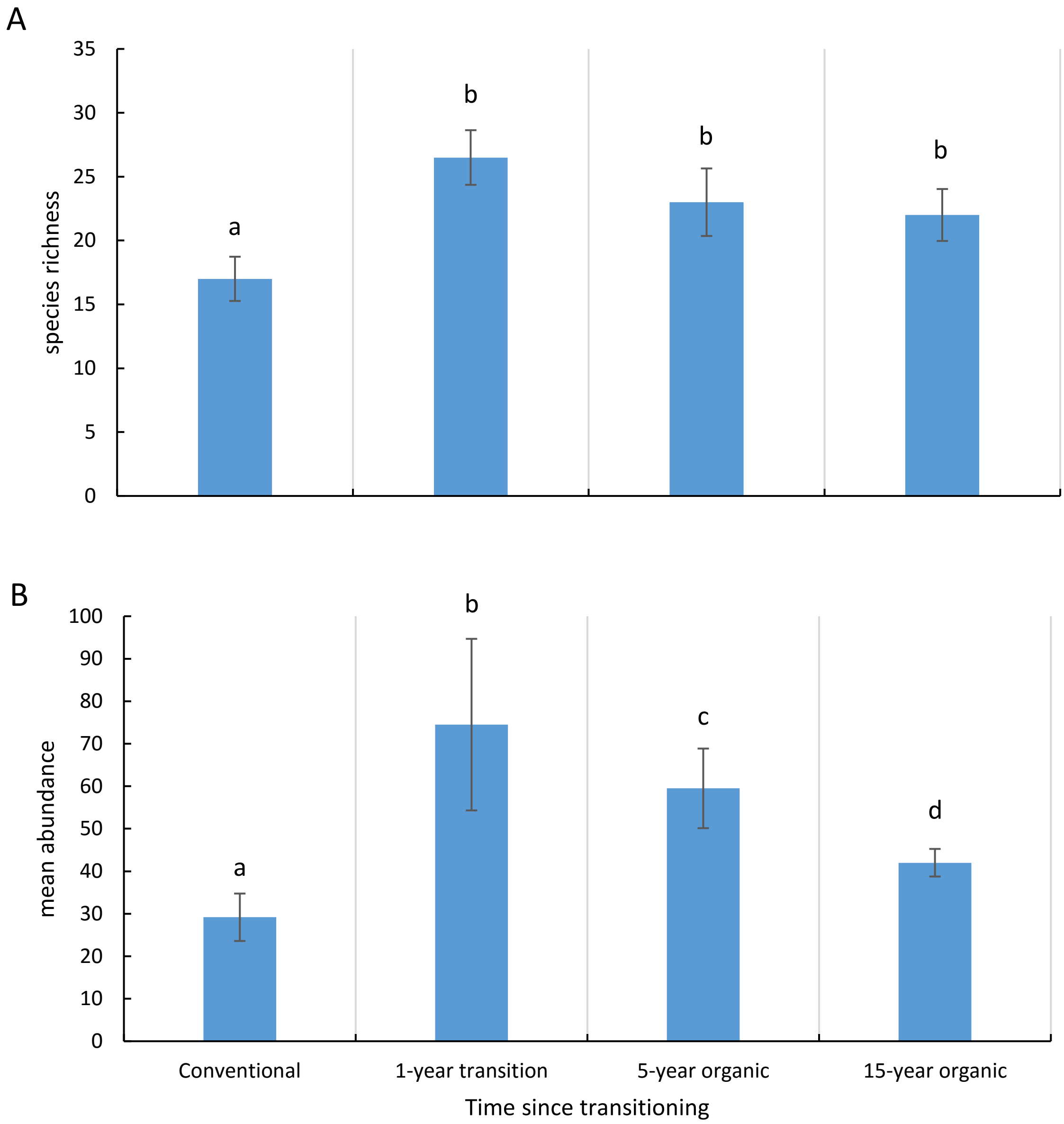

Figure 11. Mean number of morphospecies (A) and the mean abundances (B) (± S.E.) found in vineyards at different times since transitioning to organic management practices. Means with letters in common are not significantly different at $P<0.05$.

A PERMANOVA indicated that there is a significant difference in the overall arthropod assemblages between the different treatments (Pseudo-F=2.41, p=0.001). A post-hoc test showed that all the treatments differed significantly from one another (Table 1). The CAP analysis visually showed a difference in the arthropod assemblages between the different treatments (Figure 12).

Table 1. Results from PERMANOVA post hoc comparisons of the overall arthropod assemblages of vineyards at different times since transitioning.

	1-year transition	**5-year organic**	**15-year organic**
Conventional	1.48**	1.69**	1.73**
1-year transition	_	1.51**	1.51**
5-year organic		_	1.33*

*p <0.05,**p<0.005,***p<0.001

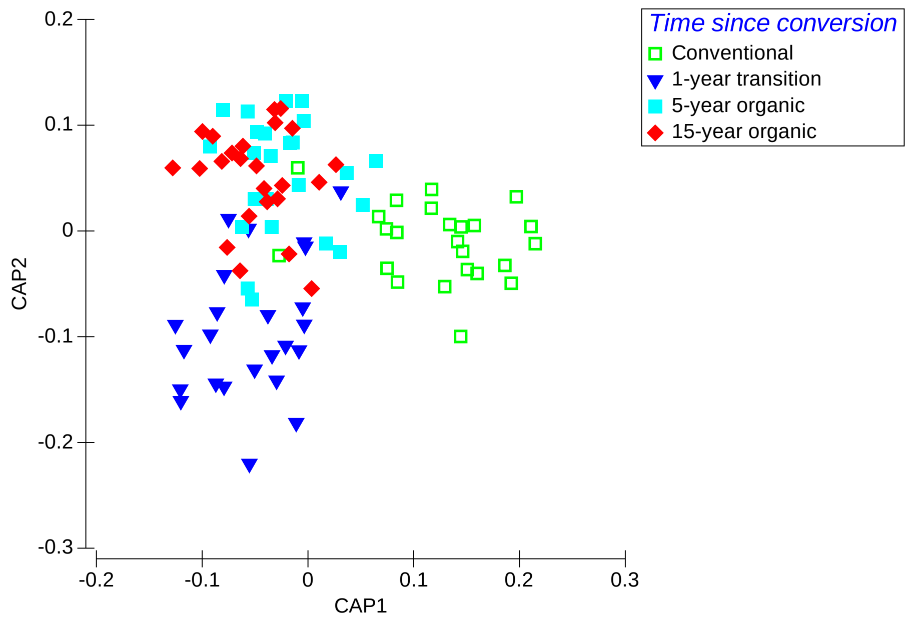

Figure 12. CAP ordination showing the assemblage structure of arthropods found in the vineyards at different times since conversion.

3.1.2 Natural enemy species richness, abundance and assemblages

The natural enemies sampled in this study accounted for 32% of all the arthropod samples (Figure 13). In the conventional vineyard had the lowest (20%) and the 15-year organic vineyard (43%) had the highest percentage of natural enemies. The percentage natural enemies in the 1-year transition vineyard and the 5-year organic vineyard were very similar at 33% and 30% respectively (Figure 13).

