Intercropping oats with annual clovers

– effects on yields and aspects of biodiversity

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Swedish University of Agricultural Sciences, SLU
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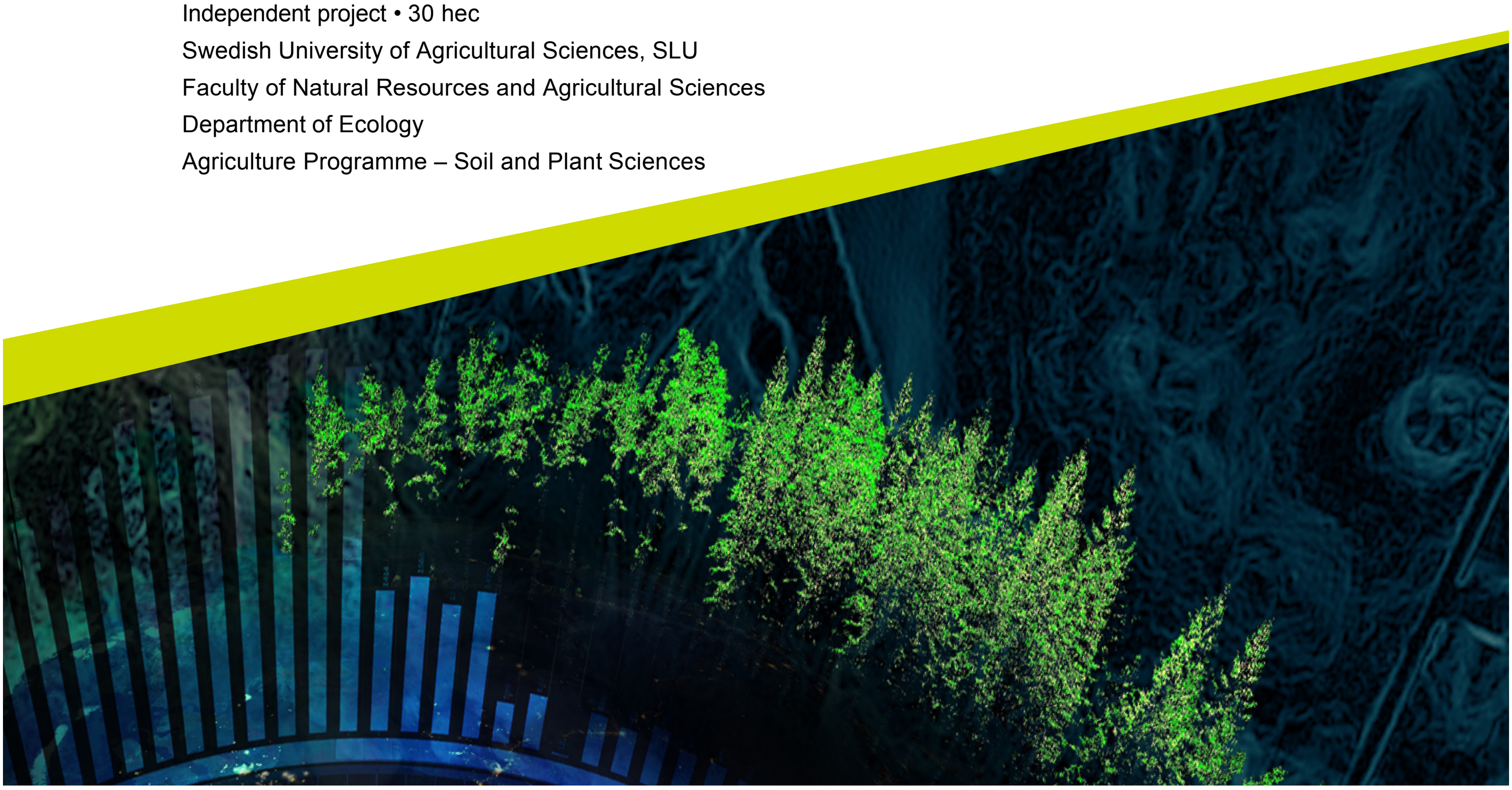

