EFFECTS OF STRIP CROPPING ON GROUND DWELLING INSECT ABUNDANCE AND DIVERSITY

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Effects of strip-cropping on ground dwelling insect abundance and diversity
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Abstract

Beneficial ecosystem services of strip-cropped systems, such as reduced pest pressure, increased nutrient uptake and higher crop yields with less agrochemicals are widely reported, but studies on the effects of strip-cropping on ground dwelling insects, and the Carabids especially, are lacking. Natural enemies, such as Carabids, have the potential to provide sustainable and ecofriendly pest insect control. In this study, we conducted experiments on the effects of strip-cropping cabbage, *Brassica oleracea* var. *capitata* (cultivar Castello), and faba bean, *Vicia faba* (cultivar Sampo), on ground dwelling insects, and compared the results to monoculture crops.

Sampling was done by pitfall trapping the insects and identifying them. Trapping was done in 4 periods, each lasting 7 days, followed by 14 days of letting the insect assemblages recover for the next week's trapping. The whole trapping period lasted from 12.6. to 21.08.2018, a total of 10 weeks. Insects were identified to taxonomic ranks varying from genus to subclass. Carabid beetles were of special interest and were all identified to genus.

In total there were 21 genera of Carabids, and this group was of keen interest due to it being comprised mostly of predatory insects and thus capable of biological pest insect control. Strip-cropping is hypothesized to increase abundance of predatory insects, which makes abundance of Carabids a useful indicator for assessing the effect.

Faba bean on its own was observed to attract the most insects. The positive effect of faba bean on insect abundance appeared also to have been carried over to the strip-cropped system. This suggests that with the cabbage and faba bean crop combination, insect abundance and diversity could be manipulated. The strip-cropped system had the highest insect diversity, giving further proof for beneficial effects of strip-cropping via increase in diversity.

PREFACE

This thesis study was a part of a larger collaboration including seven EU partner countries (including Finland, Belgium, Denmark, Italy, Latvia, the Netherlands and Spain) in a project called SUREVEG. The aim of the study is to "develop and implement new diversified, intensive cropping systems using strip-cropping and fertilization strategies combined from plant-based soil-improvers and fertilizers. The project's objective is to improve crop resilience, system sustainability, local nutrient recycling and soil carbon storage."
Work for this thesis was conducted in two locations. The field work was conducted in the summer of 2018 in an all organic field used for ecological experiments, located in Karila, Mikkeli. The use of the field and facilities was coordinated by the Natural Resources Institute Finland (LUKE). Sampling, identifying and storing the insects was done at the University of Eastern Finland
The aim of this thesis was to study the effects of strip-cropping on ground dwelling insects, compared to traditional monoculture farming. The study consisted of pitfall trap sampling of insects, identification of specimens in the insect catch and a comparison of the three plot types.
This study has the potential to identify agricultural techniques for increasing crop yields through, for example, decreasing pest infestations and increasing nutrient uptake using natural means.

As a thesis study, the second aim was to deepen understanding and skills associated with scientific experiments, writing and work. I want to thank SUREVEG, LUKE and UEF for giving me this unique opportunity to participate in a real-world scientific study and supporting me in it.

Joonas Mäkinen

Table of contents

5.1 EFFECTS OF STRIP CROPPING

5.1.1 Comparing strip-cropping and monocultures

5.1.2 Comparison of cabbage and faba bean monocultures

5.1.3 Natural enemy hypothesis

5.1.4 Trap crop hypothesis

5.2 ABIOTIC FACTORS

5.3 EFFECTS OF STRIP CROPPING

6. CONCLUSION

1. INTRODUCTION

Increased demand for food has not been matched by increased area for production, which is causing pressure to intensify food production. From 2005 to 2050, global crop demand is projected to increase by 100-110% (Tilman et al., 2011). However, conventional agriculture has caused widespread ecological problems, such as eutrophication due to increased fertilizing, nutrient deficiency in soils due to overproduction of crops, decreased ecological diversity due to large monocultures and promotion of market crops, soil and water pollution, soil erosion and deforestation (Edwards, 1989). With the environmental problems we are facing, the common consensus is that agricultural practices must evolve to be more environmentally friendly.

With the introduction of agrochemicals, agriculture has become dependent on these inputs for production of socially acceptable product and enough yield. To intensify agriculture and food production, but lower the harmful impact to the environment, land must become more self-sustainable. This requires developing new agricultural techniques, or rather, to develop existing, but forgotten techniques.

One of these “forgotten” techniques is strip-cropping also known as intercropping. Here I use the term strip-cropping, which is an agricultural technique, where two or more crops are grown adjacent to one another. Strip-cropping carries many positive effects, such as protection from soil erosion and water runoff, pest and weed control, increasing biological and functional diversity through edge effects and added niches and nutrient retention, which allows reduced use of external fertilizers (Gao et al., 2009., Głowacka, 2014., Labrie et al., 2015., Rodrigo et al., 2000).

One alternative to agrochemicals could be using natural enemies of herbivorous insects, which would restrict reproduction and spread of these harmful pests through predation. Natural enemies could help to reduce use of costly and potentially environmentally harmful chemicals. In the US, ecosystem services provided by natural enemies is valued at 4.5 billion US$/year (Tilman et al., 2011).

While positive effects of increased classical biodiversity – known as α-diversity – are well documented, functional diversity is equally, or more important (Mori et al., 2018). A strip-cropped field offers more niches and causes edge effects, which both have been shown to increase species abundance. Ecosystem services are offered by the species that occupy the area, and therefore increased species abundance has the chance to increase ecosystem

services, or functions, that they serve.
With crop selection we have direct control on the functional diversity of the crops themselves. For example, legumes have been shown to offer nitrogen retention in soil, increasing the available nitrogen for other crops sown in the field (Jeromela et al., 2017). We can also use biological pest management techniques such as intercropping known trap, barrier, repellent or cue disruptive crops with the main crop.

2. LITERATURE REVIEW

2.1 STRIP CROPPING

Strip-cropping is a technique in agriculture where two or more crops, their cultivars or wild plants are cultivated in the same field area and at the same time. It has been shown to offer many positive ecosystem services, such as, lowering water runoff from plantations, which also prevents soil erosion and nutrients from leaching out of the system, preventing pollution of surrounding and aquatic environments and improving nitrogen and phosphorous capacity of the soil (Labrie, 2016, Glowacka, 2014, Glowacka, 2013). In this case, strip-cropping is most effective in uphill areas where the runoff of water is highest (Głowacka, 2014). Benefits of strip-cropping are weed control due to added competition to the weeds, reduction of pest insect abundance through attraction of natural enemies and parasitoids and improved resource usage (Labrie et al., 2015, Rodrigo et al., 2000). Presence of an edge has an effect that improves biodiversity. With increased diversity, the number of niches that can be exploited is increased, which in turn allows more species to inhabit the area. With added niches it is important to understand that these niches could also be filled by pest insects, if the niches are most suitable for them (McCabe et al., 2017).

Strip-cropping has been shown to increase the land use efficiency ratio (LER), which is a commonly used measurement for how efficiently a given land area is being used (Cortés-Mora, 2010). Modern agriculture needs to be intensified, instead of enlarging field area. However, with intensification, agricultural systems are becoming more dependent on external inputs of nutrients and agrochemicals such as herbicides and pesticides.
Strip-cropping allows crop rotation, a technique where crops are rotated between the growing rows each year. The technique has been used for millennia, but has been in decline since the invention of agrochemicals (Francis et al., 1986). Crop rotation has been shown to affect the soil microbial community, litter soil pH, functional biodiversity and to increase yields (D'Acuntoa et al., 2018). Crop rotations are a way for a field to become less dependent on external inputs of nutrients, by using the existing land more efficiently. This happens by increasing soil microbial diversity and metabolic diversity of the soil microbial communities, which affect how efficiently soil microbes obtain the energy and nutrients to live and

reproduce. More diverse microbial communities contribute to soil aggregate formation. Changes to soil pH are linked with nutrient cycling and thus plant functions and by lowering competition with natural weed control (D'Acuntoa et al., 2018). In addition to increase in yields, lower use of agrochemicals will decrease water body pollution.However, crops belonging to different guilds carry different traits and functions, thus not all crops have the same ecological impact on soil, and so, detailed knowledge of the crops cultivated is required to efficiently use crop rotations and intercropping (D'Acuntoa et al., 2018 and Davis et al., 2012). In addition to the use of different crops, the number of strips has been shown to affect the efficiency of crop rotation and intercropping.

Heterogeneity of the roots in the strips can improve resource capture, and resource competition is lowered when crops have different growing seasons (Rodrigo et al., 2000). Strip and intercropping have also been shown to increase crop yields (Gao et al., 2009), which is mainly due to the ecological services mentioned. As well as having many ecological upsides, strip-cropping allows for mechanized farming, as rows can be planted in a harvestable way by machines (Mahallati et al., 2014). For farmers, strip-cropping also provides insurance, if one crop fails the other intercrop could still be viable.
However, visual difference from long standing monoculture plantations may cause hesitance to adopt strip-cropping (Wojtkowski, 2005). A second reason for hesitance may be that studies on crop diversification show great variance in insect responses (Potting et al.,2004). Width of the rows are a factor in efficiency of strip-cropping (Labrie et al., 2015).

Non-competitive crops should be planted adjacent to one another, or a buffer row should be used as an option to lower competition (Wojtkowski, 2005). The secondary buffer row may then later be cut for economic gains, as regular crops, or thrown on the other crop rows to provide fertilization, or they can be laced with herbicides prior to throwing to provide fertilization and also control weeds (Wojtkowski, 2005).

2.1.1 Soil erosion and nutrient leak

Soil erosion can cause nutrients to leach from an area with water runoff, which is an especially significant issue in the early stages of crop planting, when soil is more uncovered, and roots have not burrowed deep into the soil (Gilley, 2005). At this stage, soil is subject to rainfall, water flows and wind. Loss of surface soil is especially harmful, because subsoil beneath it is usually finer in texture and has lower water infiltration capacity, water storage and nutrient abundance (Gilley, 2005). Nutrients, pesticides, herbicides, fungicides and pathogens leached from fields can end up in water bodies such as lakes or seas, causing them to be polluted. (Haridjaja, 2011 & Rogobete and Grozav, 2011). This is visible in the Baltic sea for example, where eutrophication and pollution are a major problem. This is mainly due to pollutants being transported via numerous rivers, from eight agriculturally intensive countries.