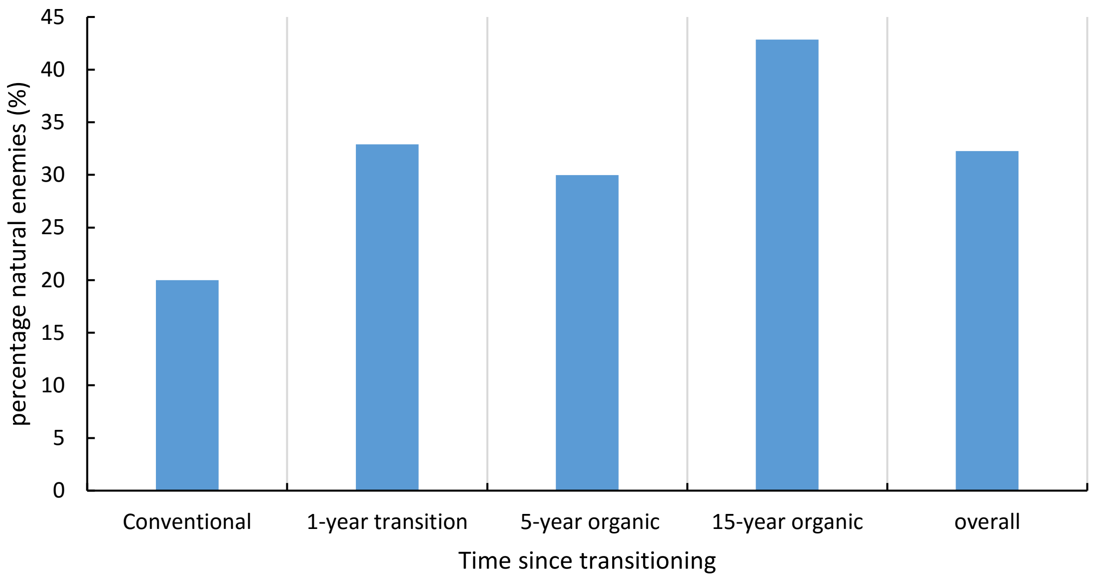

Figure 13. The percentage natural enemies sampled in each vineyard at the different times since transitioning, as well as the overall percentage of natural enemies sampled.

There was a significant difference in natural enemy species richness between the treatments (χ^2= 4.75, P<0.001). A post hoc-Tukey test showed that the only significant difference in the species richness was between the conventional and the 1-year transition vineyard. The highest species richness of natural enemies was found in the 1-year transition vineyard, followed by the 5- year and 15-year organic vineyards, and the lowest for the conventional vineyards (Figure 14a).

There was a significant difference in the abundance of natural enemies between the treatments (χ^2= 30.72, P<0.001). A post hoc-Tukey test showed that the conventional and the 1-year transition vineyard were significantly different from each other and different to the 5-year and 15-year organic vineyards. The highest abundance of natural enemies was found in the 1-year transition vineyard, followed by the organic vineyards and with the lowest abundance in the conventional vineyards (Figure 14b).

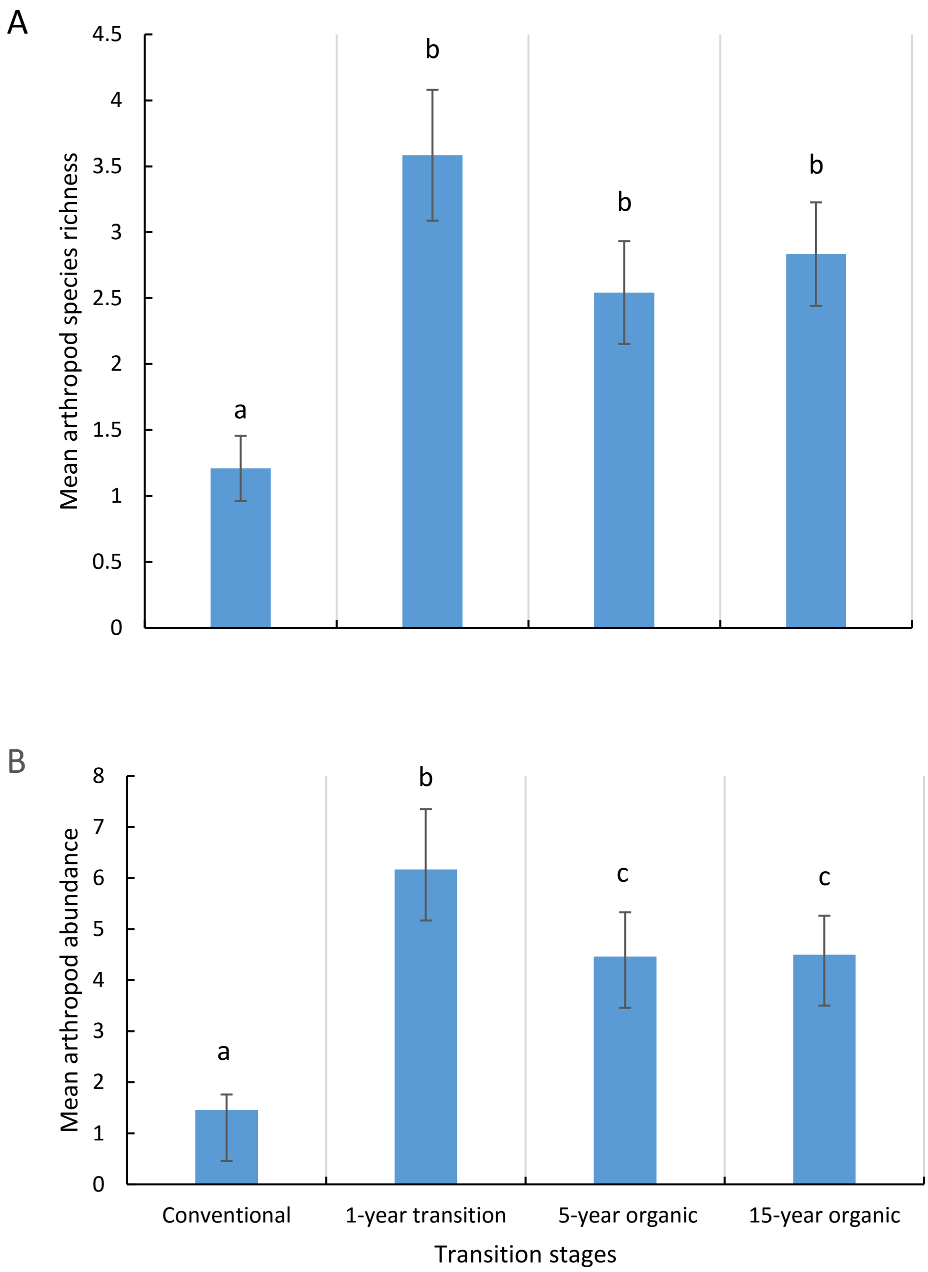

Figure 14. Mean species richness (A) and mean abundance (B) (±SE) of spider and parasitoid natural enemies found in vineyards at different times since transitioning from to organic management practices. Means with letters in common are not significantly different at P<0.05.