Intercropping oats with annual clovers – effects on yields and aspects of biodiversity

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Popular science summary

Imagine that you are a bumblebee flying over the landscape in search for nectar from flowers to ease your hunger. A hundred years ago, the landscape used to have a mosaic pattern with small scattered fields and pastures. A diverse landscape that makes room for many kinds of life, such as animals and plants, which had plenty of food for a starving bumblebee. But for humans, growing crops for food in these landscapes was very time consuming and the yields relatively low. Now, in your search for food, it takes you a longer time to find flowers and you have to fly over larger distances. This is because the landscapes have undergone big changes to ease the growing of food for humans. Small fields have been merged together to create larger ones, covered one after another by one single plant species grown to feed humans and livestock. The bridges once needed for passing over ditches dividing small fields, when moving workers and machineries from one field to another, is now replaced by pipes burrowed down into the soil leading away redundant water from the fields. When pest insects eat of the crops or unwanted weed plants appear in the field, chemicals are used to kill them. Chemicals, which might potentially poison you or the plants carrying pollen and nectar that you feed on. The landscapes have become simple in appearance, with no room left for diversity and the life that depend on a diverse landscape. Your bumblebee community is suffering from lacking food in a landscape where mostly cereals such as oats are grown, leaving little room for wild flowers with nectar to feed from.

That is why this thesis has investigated whether oats grown to provide us food such as porridge, can be grown together with flowering clovers as food for bumblebees. If bumblebee communities are healthy and strong, they in turn pollinate crop plants such as bean flowers and provide us with beans. A diverse landscape can also support natural predators that prey on insects damaging oat plants. I found that this indeed is a win-win situation. The fields containing a mixture of clover and oat plants had a higher abundance of bumblebees and still got the same oat yield as the fields only containing oats. Bumblebees do not need to starve for us to get food!

Abstract

The use of fertilizers, pesticides and herbicides has contributed to greatly increase the crop yields per hectare. Humanity has become reliant on artificial inputs overshadowing usage of resources from ecosystem services that we continue to weaken further, by using agricultural practises decreasing landscape and species diversity. Before fertilizers and pesticides became available, farmers depended on ecosystem services such as pest control provided by natural enemies to pests and complementary crops in mixes competing with weeds. Today, ecosystem services are threatened e.g. by declining pollinator abundance important for crop yield and quality as well as loss of habitats for natural arthropod predators supporting pest control. Combining a main crop e.g. cereals for food production, together with a supportive under-sown crop in an intercropping system enhance the resource usage efficiency. At the same time, the under-sown crop support resilience of the cropping system itself as well as to surrounding ecosystems and thereby future food production. My aim was to evaluate the effects of under-sowing oats with a mixture of the annual clover species, *Trifolium incarnatum*, *T. resupinatum* and *T. squarrosum,* both during the intercropping phase and in the autumn when clovers continued to grow to prolong effects and the continuity of vegetation cover. The field study was located in the counties of Uppsala, Stockholm, Södermanland and Västmanland in Sweden. The intercropping effects on pollinator abundance, ground-dwelling arthropod predators, aphid predation, weed biomass and yield of both clover and oats were studied. The results showed a higher abundance of flower resources and higher pollinator abundance in intercrops compared to sole crops of oats, without reducing oats yield. No effect on natural predators, aphid predation or weeds could be found. Intercropping oats with a cover crop of annual *Trifolium* species helps to boost biodiversity, have no impact on cash crop yield quantity and keeps the soil covered.