Intercropping has been shown to lower soil water and nutrient runoff, compared to monocultures. One cause for this could be the increased plant density. As the spaces between crops can be used more efficiently, it can stop soil particles from leaching off the field (Sharaiha and Ziadat, 2007).

2.1.2 Pest control

Intercropping, or strip-cropping, has been shown to reduce density of pest insects and pathogens, leading to decrease of crop losses (Ma et al., 2006). However, the results are not universal, and different vegetation induces different responses in insects (Potting, 2004). Adding additional crops to the field increases habitats for possible natural enemies, and thus increases their abundance and effectiveness. Additional crops can also offer visual repellents such as dense foliar cover, which certain insects avoid, act as a physical barrier, which repels inbound flying insects, or provide olfactory camouflage, making it harder for insects to locate the wanted cultivated crops. Plants such as onion, garlic, lemon grass and tomato can offer this camouflage (Perrin and Phillips, 1978).

In a study about soybean aphids, Labrie et al. (2015) found that prey/predator ratio was more evenly distributed in crop rows that are narrower. Rows of 18m had less aphids than 32m rows, and more predators per prey.

Another study, by Ma et al. (2006), where wheat (*Triticum aestivum L.*) and alfalfa (*Medicago sativa*) were intercropped, showed a decrease in wheat aphid (*Macrosiphum avenae*) infestation. Results showed that abundance of the aphid's natural enemy, the trombidiid mite (*Allothrombium ovatum*), was increased in strip-cropped sites, compared to in monocultures of wheat.

2.1.3 Pollination

Globally 75% of the species of crops grown as food crops are at least partially dependent on insect pollination. Wild bees provide the majority of this pollination, but in recent years their abundance has been declining. This has forced farmers to turn to commercially reared bees to ensure sufficient pollination (Campbell et al., 2017). One reason behind the decline of pollinators is pesticides and herbicides (Goulson et al., 2015). Increasing abundance of natural pest enemies and weed control allows for a downscale of pesticide and herbicide use.

Increased diversity has been shown to increase natural protection against pest insects (Labrie et al., 2015). Pollinators are adversely affected by pesticides, and so, decreasing the use of pesticides would lessen pollinator decline (Goulson et al., 2015).

Strip-cropping has also proven to alter the chemical composition of the cropped plants, and the effects vary depending on the selected crops (Horrocks ,1999). This could be a natural way to combat nutrient deficiency.

Changes in chemical composition of the plants also affects how herbivores interact with them. Intercropping with flowering plants increases the abundance of pollinators and can be used to combat pollinator decline. This also benefits other crops dependent on insect pollination, and the surrounding ecosystem (Norris et al., 2017). In a study on the effect of flower strips mixed with a crop, it was shown that pollinator visits to crops that had adjacent flowering strips were 25% higher, compared to crops that did not have flowering strips.

2.2 TILLING

Tilling practices can influence the functional biodiversity of the field (Shresthaa and Parajuleeb, 2009). Conservative tilling means, that at least 30% of the field is left covered with crop or organic residue of the last year's crop. It has been shown to increase natural predation and pest control compared to conventional tilling (Tamburini et al., 2016, & Shresthaa and Parajuleeb, 2009).

In conventional tillage the whole field is tilled, and no crop or organic residue is left on the field (Shresthaa and Parajuleeb, 2009). This helps with erosion, as the mulch absorbs and dissipates rain drop energy. For example, leaving 30% of previous year corn mulch on the field can reduce soil loss by 62-97% (Gilley, 2005).

Zero tilling practice leaves the soil as undisturbed as possible, only at the moment of sowing is a groove opened to deposit the seeds or seedlings. The aim of conventional tilling is to remove the competitive vegetation cover from the field to allow more nutrients for the crops to use. Over time, however, erosion can degrade the soil's chemical, physical, and biological characteristics (Lal, 2000, 2006). With zero tilling, erosion of the land is slowed, keeping it viable for crop production for a longer time (Telles et al., 2018). Strip-cropping carries the upside of weed control, but studies of combined effects of zero tilling and strip-cropping on weed control are currently lacking.

2.3 FUNCTIONAL BIODIVERSITY

Functional biodiversity explains functions or ecological services of the biotic actors in a given ecosystem and details the functions of single groups, or "clusters", of organisms. Species sharing the same or similar ecological functions can be put into the same group, called a functional group. For example, pollinators are one group. However, a species can belong to many groups at the same time, as one organism can serve many functions (Mori et al., 2018).

Functional biodiversity is ecologically important, because it is the measurement of ecosystem dynamics, stability, productivity, nutrient balance and other aspects of ecological functions (Tilman, 2001). It is only a section of biodiversity, where diversity refers to living organisms, not their functions in the ecosystem.

Positive impact on ecosystem services with increase of biodiversity has been observed in a number of studies (Finney et al., 2017). In the literature, however, more focus has been given to α-diversity: the number and abundance of species within local communities of interacting species. Less focus has been given to β-diversity, the variation in the identities and abundances of species among local species assemblages. It can be quantified in various ways, one being functional diversity. Changes in β-diversity can have a bigger impact on ecosystems than classical diversity, or α-diversity (Mori et al., 2018). For example, anthropological filtering can cause more cosmopolitan species with higher endurance against environmental stressors to become dominant in a given ecosystem. The number and abundance of species (α-diversity) may stay the same, but functions and traits that the species in local assemblages carry may become more homogenous (lowered β-diversity), leading to loss of ecosystem functions. Usually the first species to disappear are rare species, and rare species have been shown to carry distinctive traits and functions that common species cannot serve (Mouillot et al.,2013). This illustrates the importance of focusing on functional diversity and how more studies of its effects would be beneficial (Mori et al., 2018).

Functional biodiversity changes throughout the season. Species composition varies, and plants enter new phases of functions depending on the time of the year and even time of the day (Schoonhoven et al., 2006).

2.4 ECOLOGY OF AGROECOSYSTEMS

In agroecosystems, communities are not formed through natural competition and selection, but largely through anthropological changes in the ecosystem. Anthropological filtering such as crop selection, tilling and use of agrochemicals, all lead to biotic homogenization, which makes ecosystems more vulnerable to pest infestations, outbreaks of diseases and effects of climate change (Altieri et al., 2015). All ecosystems are dependent on ecosystem services provided by the species living in it. Agroecosystems are generally simplified in diversity of species and the services they provide, which affects their capacity to respond to stressors, such as climate change and its byproducts (Folke 2006). Strip-cropping decreases biotic homogenization and could therefore increase functionality of agroecosystems.

2.5 INSECT FORAGING PATTERNS

Herbivorous insects often search for suitable plants with a combination of random movements and detection of guiding cues. Two major cues arise that the insect can detect: plant emitted volatile organic compounds (VOCs) detected with the olfactory apparatus of the insect, or visual cues, most notably color of the plant. Visual cues are not as dependent on environmental factors as VOCs, but they are harder to differentiate as “most plants are green”, their dominant reflectance-transmittance hue is between 500-580 nm (Schoonhoven et. al., 2006). In studies, some VOCs have been found to be taxon specific, and some specialists can use them to find their host plant, even in complex arrays of VOCs as is often the case in natural environments. As VOC intensity increases the closer to a plant the insect gets, it they can be used to orientate

towards the plant. However, VOCs are directly affected by environmental factors such as wind speed and direction.
It has been shown that herbivore induced plant volatiles (HIPV) can attract natural enemies and act as an indirect plant defense (Holopainen, 2004). HIPVs can differ depending on which herbivorous insect is attacking the plant. This release of specific VOCs helps to attract natural enemies of the herbivorous insects (Schoonhoven et. al., 2006).

2.6 CARABID BEETLES

Carabid beetles are ground dwelling invertebrates that belong to the suborder *Adephaga* of the order Coleoptera. They seldom climb and fly (Thiele, 1977). For this reason, pitfall trapping is a fitting way to sample them.

Carabid beetles are an important pest insect controller, as they are often natural enemies of many pests as adults, but also in the larval stage (Rouabah et al., 2014). They hunt aphids, midges and flies, moths, caterpillars and other Coleoptera larvae (Shresthaa and Parajuleeb, 2009).

The Carabids are also sensitive to ecological disturbances such as tillage, irrigation, planting date, pesticides, herbicides and fungicides, so crop management practices could have an effect on their diversity and abundance (Shresthaa and Parajuleeb, 2009).

They also serve as a component in trophic chains and are good bio-indicators, as they are very sensitive to changes in habitat, ecological disturbances and crop management practices. (Caro et al., 2016); Shresthaa and Parajuleeb, 2009).

Some species of Carabid beetles are also herbivores and can cause damage to cropped plants. However, tradeoff between the pest controlling and herbivory is still on the positive side and with few exceptions damage done by Carabid beetles is of little economic significance (Thiele, 1977).

Increasing vegetation diversity in fields, and especially in the field margins, has been shown to increase the abundance of Carabid species. The margins provide Carabids more shelter and diverse nutrient options.

The type of field tillage has been shown to affect the variety and abundance of Carabids. A study showed that conservation tillage, where at least 30% of the field is left covered with crop or organic residue of the last year's crop, yielded more Carabids than a field where conventional tillage had been used (Shresthaa and Parajuleeb, 2009).

The Carabids are both taxonomically and ecologically diverse and different species could have different habitat requirements and may respond in different ways to this habitat structure and management (Caro et al., 2016).
Increased abundance of the Carabids has been shown to increase overall invertebrate species richness, but not as a sole factor (Cameron et al., 2012).

There are studies on Carabid beetles used as bioindicators, and Carabids possess many characteristics expected of bioindicator species. Abundance of Carabids has been shown to correlate to the overall abundance of other invertebrates (Cameron et al., 2012).

Understanding how beetles orientate and what factors affect their orientation, could facilitate their use as a natural pest insect controller. When natural pest control is used jointly with deterrent crops that impede host plant location, maximum effect can be reached (Arnold et al., 2012).

A study has shown that Carabid beetles have a preference for a strip-cropped system over a traditional monoculture. A higher number of Carabids were observed in a strip-cropped system and migration from a monoculture to a strip-cropped field was higher than vice versa (Jon-Andri et al., 1992).