A PERMANOVA indicated that there is a significant difference in the natural enemy assemblages between different treatments (Pseudo-F=1.65, p=0.005). A post-hoc test showed that all the treatments differed significantly from one another (Table 2). The CAP analysis visually shows the difference in the natural enemy assemblages between the different treatments (Figure 15).

Table 2. Results from PERMANOVA post hoc comparisons of the natural enemy assemblages of the vineyards at different times since transitioning.

	1-year transition	5-year organic	15-year organic
Conventional	1.41**	1.46**	1.29*
1-year transition	_	1.27*	1.66
5-year organic		_	0.91

*p <0.05, **p<0.005, ***p<0.001

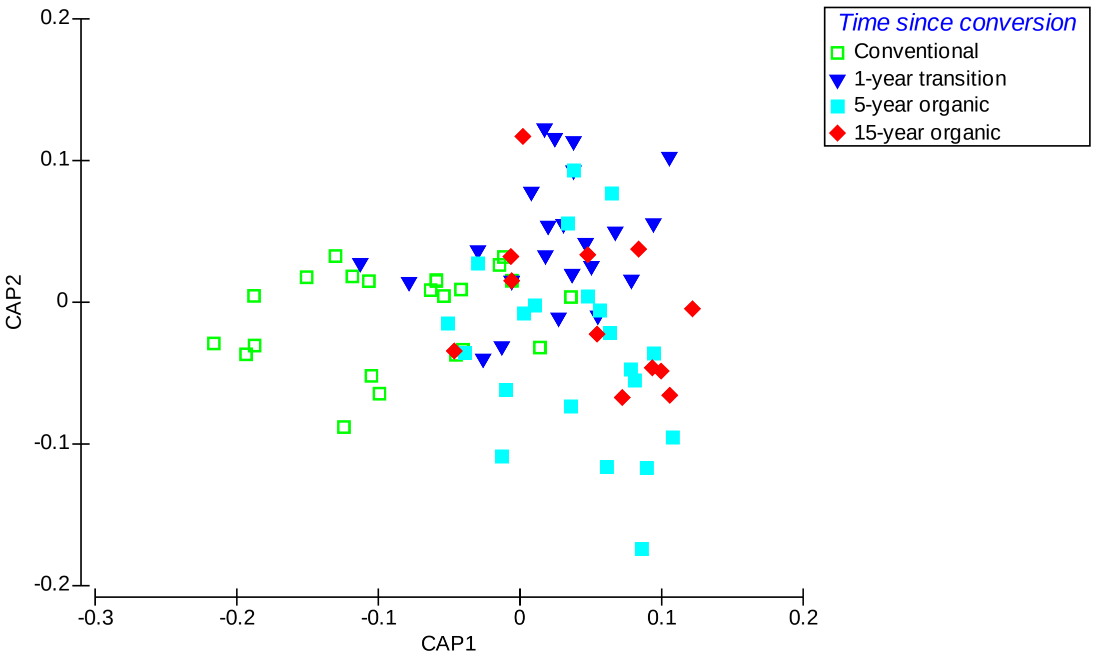

Figure 15. CAP ordination showing the assemblage structure of the arthropod natural enemies found in the vineyards at different times since transitioning to organic management practices.

3.1.3 Arthropod pest counts and percentage pest damage

Plangia graminea counts were the lowest for the conventional vineyard, the highest for the transition vineyard and intermediate for the 5-year and 15-year organic vineyards (Figure 16).

Phlyctinus callosus counts were the least for the conventional vineyard, medium for the 1-year transition and the 15-year organic vineyard and the most for the 5-year organic vineyard (Figure 16).

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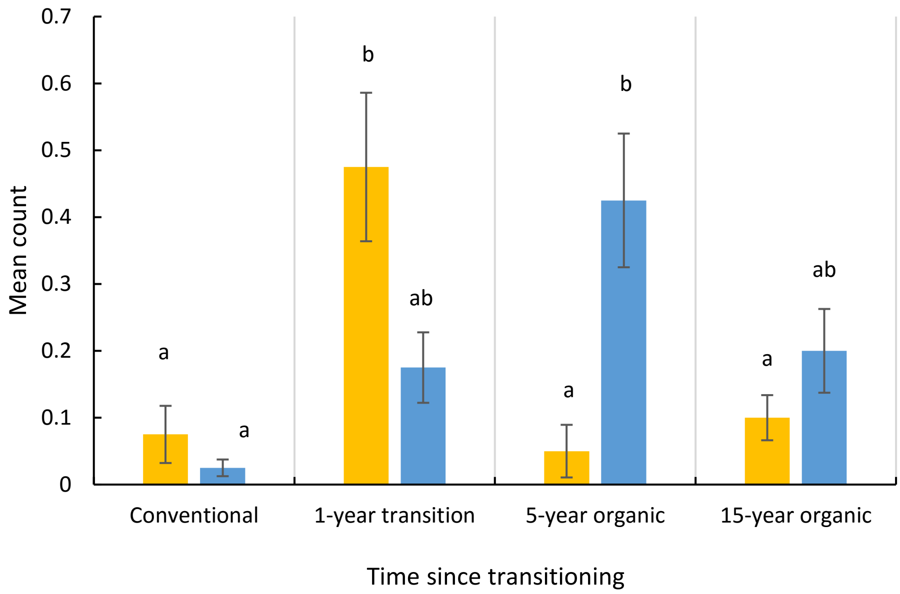

Figure 16. The pest counts for the vine weevil (*Phlyctinus callosus*) in blue and katydids (*Plangia graminea*) in yellow for the vineyards at different times since transitioning to organic management practices. Kruskall-Wallis tests were used to test for significant differences at $p<0.05$. Different letters indicate significant differences.

There was a significant difference in the bunch damage between the treatments (χ^2= 14.97, $P<0.01$). A post-hoc test showed that the 15-year organic vineyard was significantly different to the other treatments. The bunch damage was generally quite high for all the treatments, with the highest damage occurring in the 1-year transition vineyard and the lowest damage occurring in the 15-year organic vineyard (Figure 17a).

There was a significant difference in the leaf damage between the treatments (χ^2= 19.03, $P<0.001$). A post-hoc Tukey test showed that the conventional vineyard and the 1-year transition vineyard were significantly different from each other and to the 5-year and 15-year organic vineyards. The leaf damage was the highest in the 1-year transition vineyard, with the conventional and the organic vineyards having relatively low leaf damage (Figure 17b).