Keywords: Intercropping, cover cropping, pollinators, natural predators, ground-dwelling arthropod predators, weeds, clover, oats

Preface

This master thesis was based on field experiments during the summer of 2020, exploring the effects on arthropod biodiversity by intercropping oats with annual clover species, as a part of a project led by Ola Lundin at the Department of Ecology at Swedish University of Agricultural Sciences (SLU). I have been delighted and thankful for the opportunity to work as a field assistant as well as writing my master thesis within this project. My supervisors Ola Lundin and Göran Bergkvist at SLU have continuously provided me opportunities to deepen my knowledge and improve my analytical ability. Thank you! Stort tack!

I have been studying at SLU for seven years now. After the first two years I got a Higher Education Diploma in Agricultural and Rural Management, followed by agronomy studies for five years within the Agriculture program – soil and plant sciences. It has been a fantastic journey with lots of very interesting and inspiring lectures! During these years, I have also had the opportunity to work as a field assistant in four different research projects led by researchers within either the Department of Plant Protection Biology or the Department of Ecology at SLU. I am very grateful and humble by the all the knowledge researchers and lecturers have past on to me during these years. Finally, I also want to thank my partner Jens Hallman and Geraldo Caseiro Rodrigues for support e.g. lending a hand in field work in times of high workload during the autumn of 2020!

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1. Introduction

Fertilizers and pesticides, as parts of the green revolution, have greatly increased the crop yields per hectare and boosted breeding for high yielding varieties (Naylor 1996). But its usage has come with a high cost of impacting the agro-ecosystem functioning as well as the surrounding nature, e.g. arthropod poisoning by pesticides (Cardoso *et al.* 2020), reducing abundance and diversity of pollinators (Goulson *et al.* 2005), decreasing weed plant diversity (Meyer *et al.* 2013) and causing redundant nutrients to escape to surrounding bodies of water, setting ecosystems out of balance (Ansari & Gill 2014; SJV, 2013). The long-term usage increases pesticide and herbicide resistance facilitated through its co-evolution with pests and weeds respectively (Leadbeater 2014). The cropping system has become altered to fit high inputs, which efficiency has been reached by large field sizes (Lin & Huang 2019) and the same crops reoccurring one by one, year after year. Alternative managements to improve and sustain yields are needed, which do not further diminish biodiversity and threaten ecosystem resilience (Rockström, *et al.* 2009) and thereby food production. In order to handle decreasing biodiversity, a regain of diversification of the agricultural landscape is needed (Tamburini *et al.* 2020). Enhancing diversification within cropping systems is most commonly done by crop rotation where crop species are grown in an altering order that prevents pests and diseases (e.g. Mazzilli *et al.* 2016 and Flower *et al.* 2019). Before artificial fertilizers became available to farmers, apart from rotate crops it was also common to mix crop species within the same field to add nitrogen to cropping system (Hauggaard-Nielsen *et al*. 2008; Heap 2014). Intercropping techniques, where more than one crop is grown at the same time in the same place, is a way of enhancing diversification within the fields and thereby provide valuable ecosystem services.

If using a combination of an old system based on intercropping together with the elevated knowledge and technology we have today, we can support ecosystem functioning and at the same time food production. Intercropping could provide a higher resilience of the agro-ecosystem by increasing biodiversity (Malézieux *et al.* 2009) and thereby create a higher flexibility of the agro-ecosystem to manage climate change (IAASTD 2009). Intercropping systems have also been shown to reduce soil respiration and thereby carbon emissions (Qin *et al.* 2013).

2. Aim

By under-sowing oats with a mixture of annual clover (*Trifolium*) species I sought to find out if it affects oat crop yield and arthropod diversity and abundance. The effects of intercropping a mix of *Trifolium incarnatum*, *T. resupinatum* and *T. squarrosum*, with oats (*Avena sativa*) were examined. The applicability of these annual clovers in an intercropped system was studied, as well as the biodiversity effects on ground-dwelling arthropod predators and pollinators. The applicability was estimated by measuring 1) the emergence of plants of the clover species in oats, 2) the effect of clover species on weed cover and biomass and 3) the effect of clover on oats yield and nitrogen content. The effects on arthropod diversity were estimated by measuring a) the abundance of pollinators, b) the abundance of arthropod predators and c) the predation of aphids.