2.7 PITFALL TRAPS

Pitfall traps are a widely used method for catching ground dwelling invertebrates, and they have evolved into various designs, from a simple cup dug into the ground to more complex systems, such as the one used in this study (Figure 2). The basic idea of the trap is unchanged; the insect walks to the edge of the trap, falls in, and is trapped and often killed by a liquid at the bottom. It may be necessary to use a preserving and killing liquid, as predatory insects and vertebrates could ingest trapped specimens, and distort the data (Pearce et al., 2005).
A study conducted by Santos et al., (2006) also discovered that catch rate of traps with a preservative mixture (70% ethanol and 2% glycerol) was increased compared to traps with water or empty traps.
Pitfall traps are a cost effective passive form of sampling, as the traps continue to function as long as they are in place and require little care (Pearce et al., 2005, Lange et al., 2010).

Depending on the design they can be used to capture different invertebrates. Studies have also shown that modifications to the basic form of the traps can reduce the number of unwanted vertebrates (Pearce et al., 2005; Lange et al., 2010). Rooves can be placed over the traps to prevent them from filling with rain.

2.8 PREVENTION OF PEST INSECT HYPOTHESES

Five hypotheses can be associated with the beneficial effects of strip-cropping:

- The disruptive crop hypothesis, also known as the resource concentration hypothesis. Host plants may be harder to find with the presence of an intercrop, which lowers the number of specialist insects. Disruption works by masking the host plants olfactory and visual cues. Olfactory cues are disrupted with VOCs emitted by intercropped plants and visual cues such as vegetation color are also disrupted by the intercropped plants.
- The trap crop hypothesis. The intercrop attracts the pest insects, leaving the actual host plant less affected. The trap crop can also be planted prior to the primary crop, then trap crop and the associated insects can be destroyed emptying the field of all pests, which are "trapped" by the trap crop. After trap crop destruction, the primary crop can be planted, and it will reduce the costs of pesticide use, because the field will be smaller with only the primary crop in place.
- The repellent crop hypothesis. Insects that forage based on olfactory cues will be deterred from entering the field, due to the unattractive VOCs emitted by the intercropped plants.
- The barrier crop hypothesis. Intercrop may act as a physical barrier limiting the pest insects' movements and reducing their ability to spread on the field. The barrier may also direct birds to the secondary crops, this curbs the spread of unwanted insects.
- The natural enemy hypothesis. Increased insect diversity of strip-cropped systems may increase the number of natural enemies and parasitoids of the pest insects. Increased predation will reduce the pest insect populations.

2.9 AIMS AND HYPOTHESES OF THIS STUDY

Planted crops in our study: *Brassica oleracea* and *Vicia faba*

Legumes increase soil nitrogen through symbiotic fixation and rhizodeposition (Felipe Alfonso Cortés-Mora et al., 2010), and a study on intercropping legumes with Brassicaceae found that the intercropping increased nitrogen uptake of the Brassicaceae and decreased the competition of the two crops (Jeromela et al., 2017). Intercropping has also been shown to increase solar radiation absorption, and with increased nitrogen in soil this increases photosynthesis rate. However, with more rows in the field the solar absorption rate was observed to be lower (Mahallati et al. 2014).

This natural nutrient increase could allow decreased use of artificial fertilizers, which have adverse effects on the ecosystems, such as eutrophication.

With the positive effects of strip-cropping on crops, hypotheses of pest insect prevention, and legumes' natural ability to fix nitrogen in soil, my hypothesis for this study is, that the strip-cropped plot will have the highest insect diversity and the highest number of predatory insects. This study is aimed to explore these hypotheses and provide groundwork for continued studies on strip-cropping and its effects.

3. MATERIALS AND METHODS

3.1 STRIP CROPPING EXPERIMENT

The study site was in Mikkeli, Karila (61°40'37.1"N 27°13'08.7"E). The field (240m^2) was laid out in 3 separate plots, the distance between each individual field plot was 50m (Figure 1). All plots were fertilized with “ECOLAN AGRA ORGANIC 8-4-8” fertilizer.

The first field for the strip-cropping experiment (SC field) was 27m x 10m in size with 3-meter-wide alternating strips of cabbage *Brassica oleracea* var. *capitata* (cultivar Castello) and faba bean *Vicia faba* (cultivar Sampo). The cabbage seedlings were store bought from a local farmer and arrived at the field site the day before planting. After planting, seedlings were covered with gauze, to prevent early insect infestations. The distance between each cabbage seedling was 60cm and faba beans were planted at a density of 70 pcs/m^2, to a depth of 6cm, germinative capacity of 97%. In addition, there were 1,5m protective strips of cabbage at both ends of the field. Cabbage was planted from the 16.-18.5.18, Faba bean was sown on the 22.5.18. The field was surrounded by a fence to keep hares from damaging the cabbages.

The second field was for a faba bean monoculture (F field). The field was 27m x 10m in size, and had 1,5m protective strips at both ends of the field. Faba beans (cultivar Sampo) were planted at a density of 70 pcs/m^2, to a depth of 6cm, germinative capacity of 97%, weight of a thousand seeds was 256,8g. Faba bean was sown on 22.5.2018.

The third field was for cabbage (cultivar Castello) monoculture (C field), the field was 27m x 10m in size, and had 1,5m protective strips at both ends of the field. Cabbages were planted in a matrix form, and the distance between each seedling was 60cm. Cabbage was sown on the 16.5.2018. The field was surrounded by a fence to keep hares from damaging the cabbages.

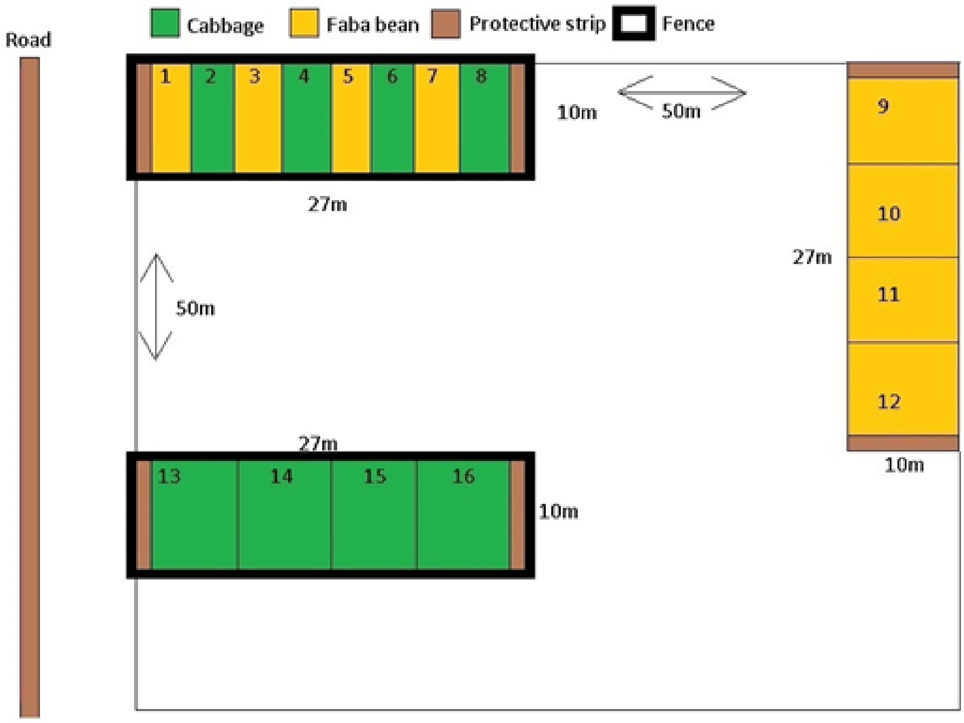

Figure 1. Field layout in Karila

3.2 PITFALL SAMPLING

Pitfall sampling was done in four trapping rounds, each lasting one week, from 12.06.2018 to 21.08.2018. After a week of trapping, the field was left to recover for one week, before the next round of trapping (Table 1). The SC field had one trap per strip, the F and C fields had two traps per plot, for a total of twenty-four traps in the field and 8 per treatment. Four rounds of trapping yielded 96 samples for analysis.

Table 1. Pitfall trapping schedule

Trapping number	schedule	Number of traps
1.	12.6.-19.06.2018	24
2.	3.7.-10.7.2018	24
3.	24.7.-31.7.2018	24
4.	14.8.-21.8.2018	24

3.2.1 Design of the traps

Pitfall traps were comprised of two cups, where an outer secondary cup stayed in the soil for the duration of the experiment, and an inner primary cup served as the trap, which after each week of trapping was removed and a new cup fitted in its place. Traps were dug in the soil, so that the edge of the trap would not be above ground level, preventing the insects from entering.

Traps also had rain guards, which helped to keep small vertebrates out. Rain guards were non-transparent, possibly causing changes in the yield, compared to transparent lids (Figure 2) (Bell, et al., 2014).

Dimensions of the trapping cups were 8,5cm in diameter and 8cm in depth. Cups were bought from Lahtisen vahavalimo, Oitti, Finland.

Trapping cups were made of transparent plastic and the rain guards were dark brown plywood.

Each trap had 100ml of trapping liquid, with drops of detergent to lower the surface tension. The detergent used was Rainbow sensitive dishwashing liquid.

The trapping liquid was 20% propylene glycol ($C_3H_8O_2$, 1-2-propyleneglycol), which was prepared by diluting 100% propylene glycol in water, lowering the concentration to 20%. Propylene glycol was clear and odorless “TYFOCOR L”, Hamburg, Germany.

Next to each of the pitfall traps, a yellow sticky trap was placed (Figure 3). Results from these trappings are a part of the same SUREVEG project, but not a part of this thesis.