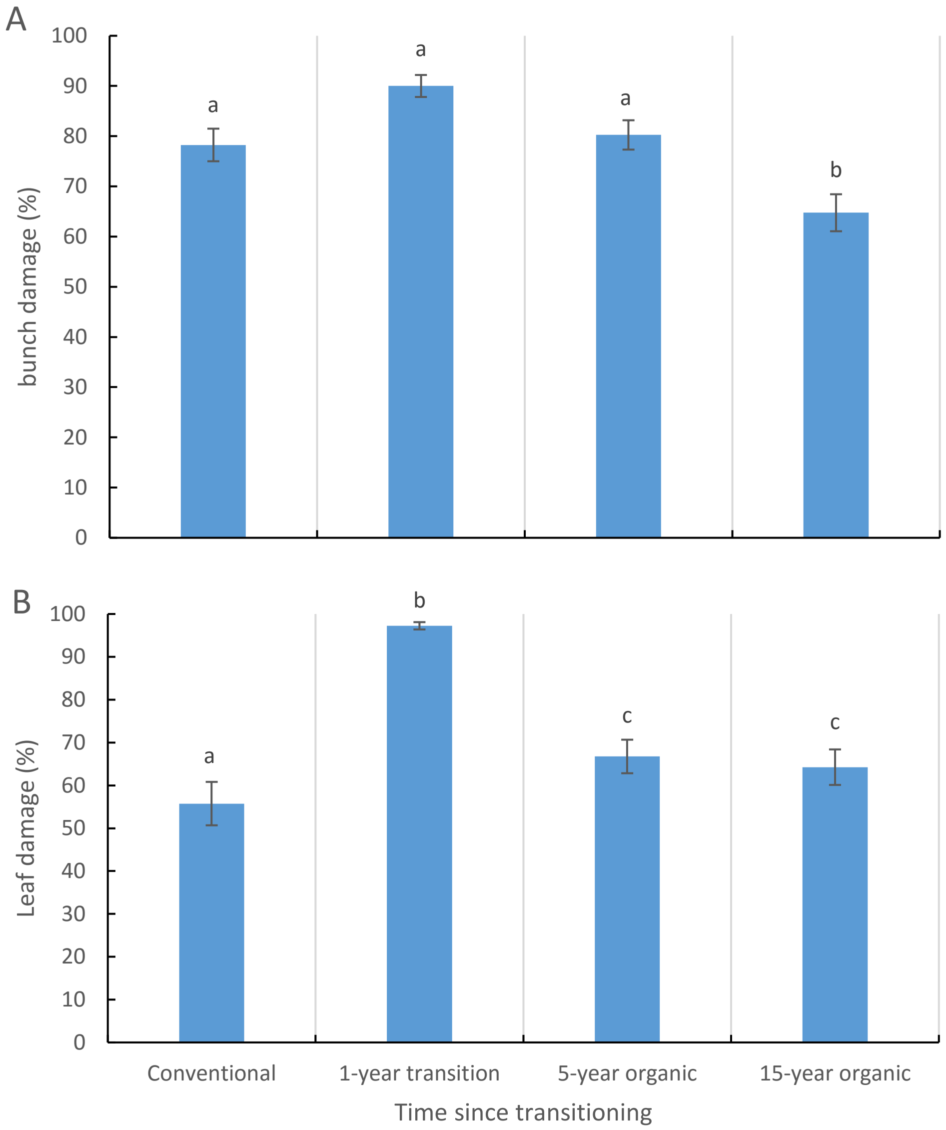

Figure 17. The mean percentage leaf and bunch damage (±SE) for the different times since transitioning to organic management practices. Different symbols (bunch damage) and letters (leaf damage) indicate significant differences ($P<0.05$).

3.1.4 Vineyard management intensity

The vineyard intensity levels for each management practice is summarized in Table 3. The conventional farm received the highest intensity levels for all the management practices, except the fertilizer application. This is because both farms apply fertilizer every second year and the organic farm happened to apply the fertilizer in the same year as this study, whereas the conventional farm applied none. A complete list for the calculations for the vineyard intensity levels can be found in Appendix B.

Table 3. Intensity levels for each management practices for the different times since conversion (see Appendix B for the calculations).

Management practice	Conventional	1-year transition	5-year organic	15-year organic
Herbicide	3	0	0	0
Fungicide	10	4	4	4
Pesticide	2	0	0	0
Fertilizer	0	4	4	4
Tillage	4	3	3	3

The non-parametric Spearman Rank-Order test showed that all the management practices were significantly correlated with a weak negative correlation to the arthropod species richness and abundance (Table 4). See Appendix C and Appendix D for the scatterplots indicating the relationships between the vineyard management intensity to the species richness and abundance**.**

Table 4. Spearman's Rank-Order correlation coefficients (r) and the p-value between the vineyard intensity levels and the arthropod species richness and -abundance. Significant correlations at a 95% confidence interval are indicated with *.

Management practice intensity	Arthropod species richness		Arthropod abundance	
	p-value	**r**	**p-value**	**r**
Herbicide	0.004*	-0.294	0.00*	-0.335
Fungicide	0.004*	-0.294	0.00*	-0.335
Pesticide	0.004*	-0.294	0.00*	-0.335
Fertilizer	0.004*	0.294	0.00*	0.335
Tillage	0.004*	-0.294	0.00*	-0.335

3.1.5 Environmental variables

The environmental data is summarized in Table 5. The variables that stood out is the conventional vineyard, which had the highest plant species richness and mean plant cover and the lowest soil compaction. The 5-year organic vineyard had a low species richness, plant height, mean plant cover and litter cover.

Table 5. Vegetation data collected for each stage in the transition process from conventional to organic management.

Time since transitioning	Plant species richness	Estimated plant height (cm)	Mean plant cover (±SE) (%)	Mean detritus (±SE) (%)	Mean soil compaction (±SE) (kPa)
Conventional	11	50	52.67 ± 11.05	41.50 ± 8.19	98.33 ± 24.30
1-year transition	7	20	42.17 ± 11.64	82.50 ± 6.24	175.00 ± 36.07
Year 5	5	10	15.50 ± 3.04	38.67 ± 7.26	157.08 ± 51.99
Year 15	6	50	41.50 ± 6.07	79.67 ± 4.47	131.25 ± 53.64

The Spearman Rank-Order correlation showed that the only significant correlation was between the canopy height and the arthropod species richness and abundance, both showing weak negative correlation (Table 6). See Appendix E and Appendix F for the scatterplots indicating the relationships between the environmental variables and the species richness and abundance.

Table 6. The p-values and Spearman's rank correlation coefficients (r) between the environmental variables and the arthropod species richness and -abundance. Significant correlations at a 95% certainty indicated with *.

	Arthropod species richness		**Arthropod abundance**	
	p-value	**r**	**p-value**	**r**
Plant species richness	0.668	-0.043	0.128	-0.156
Plant cover (%)	0.291	-0.109	0.072	-0.185
Detritus (%)	0.097	0.169	0.706	0.039
Canopy height (cm)	0.037*	-0.214	0.002*	-0.308
Soil compaction (psi)	0.212	0.129	0.114	0.162

4. Discussion

4.1 Overall biodiversity

Organic agriculture has been shown to benefit arthropod biodiversity in farmlands (Bengtsson 2005; Hole *et al.* 2005; Kleijn 2006). The same has been shown in the current study area of the Greater Cape Floristic Region (Gaigher *et al*. 2010; Gaigher & Samways 2014; Kehinde & Samways 2011). The results for this study corresponds to these findings and the overall species richness was higher in the organically managed vineyards compared to the conventional vineyard. However, the focus of this study was not to determine whether there is a difference, but to see how biodiversity and pest control ecosystem services change over time under organic management practices.