The clover species were studied as a unit that complement each other and have different characteristics in growth, development and flowering traits. The oats biomass and emergence of shoots of clover was measured in order to better understand the effects of intercropping clover in oats.

Hypotheses:

1. The weed coverage and weed biomass is lower in the intercrop compared to sole crop of oats.
2. The oat yield and nitrogen content is higher in the sole crop of oats than in the intercrop.
3. The abundance of pollinators is higher in the intercrop than in the sole crop of oats.
4. The abundance of natural predators is higher in the intercrop than in the sole crop of oats.
5. The aphid predation is higher in the intercrop than in the sole crop of oats.

3. Background

3.1. Agricultural landscapes

The main reason for decreasing abundance of arthropods, such as ground-dwelling predators and pollinators, is thought to be intensified agriculture (Persson & Smith 2013; Hallmann *et al.* 2017) causing habitat destruction by herbicides and habitat alteration and acidification caused by fertilizers (Cardoso *et al.* 2020). This causes shortage of food and nests both within the field and in its surroundings (Persson & Smith 2013). In non-cultivated grassland ecosystems, grass-clover mixtures are common (Bedoussac *et al.* 2015). However, the landscape mosaic pattern changes (Herbertsson *et al.* 2018) when agriculture intensifies and field borders disappear as fields are merged to increase management efficiency, reducing potential habitat availability for many arthropods (Persson & Smith, 2013). Simple landscapes that contain few semi-natural habitats, large homogenous fields and no permanent grassland, are limited in floral resources already by midsummer. The more complex landscapes have 30 times more floral resources and bumblebees, mainly due to species rich border zones and presence of pastures (Persson & Smith, 2013). The scattered semi-natural habitats still existing are very important to many arthropods for finding food and nests (Öckinger & Smith, 2007). Moreover, growing of flowering legumes for seed, e.g. clover seed production, has been declining with 90 % since 1940 (Rundlöf *et al.* 2014) and the areas of semi-natural pastures have been reduced by 97 % since 1850 in Sweden (SJV, 2009). The growing of fodder crops, generally relatively high in species diversity, and extensive managed grasslands have also been reduced (Persson & Smith 2013; Bommarco *et al.* 2012). Organic farms enhance the abundance of arthropod predators, but the species richness also depends on biotopes provided by the surrounding landscapes (Galloway *et al.* 2021). The characteristics of agro-ecosystem drivers acting upon arthropod abundance and diversity could be summarized as: vegetation diversity surrounding the field agro-ecosystem, permanence and food quality of crops in the field agro-ecosystem, isolation from natural vegetation and management intensity (Norris *et al.* 2017; Tscharntke *et al.* 2002).

3.2. Ecosystem services

Pollinators support several crop species (Benton 2006), e.g. both yield quality and quantity are improved by pollination of cash crops like *Brassica napus* L. (Bommarco *et al.* 2012), enhance yield quantity of field beans *Vicia faba* L. (Nätterlund, 2007) and is particularly important in seed production of legumes such as *T. pratense* L. (Lankinen & Ölund, 2013). Bumblebees are important pollinators that are consistent in their choice of flowers (Benton, 2006). About 40 species exist in Sweden (Söderström, 2017). They can forage in cold weather with light rain (Westphal *et al.* 2009), have a high diversity in tongue length among the species, which matches corolla depth of flower species (Goulson, 2010). This makes bumblebees more efficient pollinators than both honeybees and the shorter lived solitary bees. To get large pollination effects, large colonies are needed. To be able to get large bumblebee colonies, floral resources are needed through the colony life-time to ensure a large enough worker population to carry out the work (Riedinger *et al.* 2015) as well as to ensure new colonies the following year (Williams *et al.* 2012). If bumblebee queen larvae can be supported throughout the reproduction phase of bumblebee communities, there will be new queens to form new colonies the following year (Goulson *et al.* 2005; Westphal *et al.* 2009). The combination of crops without any nectar or pollen grown year after year and an ongoing merging of agricultural fields to large homogeneous units cause a decline in natural habitats e.g. the loss of field verges creates critical resource bottlenecks for arthropods (Schellhorn *et al.* 2015). The use of herbicides has decreased weed species diversity (Meyer *et al.* 2013), and thereby further reduced potential food sources for arthropods in fields.