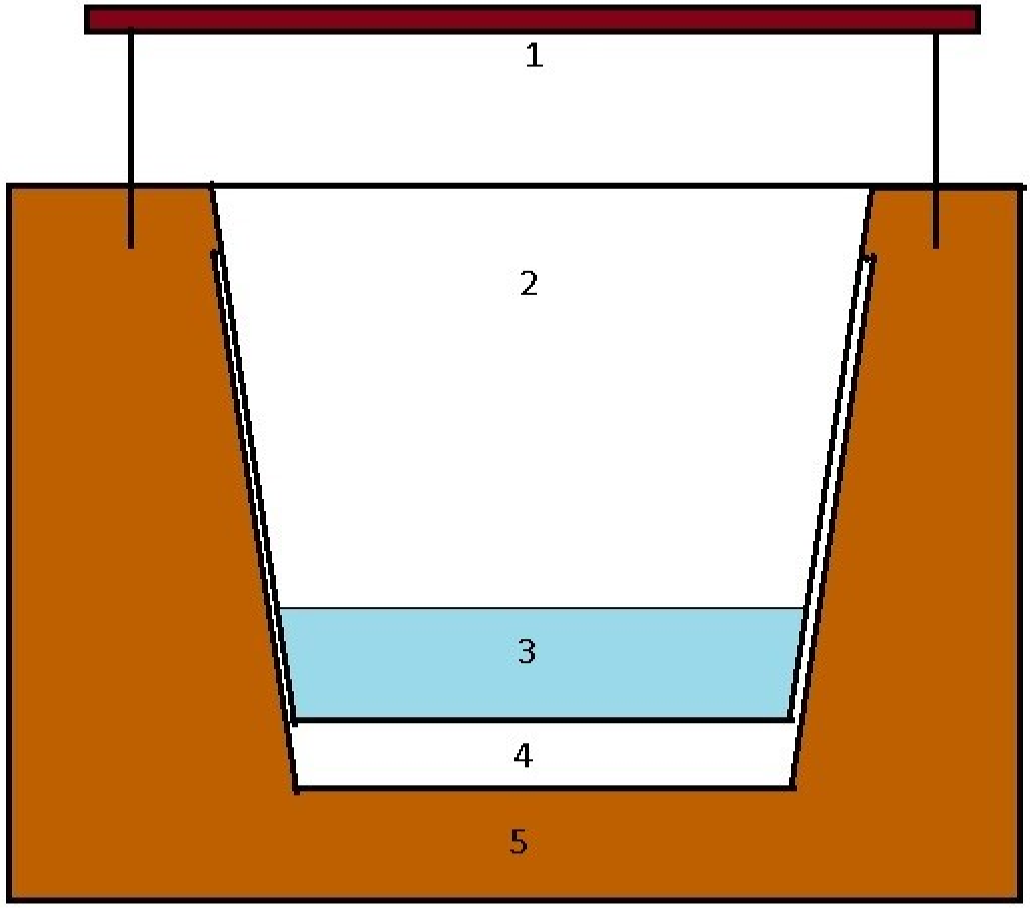

Figure 2. Design of the pitfall trap labels as follows:

1. Rain cover
2. Primary trapping cup
3. Trapping liquid
4. Secondary trapping cup
5. Soil

Figure 3. Pitfall trap without the rain guard and a yellow sticky trap in place

3.3 IDENTIFICATION

Insects were identified to various levels of taxonomic rank, but the focus of this thesis, Carabids, were identified to genus level. A full table of taxonomic level identification can be found below (table 2.)

Table 2. Taxonomic ranks to which insects were identified

Insect group	genus	Family	Subclass	Order
Carabidae	x			
Acari			x	
Aphidinae		x		
Aranae				x
Cantharidae		x		
Chrysomelidae		x		
Formicidae		x		
Geotrupidae		x		
Isotomidae		x		
Isopoda				x
Opiliones				x
Reduviidae		x		
Staphylinidae		x		
Staphylinidae larva		x		

Recording was done in Excel 2016, Identification was done using a Wild M5A stereomicroscope, made by Wild Heerbrugg (Heerbrugg, Switzerland). Identification keys used were for Carabids (Lindroth, 1974 and Hackston 2013), for Aphinidae, Acari, Aranae, Chrysomelidae, Formicidae, Isopoda, Opiliones, Reduviidae Staphylinidae (Pronskiy, n.d), and for Cantharidae and Geotrubidae (Potts, n.d). Prior to identification and after, the insects were stored in 70% ethanol to prevent degradation.
The ethanol used was ETAX A 12 with 91% concentration that was then diluted.

3.4 STATISTICAL ANALYSES

The data collected was not normally distributed, and could not be transformed into a normally distributed form. Therefore, a non-parametric test was selected to analyze the data. The non-parametric test was the Kruskal Wallis independent samples test. Each sample (T1-T4) was analyzed independently, but the samples were also analyzed together, to determine the seasonal changes to the taxa. Seasonal variation was analyzed by cross comparing the four sampling points, to identify the changes in insect abundance and diversity.

The Shannon's diversity index was also calculated for the data. It is a unitless value that measures the diversity in a given data set and informs whether diversity is higher in sample A compared to Sample B. The higher the value, the more diverse it is. Shannon's index can be used to see if there are diversity differences in data sets, in this study the field plots. It does not tell that something is diverse or not, it simply allows comparison. The formula for Shannon's index is H = $\sum_{i=1}^{S} pi ln pi$

Where:

H = the Shannon diversity index

Pi = fraction of the entire population made up of species i, here all individuals in their respective plots (Cabbage, faba bean and strip-cropped)

ln = natural logarithm

S = numbers of species encountered

$\sum$ = sum from species 1 to species S

4. RESULTS

4.1 INSECT DIVERSITY AND ABUNDANCE

The total number of identified insects from the four sampling periods was 4785 (table 3.) The largest taxon was the Staphylinidae (family), it comprised 40% of all the insects. The second largest was the Carabidae with 20,9%, and the third largest was the Aranae (order) with 18,2%. Among the Carabidae the most represented genus was the *Pterostichus* with 9,59% of all Carabidae (Figure 4).

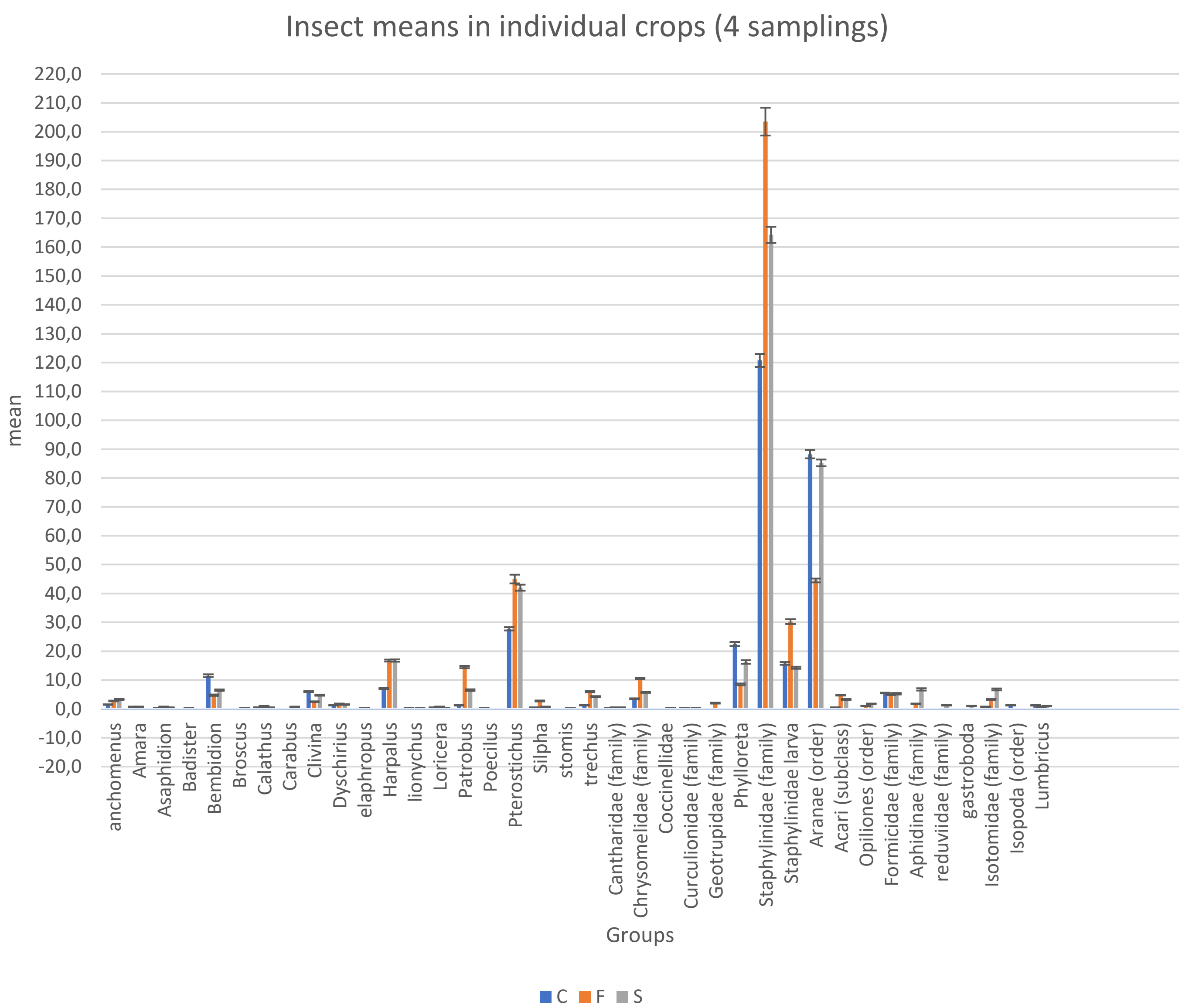

Figure 4. Mean number of each insect group per sampling (n=4). C stands for cabbage, F for

faba bean and S for strip-cropping. Error bars represent calculated standard error. Carabidae are taxons from *Anchomenus* to *Trechus*

Table 3. Total number and means of insects in the plots

Total number and means of insects				
	total	Cabbage	Faba bean	Strip-cropped
Total number	4785	1286	1888	1611
mean		322	472	403

Table 4. Total number and mean of Carabidae with standard error. Pooled data from all four samples (T1-T4)

Plot	Number of Carabids	Mean number	Standard error
Cabbage	243	11,6	5,8
Faba bean	402	19,1	9,4
Strip-crop	356	17	8,7

4.2. SAMPLING RESULTS

4.2.1 Results for all the 4 samplings (T1-T4)

During the entire sampling period (T1-T4), statistical significances in plot distributions were measured for Acari, Aphidinae, Aranae, Chrysomelidae*, Harpalus, Patrobus,* Staphylinidae and *Trechus* (tables 5-9).

For *Acari* a statistically significant distribution difference was measured between cabbage and faba bean plots (plots 1 and 2), where Acari were more abundant in the faba bean plot than the cabbage plot (*P* value 0,001).