In review on biodiversity studies comparing organic to conventional agriculture, Hole *et al*. (2005) proposed that biodiversity could show a time lag of multiple years when transitioning to organic management practices. Looking only at species richness, the results here suggest otherwise. There seems to be a rapid increase in arthropod species richness a year after transitioning to organic management practice. This result corresponds to other studies, which also show a rapid increase in species richness after transitioning (Andersson *et al*. 2012; Lundgren *et al*. 2006; Jonason 2011). After the initial increase, the species richness seems to first decrease and then stabilize under organic management practices. The overall trend corresponds to a study by Jonason (2011), who showed that butterfly species richness increased rapidly after transitioning and it did not change over a 25-year period under organic management practices.

The arthropod abundance increased significantly in the transition period and afterwards, it decreased under organic management practices. In comparison, Jonason (2011) found that the butterfly abundance increased gradually over time under organic management practices. The differences in the trends, could purely be because butterfly abundances respond differently to the overall arthropod abundances.

The trend for the overall species richness and abundance data seems to be very similar. Both showed an initial increase in the transition period and afterwards it decreased slightly under organic management practices. This trend could be explained by the Intermediate Disturbance Hypothesis (Connell 1978). The conventional vineyard had high levels of disturbances and therefore, had a low species richness, possibly because only a few hardy species survived the frequent disturbances. On the other side of the disturbance spectrum, the organic vineyards had low levels of disturbances and therefore had relatively low species richness, which may be due to competitive exclusion of the dominant species. The 1-year transition vineyard had intermediate disturbance levels, which contributed to a higher species richness.

A study by Bruggisser (2010) tried to determine how biodiversity in vineyards was influenced by the different farm management intensities. In contrary to what this study showed and to what is generally expected, they did not find a significant difference in the biodiversity between the conventional and organic vineyards. They used the Intermediate Disturbance Hypothesis as an explanation for the lack of a differences in biodiversity. They suggested that the level of disturbances in the organic vineyards was so low, that the organic vineyards were dominated by a few species, which prevented other species from establishing. This is clearly not the case in the current study, because the overall arthropod species richness was significantly higher in the organically managed vineyards compared to the conventional vineyard. However, it does seem to be valid explanation as to why the species richness decreased over time under organic management practices in this study.

As previously mentioned, the overall abundance and species richness was significantly higher in the organically managed vineyards, which agrees with other studies (Bengtsson 2005; Attwood *et al*. 2008). There are multiple factors that are known to impact arthropod diversity in agroecosystems, these include the intensity of management practices, environmental- and landscape factors. The influence of landscape factors (e.g. distance to nearest source habitat) in this study was negligible, because the study is done at farm scale, the vineyards are adjacent to each other and the influence of landscape factors are therefore negligible. The reduced management intensities seem to be the biggest contributing factor for the higher species richness and abundance in the organically managed vineyards. Most of the different types of management practices showed a positive effect on the species richness and abundance. The only management practices that showed the contrary to what is expected, was the fertilizer application index. An increase in fertilizer intensity i.e. the increase in amounts of inorganic fertilizer, is generally considered to adversely impact arthropod biodiversity. The results for this study suggested the opposite, however this was because the organically management vineyards received fertilizer whereas the conventional vineyard received none, owing to a higher fertilizer intensity in the organically managed vineyards.

The environmental variables did not influence the arthropod species richness and abundance. Plant heterogeneity is normally one of the main components to facilitating arthropod biodiversity in farmlands (Benton *et al*. 2003). A heterogeneous vegetation creates structural complexity and provides food resources, shelter and a microclimate to arthropods (Landis 2000). However, at the time this study took place, the GCFR was experiencing a drought and the vineyards under organic management practices were mowed frequently, to reduce the water stress on the vines. This explains why the plant height in the organically managed vineyards were quite low. The frequent mowing could also explain why the percentage plant cover and the percentage detritus was quite low and the soil compaction was quite high for the vineyards under organic management practices.

The trend for the overall arthropod species richness can be interpreted as the following: the high levels of biodiversity can be achieved relatively quickly and that the organic management practices did not seem to hold any additional benefits to biodiversity over the long-term. Like this interpretation, the species richness is often used as synonymous to biodiversity however, species richness is not the only measure of biodiversity (Hooper *et al*. 2005). When we look at the arthropod assemblage structure, the assemblages clearly change over time, despite the species richness staying relatively constant. The different assemblages in the different times under organic management practices, indicates that there were differences in the conditions between the treatments, which favoured different arthropod taxa. However, again it does seem as if there is less of a difference between the species assemblages in the 5-year and 15-year organic vineyards, which could indicate that the assemblage structure might be stabilizing over time.

4.2 Natural enemy diversity and abundance

The natural enemies (spiders and parasitoids) accounted for 32% of all the arthropods sampled in this study and thus seem to be an important component or the arthropod community structure in the vineyards. These natural enemies are known as effective biological control agents in crops (Dippenaar-Schoeman 1999). As expected, the natural enemy species richness and abundance was significantly higher in the organically managed vineyards compared to the conventional vineyard, which agrees with other studies (e.g. Attwood *et al*. 2008; Letourneau 2009; Mäder *et al*. 2002).

Over time under organic management practices, the natural enemy species richness followed the same trend as the overall arthropod species richness and abundance, with a rapid increase one year after transitioning. If we were to measure the natural enemy species richness and abundance in the second year of the transition period, we can expect an even greater increase, if it were to follow the same trend found by Lundgren *et al.* (2006). Over the long-term, the natural enemy species richness and abundance first decreased and then stabilized after the 5-year organic vineyard. The natural enemy assemblages also seem to suggest that the assemblages might have stabilized over time under organic management practices.

Despite the apparent influx of natural enemy abundance and diversity in the transition period, the percentage of natural enemies seems to still be low compared to the fully organic vineyards. This gives us a good indication of the how the functional composition changes over time under organic management practices. The percentage of natural enemies sampled in the conventional vineyard was very low, accounting for 20% of the overall arthropods sampled. The transition vineyard and the 5-year organic vineyards composed of about 30% of natural enemies, whereas the natural enemies in the 15-year organic vineyard accounted for nearly 43% of the arthropods sampled.

4.3 Pest counts and damage levels at different times since transitioning

When we compare the pest damage to the pest count data, they do not seem to correspond. The pest count data was the lowest in the conventional vineyards, this did however not mean the pests were absent, because the damage was still quite high. There are many reasons as to why there is a lack of correspondence between the pest counts and pest damage. The conventional and organically managed vineyard were under different management practices and it could be that the timing of pest count data was influenced by other variables, such as the spraying timetable. I therefore decided only to focus on the pest damage, which is a more direct measure of the relative pest control ecosystem services in the vineyards.