Ground-dwelling arthropod predators, such as carabids (Carabidae), spiders (Araneae) and rove beetles (Staphylinidae), are important predators of common cereal pests, e.g. aphids and leafhoppers (Symondson *et al.* 2002). One of the most essential pests that they prey on, transmitting barley yellow dwarf virus in cereals, e.g. barley and oats, is the bird cherry-oat aphid *Rhopalosiphum padi* L. (Leather *et al.* 1989). The cereal yield has shown to be elevated by 51 % by the presence of ground-dwelling predators as carabids, spiders and rove beetles compared to field with no ground-dwelling predators (Östman *et al.* 2003). In several cases up to 70 % reduced abundance of aphids and leafhoppers have been found, together with reduction of yield damage by 50 % (Symondson *et al.* 2002). Ground-dwelling predators also impact the crop yield indirectly, without per se feeding on herbivores (Eubanks & Finke 2014). For instance, herbivores sharing the same predators can attract additional predators, predators can alter the feeding behaviour or movement of the herbivores and predators can alter herbivore metabolism by inducing stress. Most of the ground-dwelling predators overwinter in the field verges. In order to return to the field they have to find it as a suitable habitat, and the suitability is highly depending on the vegetation structure and presence of litter as determined by e.g., soil tillage practices (Landis *et al.* 2000).

Air contains 78 % nitrogen gas, but plants can only take up nutrients in the form of ions solved in the soil solution (Campbell *et al.* 2018). The nitrogen found solved in water comes from soil organic matter, soil particles, decaying plants, animals and other organisms (Campbell *et al.* 2018) and in agro-ecosystems they can also come from artificial fertilizers and other soil amendments (EUROSTAT, 2021). In addition, plants belonging to the Fabaceae family (legumes) can, with the help of symbiotic bacteria, fixate nitrogen from the air (Lewis *et al.* 2005). About 50 % of all nitrogen inputs to the agricultural soils have been estimated to come from nitrogen fixation by legumes used as animal fodder or for human consumption (Herridge *et al.* 2008). Legumes as the perennial clovers *Trifolium pratense* L. could fixate up to 375 kg N/yr and ha and *Trifolium repens* L. up to 545 kg N/yr and ha (Carlsson & Huss-Danell, 2003). Although the exact contribution is difficult to calculate (McKenna *et al.* 2018). Up to 42 % of the fixated nitrogen could be kept inside the root system (Peoples *et al.* 2012), and solved nitrogen can be easily lost through denitrification or leaching (McKenna *et al.* 2018). Several reports indicate that nitrogen fixation contributes 32-115 kg N /yr and ha, most includes a root factor but not all account for leaching losses (Iannetta *et al.* 2016). This means that the environmental conditions the year of study highly impact the results of any experiments measuring nitrogen fixation and uptake (McKenna *et al.* 2018). Taking all these potential losses in to account, it could mean that only 20-40 kg N/ha of legumes fixed by an annual legume grain crop might be available to the subsequent crop (McKenna *et al.* 2018), which is about the same amount as the natural mineralization process releasing nitrogen to the soil solution (SJV, 2020). The release of nitrogen from degrading legumes is a relatively slow process compared to the instant plant available nutrients of solved ions added by fertilizers (USDA, 2020; Campbell *et al.* 2018). Depending on the environmental conditions, nitrogen originating from degrading legumes have potential to at least partially support the nitrogen need of a subsequent crop e.g. the 140-165 kg/N per ha of nitrogen for a normal Swedish yield, about 7 tons, of wheat (SCB, 2019; SJV, 2020).