For *Aphidinae* a statistically significant distribution difference was measured between cabbage and strip-cropped plots (plots 1 and 3), where *Aphidinae* were more abundant in the strip-cropped plot than the cabbage plot (*P* value 0,018).

For Aranae a statistically significant distribution difference was measured between faba bean-cabbage and faba bean-strip-cropped plots (plots 2 -1 and 2-3), where Aranae were more abundant in the faba bean plot than the cabbage plot (*P* value 0,008) and also, more abundant in faba bean plot than the strip-cropped plot (*P* value 0,004).

For Chrysomelidae a statistically significant distribution difference was measured between cabbage and faba bean plots (plots 1 and 2), where Chrysomelidae were more abundant in the faba bean plot than the cabbage plot (*P* value 0,003).

For *Harpalus* a statistically significant distribution difference was measured between cabbage-faba bean and cabbage-strip-cropped (plots 1-2 and 1-3), where *Harpalus* were more abundant in the faba bean plot than the cabbage plot (*P* value 0,007) and also, more abundant in the strip-cropped plot than the cabbage plot (*P* value 0,006).

For *Patrobus* a statistically significant distribution difference was measured between cabbage and faba bean plots (plots 1 and 2), where *Patrobus* were more abundant in the faba bean plot than the cabbage plot (*P* value 0,001).

For Staphylinidae a statistically significant distribution difference was measured between cabbage and faba bean plots (plots 1 and 2), where *Staphylindae* were more abundant in the faba bean plot than the cabbage plot (*P* value 0,031).

For *Trechus* a statistically significant distribution difference was measured between cabbage and faba bean plots (plots 1 and 2), where *Trechus* were more abundant in the faba bean plot than the cabbage plot (*P* value 0,027).

Table 5. Results for Kruskal Wallis independent samples analysis of the pooled data from all time points (Figure 4.) Statistically significant results are colored in yellow.

	Plot comparison				
Group	Plot 1	median	plot 2	median	*P value*
Acari	Cabbage	0	Strip	0	0,356
	Cabbage	0	Faba	1	0,001
	Strip	0	Faba	1	0,104
Aphidinae	Cabbage	0	faba	0	0,378
	Cabbage	0	strip	0	0,018
	faba	0	strip	0	0,661
Aranae	faba	6	cabbage	9	0,008
	faba	6	strip	10	0,004
	cabbage	9	strip	10	1,000
Chrysomelidae	Cabbage	0	Strip	0	0,901
	Cabbage	0	Faba	1	0,003
	Strip	0	Faba	1	0,068
Harpalus	Cabbage	1	faba	2	0,007
	Cabbage	1	strip	1	0,006
	faba	2	strip	1	1,000
Patrobus	Cabbage	0	Strip	0	0,134
	Cabbage	0	Faba	1	0,001
	Strip	0	Faba	1	0,062
Staphylinidae	Cabbage	12	Strip	18	0,204
	Cabbage	12	Faba	17	0,031
	Strip	18	Faba	17	1,000
Trechus	Cabbage	0	Strip	0	0,281
	Cabbage	0	Faba	0	0,027
	Strip	0	Faba	0	1,000

4.2.2. Results for T1

During the first sampling (T1), statistically significant differences in plot distributions were measured for *Clivina, Harpalus, Pterostichus,* Staphylinidae and Staphylinidae larva (table 6. and figure 5.)

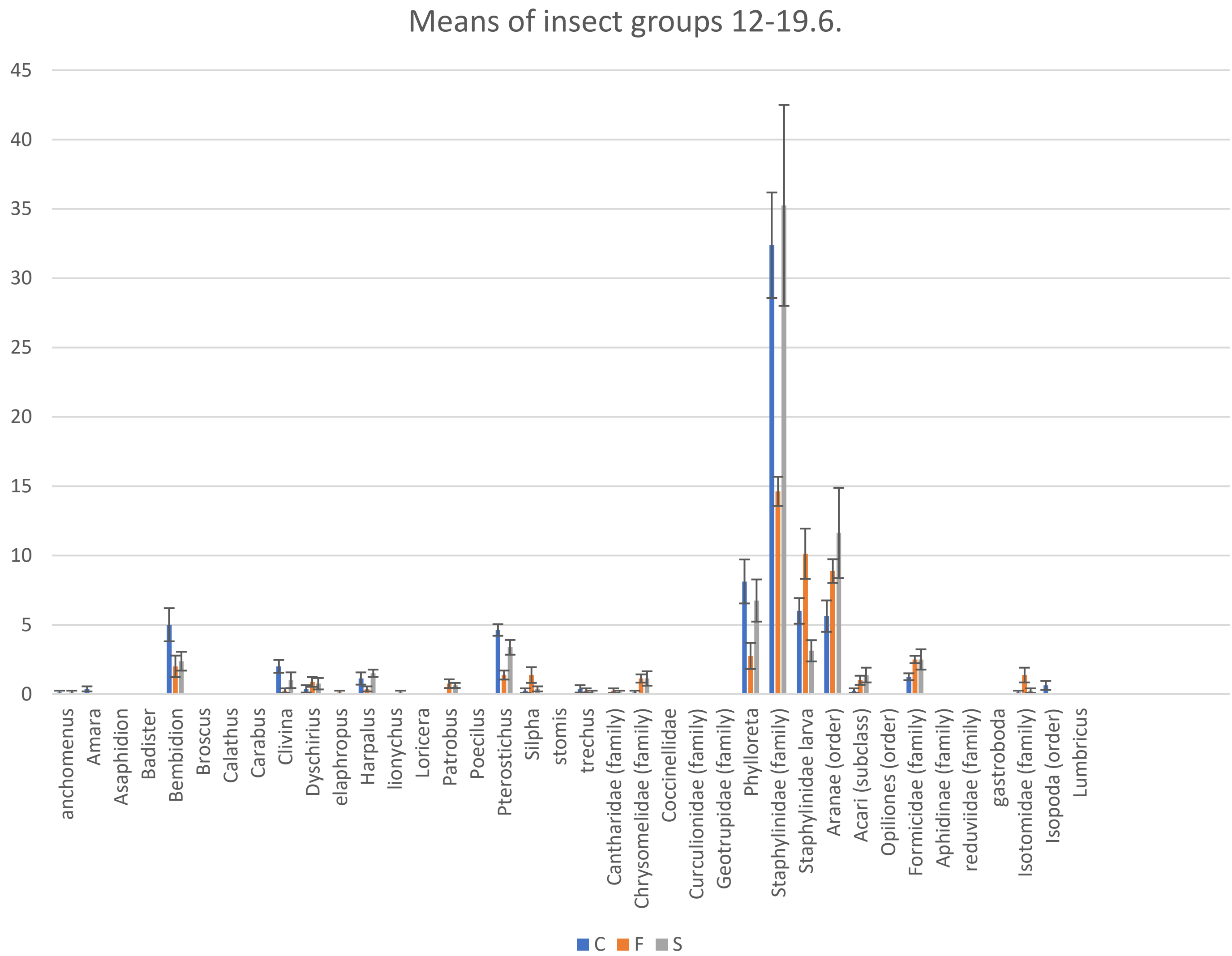

Figure 5. Mean numbers of insects from the 1st trapping period (T1). C stands for cabbage, F for faba bean and S for strip-cropping. Error bars represent calculated standard error. Carabidae are represented by the taxa from *Anchomenus* to *Trechus.*

The statistically significant results are explained below.

For *Clivina,* a statistically significant distribution difference was measured between faba bean and cabbage plots (plots 2 and 1), where *Clivina* were more abundant in the cabbage plot than the faba bean plot (*P* value 0,023).

For *Harpalus,* a statistically significant distribution difference was measured between faba bean and strip-cropped plots (plots 2 and 3), where *Harpalus* were more abundant in the strip-cropped plot than the faba bean plot (*P* value 0,011).

For *Pterostichus,* a statistically significant distribution difference was measured between faba bean and cabbage plots (plots 2 and 1), where *Pterostichus* were more abundant in the cabbage plot than the faba bean plot (*P* value 0,001).

For Staphylinidae, a statistically significant distribution difference was measured between faba bean-cabbage and faba bean-strip-cropped plots (plots 2-1 and 2-3), where Staphylinidae were more abundant in the strip-cropped plot than the faba bean plot (*P* value 0,038) and also the cabbage plot than the faba bean plot (*P* value 0,028), making the faba bean plot least inhabited.

For Staphylinidae larvae, a statistically significant distribution difference was measured between strip-cropped and faba bean plots (plots 3 and 2), where Staphylinidae larva were more abundant in the faba bean plot.

Table 6. Results for Kruskal Wallis independent samples analysis of T1. Statistically significant results are colored in yellow

	Plot comparison				
Group	Plot 1	median	plot 2	median	*P value*
Clivina	faba	0	strip	0	1,000
	faba	0	cabbage	2	0,023
	strip	0	cabbage	2	0,222
Harpalus	faba	0	cabbage	1	0,353
	faba	0	strip	1	0,011
	cabbage	1	strip	1	0,551
Pterostichus	faba	1	strip	3	0,570
	faba	1	cabbage	4,5	0,001
	strip	3	cabbage	4,5	0,503
Staphylinidae	faba	15,5	strip	32,5	0,038
	faba	15,5	cabbage	31,5	0,028
	strip	32,5	cabbage	31,5	1,000
Staphylinidae larva	strip	3,5	cabbage	6	0,305
	strip	3,5	faba	10,5	0,007
	cabbage	6	faba	10,5	0,464

4.2.3 Results for T2

During the second sampling period (T2), statistically significant differences in plot distributions were observed for *Acari, Aphidinae,* Aranae, Chrysomelidae, *Pterostichus* and Staphylinidae (Table 7. and Figure 6.)