During the transition period, the pest damage is generally expected to increase, due to the changes in pest management practices and a lack of pest control (Zinati 2002). The pest damage was indeed the highest in the 1-year transition vineyard however, this was not due to a lack of natural enemies, because as mentioned previously, the natural enemies were the most abundant and diverse in the 1-transition vineyard. Many studies have shown a strong relationship between natural enemy species richness and the herbivore suppression in agroecosystems (Bianchi *et al.* 2006; Letourneau & Bothwell 2008), however this does not seem to be applicable to the early transition period in this system.

There could be numerous reasons why the high natural enemy species richness and abundance in the 1-year transition vineyard did not correspond to an increase in pest control. Firstly, although the abundance and species richness of natural enemies seems to be very high in the transition period, the percentage of natural enemies of the total arthropods sampled was still relatively low compared to the other vineyards. With the high percentage damage and a lack of natural enemies, we can only assume that the majority of arthropod in the transition period are herbivorous and pests. Secondly, the natural enemy species identity plays an important role in pest suppression, as shown by Straub and Snyder (2006), i.e. pest control is only achieved when certain highly efficient natural enemies are present in an assemblage. It could be that the natural enemies present in the transition period were mostly pioneer species, which are not necessarily responsible for pest suppression. Lastly, it could be that the predator-prey relationship between the natural enemies and the pests is not yet established in the early transition period (Bellows 2003).

The pest damage in the organic vineyards (5- and 15-year organic) was expected to either be similar (Letourneau 2001) or higher (Rhainds *et al.* 2002) compared to the conventional vineyards. The leaf damage was slightly higher in the 5- and 15-year organic vineyards compared to the conventional vineyards however, the bunch damage was the lowest in the 15-year organic vineyard. Overall, the trend in the damage results suggests that time under organic management practices does seem to play an important role for pest control ecosystem services. After the initial increase in the leaf and bunch damage during the transition period, the leaf and bunch damage decreased significantly over time, and stabilized somewhere between the 1-year transition and the 5- year organic vineyard.

5. Conclusion

Research has so far mostly focussed on the consequences intensifying agricultural systems has on biodiversity. Little has so far been done to understand how to restore biodiversity and the ecosystem services that it provides. If we are to redesign agroecosystems we need to understand more about what happens during this restoration phase.

The transition period to organic agriculture is an example of a restoration phase. Although the transition period is a controversial topic, it does seem to be a valid period for the return of arthropod biodiversity and a pest control ecosystem services. Here, I show that there is a definite influx of arthropods within the transition period and these do not seem to be beneficial. It seems as if the influx might be mostly herbivorous arthropods, which is why the proportion of natural enemies was so low and the pest damage was so high for the transition period.

From an ecological perspective, the agroecosystem stability does seem to be achieved over time under organic management practices, and both the species richness and assemblages seem to stabilize over time. Stability also seem to be important for the provision of pest control ecosystem services. The pest control ecosystems services seem to return over time under organic agriculture. This supports the idea that the natural enemy assemblages are compensating for the chemical sprays in the conventional vineyards, as suggested by Letourneau (2001). This is a typical example of a win-win situation, where not only are the vineyards under organic management practices beneficial for conservation purposes, but it seems as if pest control through natural enemies seem to be more and equally effective as conventional farming.

In this study, I only looked at 1-year into the transition period and future research should try determining how biodiversity and the associated ecosystems services change throughout the transition period. Future studies should also focus on replicating the treatments on a larger scale, to determine if these results are site specific or widely applicable. Environmental change is predicted to adversely impact the natural enemies in agroecosystems, which will result in the frequency and intensity of pest outbreaks to increase (Stireman *et al*. 2005). Here, we show that in the long term, organic farming seems to increase the overall arthropod- and natural enemy diversity and abundance, while still maintaining and improving pest control ecosystem services over time. This could also apply to other essential ecosystem services and according to the insurance hypothesis, this greater diversity will ensure that the biological functioning will remain even after species are lost (Yachi & Loreau 1999). Ultimately, using landscape softening techniques, such as organic farming, will create long term resilience in these farming systems.

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7. Appendices

Appendix A. Environmental risk codes assigned to each management practices.

Environmental Risk	Code
Biocide risk code	
Low	1
Medium	2
Medium to High	3
High	4
Tillage types	
No tillage	0
Light tillage using tine	1
Disc cultivation	2
Heavy cultivation using bulldozer	3
Fertilizer types	
No fertilizer	0
Foliar fertilizer and biodynamic intervention	1
Organic fertilizer	2
Inorganic fertilizer	3

Appendix B. Calculations to determine the environmental risk associated with the management practices.

Biocide application

Farm	**Active ingredients**	**Risk coding**	**Application index**
	Herbicide		
Organic	None	0	0
Conventional	simazine (L)	1	5
	terbuthylazine (L)	1	
	chlethodim (L)	1	
	glyphosate iso-propyl ammonium (M)	2	
	Fungicides		
Organic	sulphur (M)	2	4
	copperhydroxide (M)	2	
Conventional	sulphur (M)	2	10
	folpet (L)	1	
	phosphorous acid (M)	2	
	cynoxanil + mancozeb (M)	2	
	spiroxamine (M)	2	
	penconazole (L)	1	
	Insecticides & Nematicides		
Organic	None	0	0
Conventional	Sulphur	2	2