3.3. Intercropping systems

The definition of intercropping is that more than one crop is grown in a field at the same time during the whole or parts of the life cycle of each crop (Vandermeer, 1989). The intercropped species can overlap completely in growth cycles, but could also be sown or harvested separately at different times. In row intercropping different crops are sown in altering rows. In mixed intercropping there is no row arrangement and in strip intercropping several rows of each crop are grown next to each other, alternating with one or several crops in a pre-designed pattern. Intercropping is commonly used to produce several crop yields in the same field, such as cereal or maize intercropped with legumes such as beans (Bulson 1997) or peas (Qin *et al.* 2013). It could also be used in a system where only one cash crop is harvested and the other crop only is grown to support the main crop and the overall cropping system.

Plants grow in two different kinds of media, soil and air, as well as in two dimensions of space and time (Azam-Ali, 2003). Intercropped species could therefore utilize resources differently in time and space. This can be phrased as functional complementary (Bedoussae *et al.* 2015), where crops grown together will compete, but sometimes also facilitate each other, depending on their interactions and claims in time and space to the resource pool. If more than one species are growing in one place, there is a higher chance of resources being used more efficiently as the species complement each other in use of resources as light and nutrients (Azam-Ali, 2003; Bedoussae *et al.* 2015; Malézieux *et al.* 2009). To be successful, the ecological interactions of intercropped plants should be more or less complementary, by differing in characteristics such as canopy architecture or rooting depth in its usage of the resource pool (Raseduzzaman & Jensen 2017). Thereby the intercrops use different niches and utilize their habitat in space or time differently (Luscher & Jaquard, 1991) e.g. cereal-legume intercrops improve the use of light, energy and nitrogen-resource efficiency (Bedoussae *et al.* 2015). The interspecies competition of intercrops depends on the shoot constitution and development, that determines whether the light interception is enough for all the intercrops. If the intercrops complement each other, the total light interception of the intercrop increases compared to the sole counterparts (Bedoussac *et al.* 2015). For instance, tall species with vertically oriented leaves can be combined with short crops with horizontal leaves (Azam-Ali, 2003). A study of intercropping wheat and *T. repens,* showed negative effects of intercropping on wheat yield the first year but positive effects the following year (Bergkvist, 2003). The negative effect was a result of high competition during tillering stage, limiting the development of the wheat canopy. Competition in an early stage generally favours cereals compared to legumes, because they are early in initial growth and limits nitrogen and light availability for the legumes before they become self-sufficient by nitrogen fixation (Bedoussac *et al.* 2015). The interactions within a intercrop is also affected by the intercropped species performance in different weather conditions, e.g. lower proportion of pea yield if high soil water content (Kontturi *et al.* 2011).

The total yield of intercrops are often more stabile over time and could even be higher comparing the yield of its components as sole crops per area used (Malézieux *et al.* 2009) e.g. intercropping chickpea with wheat decreased the yield of chickpea, but the overall productivity per unit area was higher (Banik *et* *al.* 2006). The more stable effect of intercrops is thought to depend on the possibility of one crop to compensate for the loss of another (Raseduzzaman & Jensen 2017). The sole crop counterparts are more likely to suffer big losses due to pest, disease and environmental impacts, than intercrops. The direct effect of crop yield the year of intercropping could be argued to be less interesting in comparison to long-term effects of higher resource efficiency (Azam-Ali, 2003; Bedoussac *et al.* 2015) and higher abundance of natural predators for pest management (e.g. Bedoussac *et al.* 2015; Steen Jensen, 2015; Rundlöf *et al.* 2014).