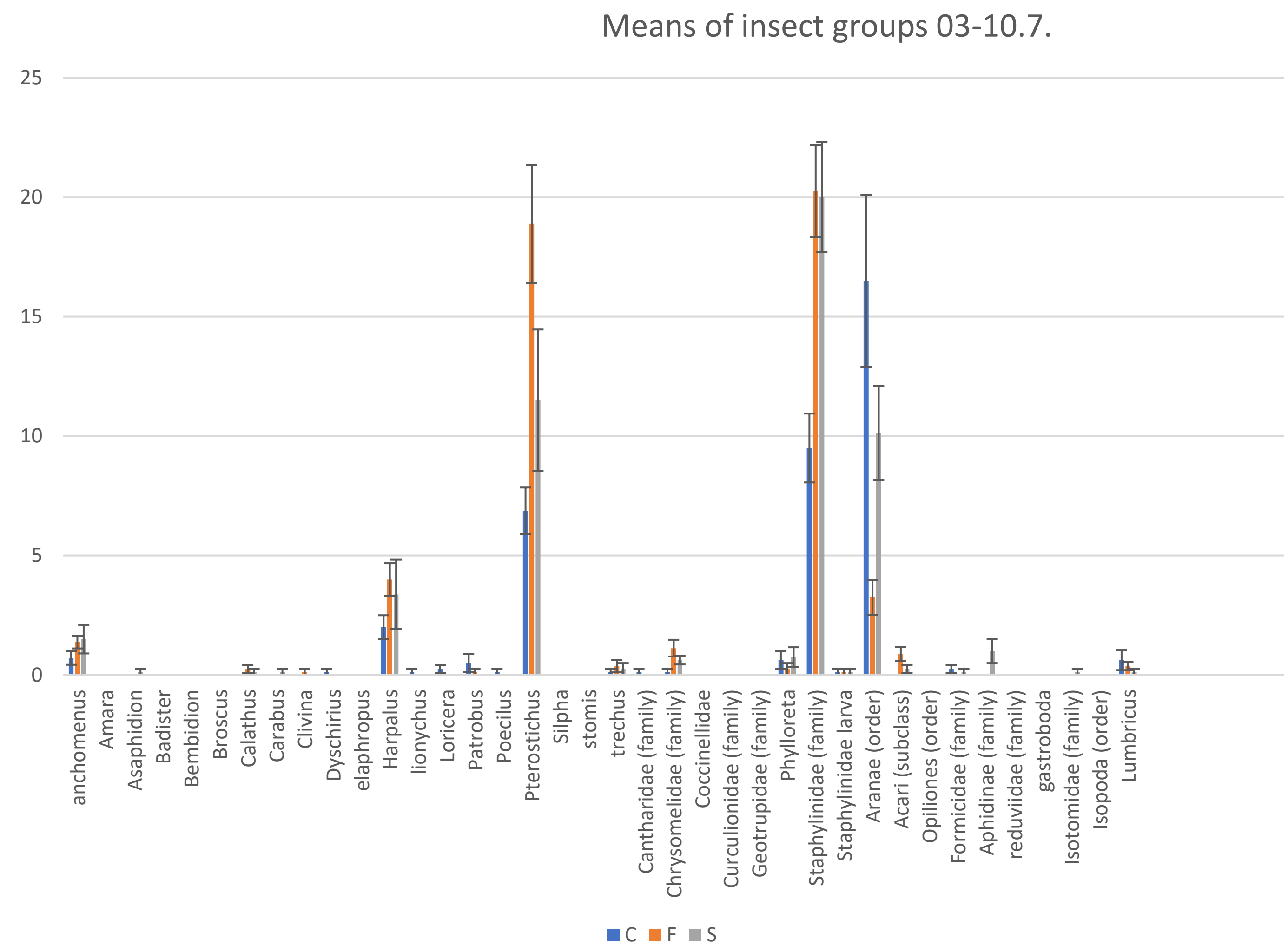

Figure 6. Means of insect numbers from the 2nd trapping period (T2). C stands for cabbage, F for faba bean and S for strip-cropping. Error bars represent calculated standard error. Carabidae are represented by the taxa from *Anchomenus* to *Trechus.* The statistically significant results are explained below.

For *Acari,* a statistically significant distribution difference was measured between cabbage and faba bean plots (plots 1 and 2), where *Acari* were more abundant in the faba bean plot than the cabbage plot (*P* value 0,018).
For *Aphidinae,* a statistically significant distribution difference was measured between cabbage-strip-cropped and faba bean-strip-cropped plots (plots 1-3 and 2-3), where *Aphidinae* were more abundant in the strip-cropped than cabbage plot (*P* value 0,027) and also the strip-cropped plot than the faba bean plot (*P* value 0,027).
For Aranae, a statistically significant distribution difference was measured between faba bean and cabbage plots (plots 2 and 1), where Aranae were more abundant in the cabbage plot than the faba bean plot (*P* value 0,005).
For Chrysomelidae, a statistically significant distribution difference was measured between cabbage and faba bean plots (plots 1 and 2), where Chrysomelidae were more abundant in the faba bean plot than the cabbage plot (*P* value 0,025).

Table 7. Results for Kruskal Wallis independent samples analysis of T2. Statistically significant results are colored in yellow.

	Plot comparison				
Group	Plot 1	median	plot 2	median	*P* value
Acari	cabbage	0	strip	0	0,988
	cabbage	0	faba	1	0,018
	strip	0	faba	1	0,299
Aphidinae	cabbage	0	faba	0	1,000
	cabbage	0	strip	0,5	0,027
	faba	0	strip	0,5	0,027
Aranae	faba	3	strip	9	0,067
	faba	3	cabbage	18,5	0,005
	strip	9	cabbage	18,5	1,000
Chrysomelidae	cabbage	0	strip	1	0,248
	cabbage	0	faba	1	0,025
	strip	1	faba	1	1,000
Pterostichus	cabbage	7	strip	11	0,791
	cabbage	7	faba	16	0,004
	strip	11	faba	16	0,114
Staphylinidae	cabbage	7,5	strip	22,5	0,016
	cabbage	7,5	faba	20,5	0,011
	strip	22,5	faba	20,5	1,000

4.2.4 Results for T3

During third sampling period (T3), statistically significant differences in plot distributions were measured for Aranae, *Clivina*, *Harpalus*, Isotomidae*, Patrobus, Phyllotreta,* Staphylinidae *and Trechus* (Table 8. and figure 7.)

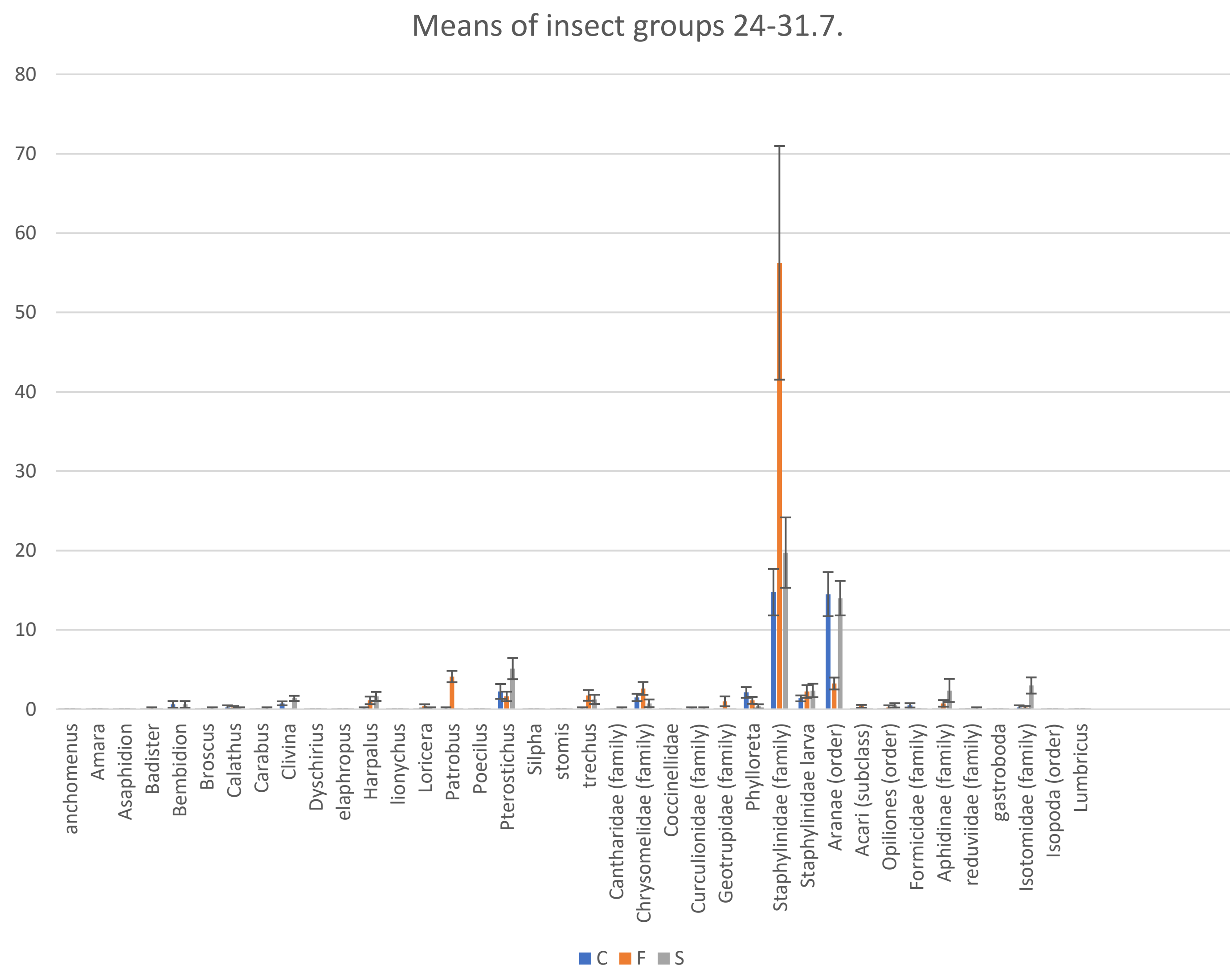

Figure 7. Means of insect numbers from the 3rd trapping period (T3). C stands for cabbage, F for faba bean and S for strip-cropping. Error bars represent calculated standard error. Carabidae are represented by taxa from *Anchomenus* to *Trechus.*

Statistically significant results are explained below.