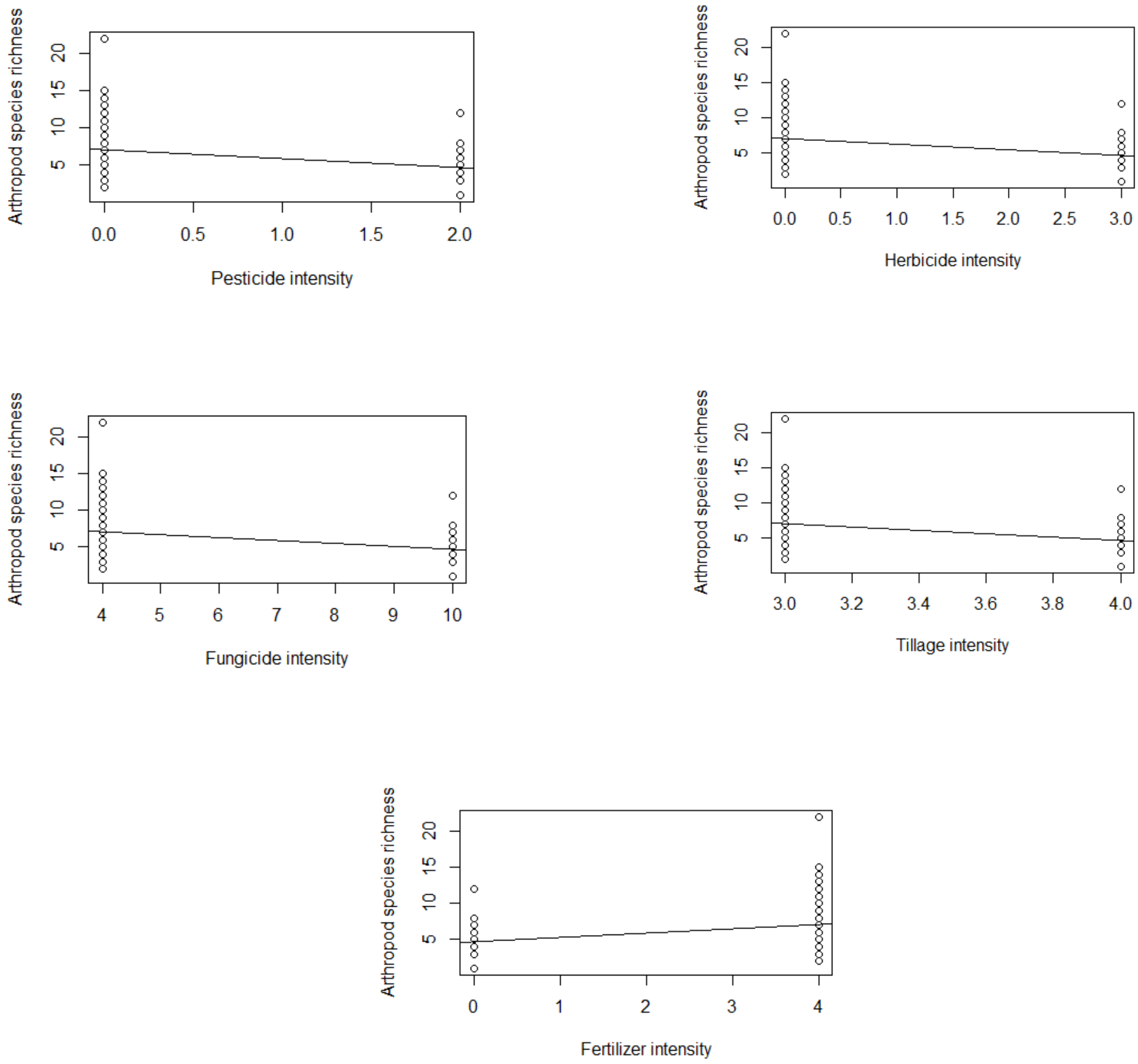
Appendix B cont.

Fertilizer application

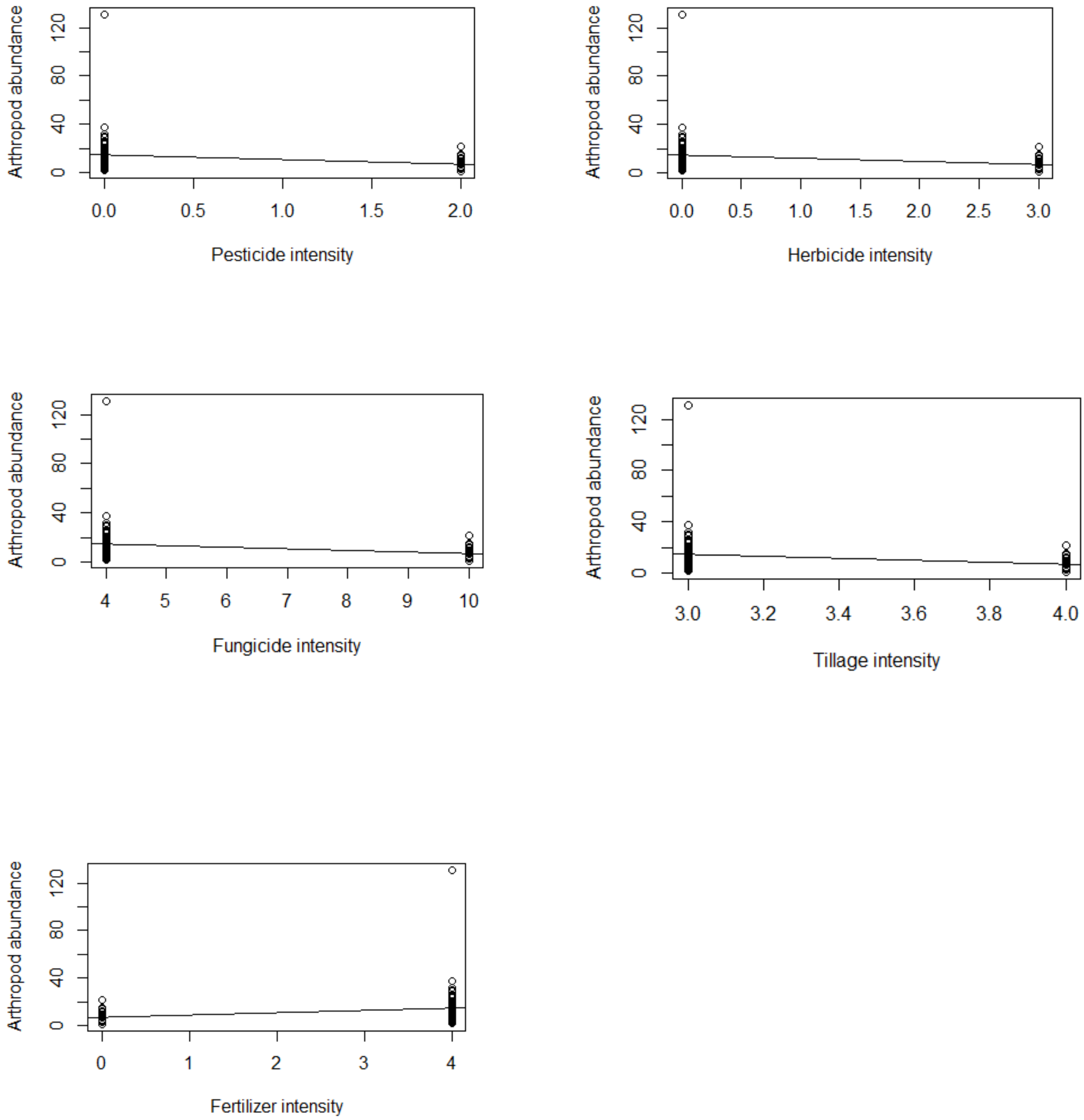
Farm	**Fertilizer type**	**Coding**	**Application index**
Organic	organic compost (cow manure, garden and vineyard refuge, grape pips and skins)	2	
	biodynamic preparation (cattle manure, quartz/silica, yarrow, stinging nettle, dandelion, valerian, chamomile, oak bark)	1	4
	organic fertilizer	1	
Conventional	None	0	0