For Aranae, a statistically significant distribution difference was measured between faba bean-cabbage and faba bean-strip-cropped plots (plots 2-1 and 2-3), where Aranae were more abundant in the cabbage plot than the faba bean plot (*P* value 0,005) and also, the strip-cropped plot than the faba bean plot (*P* value 0,006).
For *Clivina,* a statistically significant distribution difference was measured between faba bean and strip-cropped plots (plots 2 and 3), where *Clivina* were more abundant in the strip-cropped plot than the faba bean plot (*P* value 0,002).
For *Harpalus,* a statistically significant distribution difference was measured cabbage and strip-cropped plots (plots 1 and 3), where *Harplaus* were more abundant in the strip-cropped plot than the cabbage plot (*P* value 0,034).
For Isotomidae, a statistically significant distribution difference was measured between cabbage-strip-cropped and faba bean-strip-cropped plots (plots 1-3 and 2-3), where Isotomidae were more abundant in the strip-cropped plot than the cabbage plot (*P* value 0,015) and also, the strip-cropped plot than the faba bean plot (*P* value 0,031).
For *Patrobus,* a statistically significant distribution difference was measured between strip-cropped-faba bean and cabbage-faba bean plots (plots 2 and 3), where *Patrobus* were more abundant in the faba bean plot than the strip-cropped plot (*P* value 0,001) and also, the faba bean plot than the cabbage plot (*P* value 0,001).
For *Phyllotreta,* a statistically significant distribution difference was measured between strip-cropped and cabbage plots (plots 3 and 1), where *Phyllotreta* were more abundant in the cabbage plot (*P* value 0,04).
For Staphylinidae, a statistically significant distribution difference was measured between cabbage-faba bean and strip-cropped-faba bean plots (plots 1-2 and 3-2), where Staphylinidae were more abundant in the faba bean plot than the cabbage plot (*P* value 0,004) and also, the faba bean plot than the strip-cropped plot (*P* value 0,04).
For *Trechus,* a statistically significant distribution difference was measured between cabbage and faba bean plots (plots 1 and 2), where *Trechus* were more abundant in the faba bean plot than the cabbage plot (*P* value 0,027).

Table 8. Results for Kruskal Wallis independent samples analysis of T3. Statistically significant results are colored in yellow

	Plot comparison				
Group	Plot 1	median	plot 2	median	*P value*
Aranae	faba	3	strip	15	0,006
	faba	3	cabbage	13	0,005
	strip	15	cabbage	13	1,000
clivina	faba	0	cabbage	1	0,096
	faba	0	strip	1	0,002
	cabbage	1	strip	1	0,607
Harpalus	cabbage	0	faba	1	0,173
	cabbage	0	strip	1	0,034
	faba	1	strip	1	1,000
Isotomidae	cabbage	0	faba	1	1,000
	cabbage	0	strip	2,5	0,015
	faba	0	strip	2,5	0,031
Patrobus	strip	0	cabbage	0	1,000
	strip	0	faba	4,5	0,001
	cabbage	0	faba	4,5	0,001
Phyllotreta	strip	0	faba	1	0,558
	strip	0	cabbage	1,5	0,040
	faba	1	cabbage	1,5	0,745
Staphylinidae	cabbage	12	strip	17,5	1,000
	cabbage	12	faba	46	0,004
	strip	17,5	faba	46	0,040
Trechus	cabbage	0	strip	1	0,192
	cabbage	0	faba	1,5	0,027
	strip	1	faba	1,5	1,000

4.2.5 Results for T4

During fourth sampling (T4), statistically significant differences in plot distributions were measured for *Formicidae, Harpalus, Patrobus,* Staphylinidae and Staphylinidae larva (Table 9. and Figure 8.)

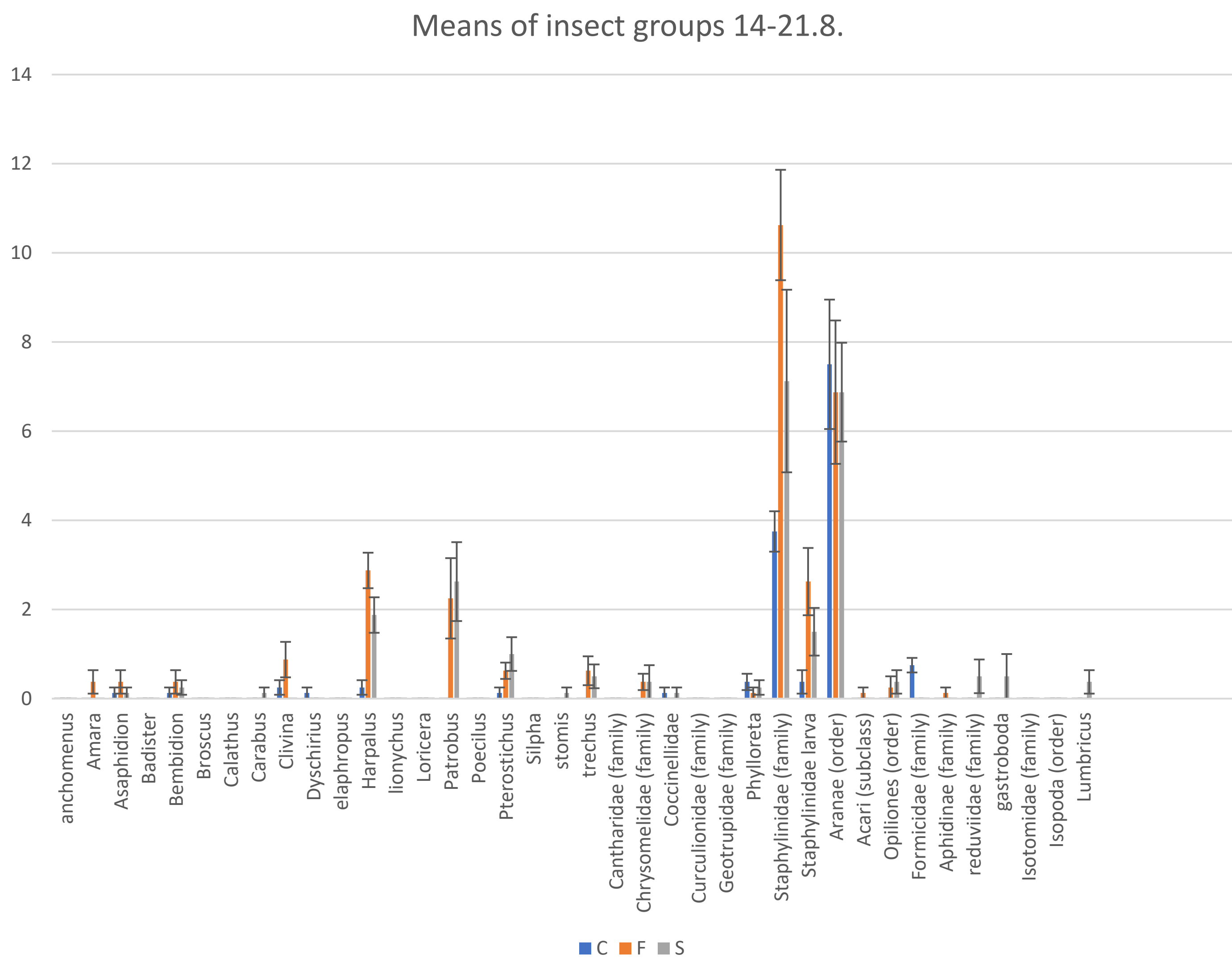

Figure 8. Means of insect numbers from the 4th trapping period (T4). C stands for cabbage, F for faba bean and S for strip-cropping. Error bars represent calculated standard error. Carabidae are represented by taxa from *Anchomenus* to *Trechus.*
Statistically significant results are explained below.

For *Formicidae,* a statistically significant distribution difference was measured between faba bean-cabbage and faba bean-strip-cropped plots (plots 2-1 and 3-1), where *Formicidae* were more abundant in the cabbage plot than the faba bean plot (*P* value 0,002) and also, the cabbage plot than the strip-cropped plot (*P* value 0,002).

For *Harpalus,* a statistically significant distribution difference was measured between cabbage-strip-cropped and cabbage-faba bean plots (plots 1-3 and 1-2), where *Harpalus* were more abundant in the strip-cropped plot than the cabbage plot (*P* value 0,029) and also, the faba bean plot than the cabbage plot (*P* value 0,001).

For *Patrobus* a statistically significant distribution difference was measured between cabbage-faba bean and cabbage-strip-cropped plots (plots 1-2 and 1-3), where *Patrobus* were more abundant in the faba bean plot than the cabbage plot (*P* value 0,028) and also, the strip-cropped plot than the cabbage plot (*P* value 0,013).

For Staphylinidae a statistically significant distribution difference was measured between cabbage and faba bean plots (plots 1 and 2), where Staphylinidae were more abundant in the faba bean plot than the cabbage plot (*P* value 0,03).

For Staphylinidae larvae, a statistically significant distribution difference was measured between cabbage and faba bean plots (plots 1 and 2), where Staphylinidae larva were more abundant in the faba bean plot than the cabbage plot (*P* value 0,039).

Table 9. Results for Kruskal Wallis independent samples analysis of T4. Statistically significant results are colored in yellow

	Plot comparison				
Group	Plot 1	median	plot 2	median	*P value*
Formicidae	faba	0	strip	0	1,000
	faba	0	cabbage	1	0,002
	strip	0	cabbage	1	0,002
Harpalus	cabbage	0	strip	1,5	0,029
	cabbage	0	faba	2,5	0,001
	strip	1,5	faba	2,5	0,540
Patrobus	cabbage	0	faba	1	0,028
	cabbage	0	strip	2	0,013
	faba	1	strip	2	1,000
Staphylinidae	cabbage	4	strip	5,5	0,465
	cabbage	4	faba	10,5	0,003
	strip	5,5	faba	10,5	0,171
Staphylinidae *larva*	cabbage	0	strip	1,5	0,404
	cabbage	0	faba	2,5	0,039
	strip	1,5	faba	2,5	0,965

4.2.6 Summary

Table 10. Summary of statistically significant test results among the sampling points

	T1	T2	T3	T4
Acari		1-2 P 0,018		
Aphidinae		1-3 P 0,027 2-3 P 0,027		
Aranae		2-1 P 0,005	2-3 P 0,006 2-1 P 0,005	
Chrysomelidae		1-2 P 0,025		
Clivina	2-1 P 0,023		2-3 P 0,002	
Formicidae				2-1 P 0,002 3-1 P 0,002
Harpalus	2-3 P 0,011		1-3 P 0,034	1-3 P 0,029 1-2 P 0,001
Isotomidae			1-3 P 0,015 2-3 P 0,031	
Patrobus			3-2 P 0,001 1-2 P 0,001	1-2 P 0,028 1-3 P 0,013
Phyllotreta			3-1 P 0,040	
Pterostichus	2-1 P 0,001	1-2 P 0,004		
Staphylinidae	2-3 P 0,038 2-1 P 0,028	1-3 P 0,016 1-2 P 0,011	1-2 P 0,004 3-2 P 0,040	1-2 P 0,003
Staphylinidae larva	3-2 P 0,007			1-2 P 0,039
Trechus			1-2 P 0,027	

4.3 DIVERSITY

To quantify diversity of the sampled insects, Shannon's diversity index was calculated for the three study plots.

The index was calculated for the pooled data across all time points.
The strip-cropped plot had the greatest diversity among the three plots, faba bean was second and cabbage had the lowest diversity.

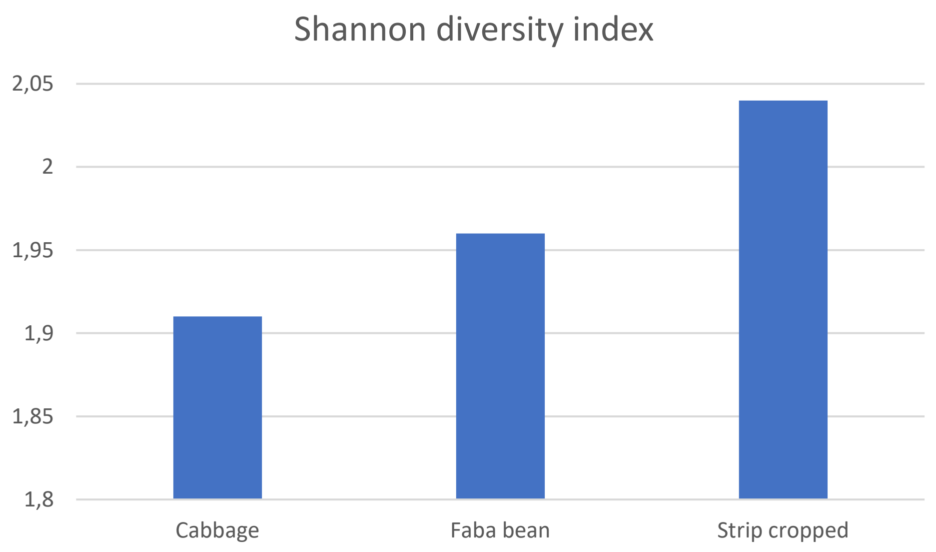

Figure 9. Shannon diversity index from the pooled data of all 4 time points

5. Discussion

5.1 EFFECTS OF STRIP CROPPING

5.1.1 Comparing strip-cropping and monocultures

Predatory Carabids were most abundant in the faba bean plot, and it appears that the effect could have carried over to the strip-cropped plot. McCabe et al. (2017) found that flowering strips bordering a monoculture crop field increased the number of Carabid beetles, compared to a monoculture without the strips, which is in common with our observation of a higher number of Carabids in the strip-cropped plot than the cabbage monoculture. Asiry (2013) found that intercropping faba beans and wheat increased abundance of predatory *Araneae,* Staphylinidae*,* Carabidae and *Chrysopidae* in organic systems, but this also increased the number of herbivorous insects. The increase in predatory insects is in line with the results of this study, but due to the small sample size of herbivorous insects, which were not the target of of the pitfall trapping, no conclusions can be drawn for them.

5.1.2 Comparison of cabbage and faba bean monocultures

Further evidence for faba bean's effects on insect assemblages comes from the results of the statistical analysis of plot comparison. Eight statistically significant results were found for insect abundances among the plots. Comparing the sole effect of crop selection, that is a comparison of the cabbage and faba bean plots, only *Aranae* had a higher abundance in the cabbage plot than the faba bean plot.

Further studies are needed to confirm if faba bean consistently offers the ecosystem services shown in these results. Faba bean has already been shown to offer ecosystem services by symbiotically fixating nitrogen from the atmosphere to the soil and into a plant usable form (Köpke et al., 2009). If findings in this study can be replicated and hold true, faba bean has the potential to be a vital crop in biological pest control and in lowering fertilization dependency.

Insect activity is seasonal, which could explain why statistically significant results were not found throughout the sampling period, except for with the Staphylinidae. The period when insects are active often corresponds to the time when their host plant is most nutritious, or has the lowest defenses against insect feeding (Schoonhoven et al., 2006). This may explain some of the differences in observations between cabbage and faba bean monocultures.

Further evidence for seasonality of insects comes from how the numbers of the insects varied between different time points. Knowing the peak seasons of desirable and undesirable insects helps to plan strip-cropped systems to achieve maximum benefits with pest control.

5.1.3 Natural enemy hypothesis

The high number of insects in the faba bean plot, and possibly in the strip-cropped plot due to the presence of faba bean, could mean that the "natural enemy" hypothesis is validated. This is due to the possibility that faba bean may have increased the number of insects in the strip-cropped plot, and because the majority of identified insect groups were predatory insects (Figure 4, Table 3. and Table 4.) This is especially true of the largest group of insects, the Staphylinidae.

The verification of the natural enemies- hypothesis is in line with previous studies. Andow 1991, performed a literature review of 209 studies on comparing abundance of pest insects in monocultures and strip-cropped systems. Natural enemy populations in intercropped systems were higher in 53% of the studies and lower in 9% of the studies. However, in this study increased numbers of natural enemies in the strip-cropped plot, are only statistically significant for the Aranae and *Harpalus* (table 5).

5.1.4 Trap crop hypothesis

A high number of insects in the faba bean plot could also mean that faba bean acted as a trap crop. However, the number of herbivorous insects was low throughout the experiment, and while significant results in favor of faba bean were found for herbivorous insects as well, no clear conclusions on faba bean's effect on herbivorous insects can be drawn due to the low sample size. Smith et al., (2013) experimented on faba bean's effectiveness as a trap crop. They intercropped faba bean with snow pea and found that faba bean did not act as a trap crop, instead it increased the amount of *Thripidaes* in the intercropped system. *Thripidaes* are capable of flight and it could be that they use faba bean for nutrition, or that because flying insects can travel further and faster, trap cropping does not perform as well against them. This study was also conducted in Guatemala, which has a very different climate and insect fauna to Finland.

5.2 EXPERIMENTAL SETUP

The test site was 240m^2 in size and the distance between fields was 50 meters. Although it is a significant distance between plots, it does not rule out random movement of insects between plots. A larger test site could have yielded different results. Also, four sampling points may have been too few to properly sample the field. The study could have benefitted from more than one replicate of each plot, where there could have also been variation on the placements of the crops, as it has been shown that crop width can affect the results. It is also advisable to replicate these kinds of studies over several years, although that was not possible within the framework of this thesis.

Trapping did, however, yield a high number of insects, 4785 in total (table 3). This suggests that the sample size was adequate to draw reliable results for most insect groups, including the Carabids.

In this study we only used one combination of crops, and the combination of crops has been shown to affect the effectiveness of strip-cropping in improving insect diversity (Caballero et al., 2004). The faba bean plot had the highest total number of insects and it is possible that the presence of faba bean in the strip-cropped plot increased the insect numbers in that plot, due to edge effects and added niches.

5.3 ABIOTIC FACTORS

Summer and spring of 2018 saw record-breaking high temperatures that exceeded 30 degrees Celsius for extended periods of time, and averaged above normal and with less than normal rainfall (table 11). Bishop et al., (2016) conducted a study on how heat stress affects faba beans. They measured an "increase in the pollinator-dependency of experimental plants with heat stress, from 16% dependency at control temperatures, to 53% dependency in plants exposed to 30 °C treatment". During summer of 2018, temperatures reached this 30 °C threshold, and this could have affected the performance of the faba beans in the experiment. Insects and plants interact with one another, for example through feeding and oviposition and through plants offering insects living spaces and shelter. Changes in plants can have changes in insect assemblages dependent on the plants, such as herbivorous insects, and through herbivorous insects the effects can carry over to predatory insects dependent on their prey.

Through these interactions, the hot summer could have altered the results, but it also offers interesting insight into how insects might respond to elevated temperatures.

These findings, however, hint that strip-cropping can have a positive effect, and that selection of the crops may be important. More studies are needed to get a better understanding of how strip-cropping affects the complex interactions of organisms in the field and these findings give grounds for future studies on the subject.

Table 11. weather data of the summer 2018 at Jyväskylä observation point
Source: Finnish meteorological institute

Month	Average temperature ºC, 2018	Average temperature ºC 1981-2010	Average rainfall mm, 2018	Average rainfall mm,1981-2010
May	13,7	8,9	22	44
June	14,1	13,7	66	67
July	20,3	16,5	27	84
August	16,6	14,1	39	78

6. CONCLUSIONS

Original hypotheses were, that strip-cropping could increase insect diversity and attract more predatory insects to the field and lower the number of herbivorous insects. Strip-cropping did increase the diversity of the insects and the strip-cropped plot was the most diverse plot (Figure 9.) Strip-cropping also increased the number of predatory Aranae and *Harpalus* in the strip-cropped field and the results were statistically significant.

Comparing each time point (T1-T4) independently did not yield clear evidence that seasonal changes during summer would affect insects' host plant or predatory orientation. A more likely explanation for seasonal changes in insect abundances among the plots is that insects themselves are seasonal, each having different activity periods during the summer time. The active time often corresponds to the time when host-plants are most nutritious, or prey is most abundant (Schoonhoven et al., 2006).

Comparing all time points together showed evidence that ground dwelling insects oriented towards the faba bean plot (table 5), which can be seen in the highest number of counted insects in that plot (table 3 and 4). The high number of recorded insects in the faba bean plot could also mean, that faba bean increased the number of insects in the strip-cropped plot. The increased number of insects on the strip-cropped plot could increase functional diversity and thus promote the presence of natural enemies. For example, it seems, that presence of cabbage in the strip-cropped plot increased the number of predatory Aranae and presence of faba bean in the strip-cropped plot increased the number of predatory Staphylinidae. However, only for the Aranae are the results statistically significant.

The results of this study give grounds for future studies on how different crop combinations affect the insect assemblages. Abnormal weather conditions during the sampling both give insight into how in the future with rising temperatures insect assemblages could cope, but more studies are also needed to assess how the insects respond to different crop combinations under normal weather conditions.

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