Tillage regime

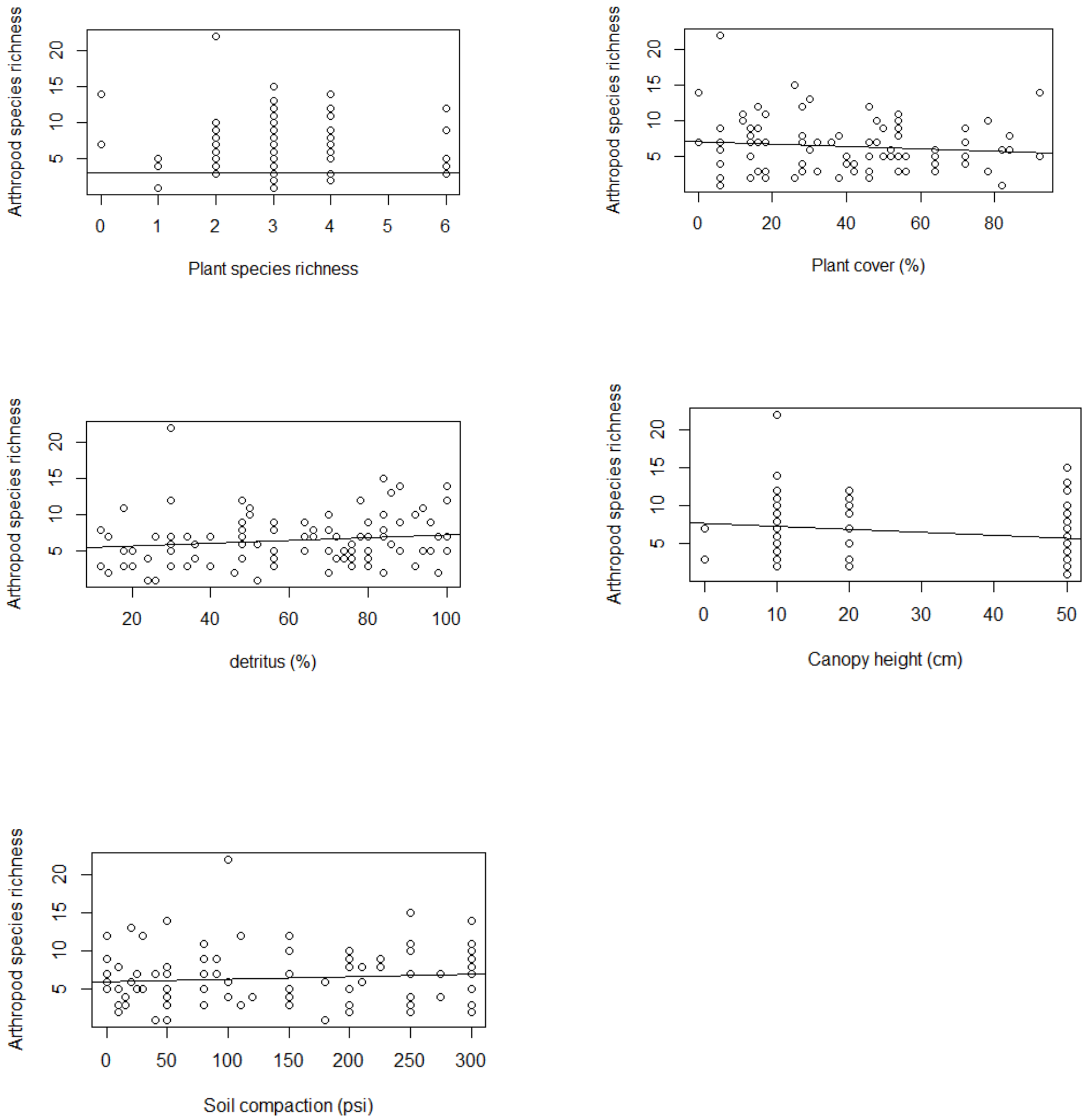
Farm	**Tillage method**	**Coding**	**Tillage index**
Organic	Disc	2	
	Grop (tine tillage)	1	3
Conventional	Disc x2	2	4



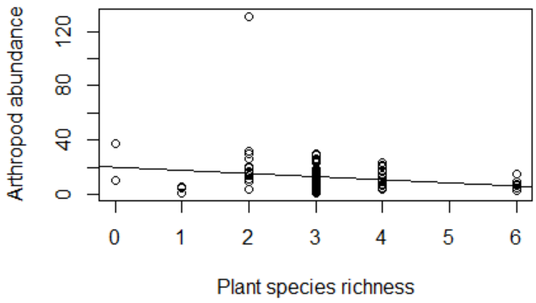
Appendix C. The scatterplots indicating the relationships between the vineyard management intensity and the arthropod species richness.

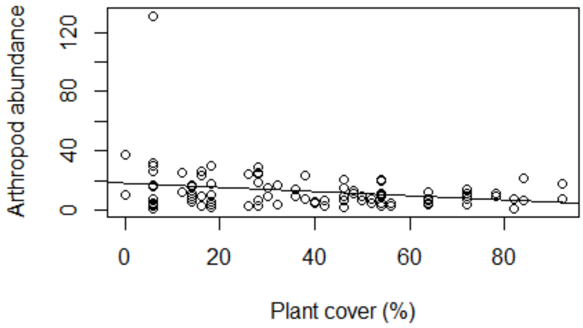


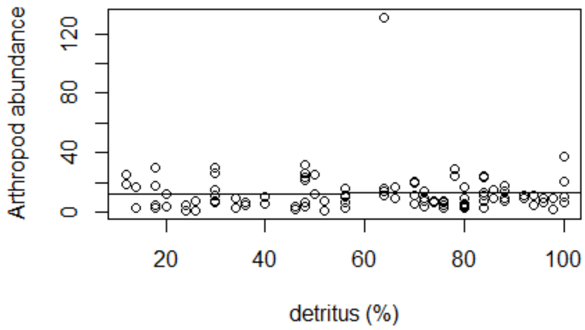
Appendix D. The scatterplots indicating the relationships between the vineyard management intensity and the arthropod abundance.

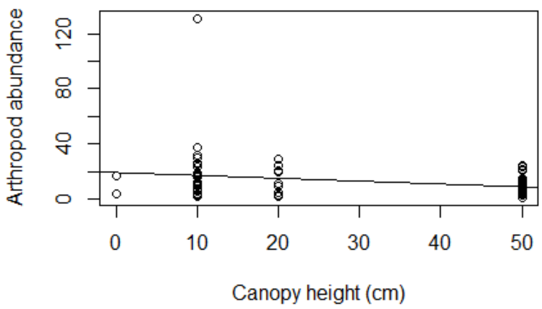


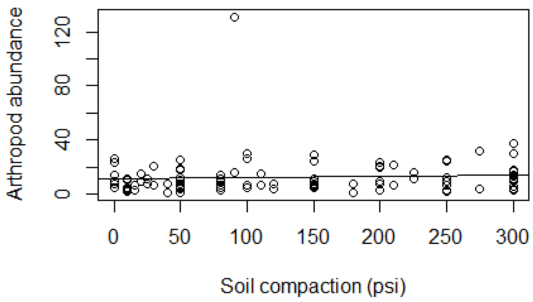
Appendix E. The scatterplots indicating the relationships between the environmental variables and the arthropod species richness.











Appendix F. The scatterplots indicating the relationships between the environmental variables and the arthropod abundance.