3.3.1. Fertilization through nitrogen fixation

Intercropping studies have found nitrogen content to increase in cereals grown together with legumes (e.g. Bulson *et al.* 1997; Kontturi *et al.* 2011) and in a few cases also higher yield of cereals if legumes are present (Steen-Jensen *et al.* 2015). Since legumes are weaker competitors of nitrogen than cereals, a higher amount of nitrogen is fixated from air when soil mineral nitrogen is mainly taken up by the cereal component of the mixture. This explains why nitrogen-poor agro-ecosystems benefit more from intercropping legumes with cereals than agro-ecosystem richer in nitrogen (Bedoussac *et al.* 2015). However, uptake originating from nitrogen fixation is difficult to measure.

3.3.2. Intercropping for weed management

Weed species composition and biomass could be affected by intercropping through competition for water, light or nutrients, or by release chemical compounds inhibiting plant growth, called allelopathy (Malézieux *et al.* 2009). Weeds suffering from heavy competition are hindered in development and growth (Bulson *et al.* 1997). Shading and nutrient competition lead to poor establishment of plants (Anil *et al.* 1998) or in decreased production of reproductive structures that leads to reduction of soil weed seed banks (Reddy, 2017). Relay intercropping, crops overlapping shortly by sowing the subsequent crop before the first one reaches maturity (Azam-Ali, 2003), of cover crops has been shown to reduce the abundance of weeds (Reddy, 2017). The intercropping of annual clover species such as *Trifolium resipunatum* and *T. incarnatum*, in under-sown seed mixtures, to support maize or spelt wheat have been shown to reduce weed biomass without reducing main crop yield (Verret *et al.* 2017). The annual clover species *T. squarrosum* has been shown to strongly negatively correlate with weed biomass (Ranaldo *et al.* 2019). However, used in an under-sown seed mixture, *T. squarrosum* did not show any effect on weed biomass or weed communities in subsequent crops (Adeux *et al.* 2021). The outcome of competition is often determined in the early growth stages (Andersen 2005). A negative effect of intercropping on weed abundance could be found if the intercrops are competing for resources. If one of the intercrops is a strong competitor against weeds then it could indirectly facilitate the other intercrop by providing space. For instance, because legumes are self-sufficient in nitrogen they do not compete with cereals as non-fixating weeds might do (Andersen 2005; Hauggard-Nielsen *et al.* 2009). A reduced amount of weed biomass was found in beans intercropped with wheat compared to both wheat and beans as sole crops (Bulson *et al.* 1997). Comparing sole crops of beans and wheat, beans had more weeds. Chickpea is another legume intercropped with wheat that has shown reduced weed biomass and density compared to both crops in sole stands (Banik *et al.* 2006). The effect on weeds does also depend on the row spacing of the intercrops, as shown by a study of intercropped baby corn with either fenugreek or fodder cow pea (Rathika *et al.* 2013).

High weed species diversity is not necessarily a bad thing. It enhances the effects of cover crops, as long as they do not become severe problems in succeeding crops (Baraibar *et al.* 2021). A higher plant biodiversity also results in higher above ground population of decomposing arthropods due to the overall higher biomass (Ebeling *et al.* 2014), when species are filling up different niches. Plant species richness has also been found to correlate positively to both arthropod herbivore and predator species richness in grasslands (Haddad *et al.* 2009).

3.3.3. Intercropping to boost pollinator abundance

In farmlands, the main food resources for bumblebees in the Northern Hemisphere during summer come from managed semi-natural habitats such as field verges and managed habitats such as flowering crops (Westphal *et al.* 2009; Williams *et al.* 2012). In spring and early summer, the floral resources are located in woodland (Williams *et al.* 2012). Any shortage in floral resources during bumblebee colony growth could have a devastating outcome, because bumblebees do not store food in their nests (Rundlöf *et al.* 2014). A consistency in floral resources is crucial for the colony survival and potential for new colonies following years. Because bumblebees are central place foragers, the floral resources must bee within flight distance from their nest (Westphal *et al.* 2006). Large bumblebee species are able to fly longer distances than smaller (De Luca *et al.* 2019). It is not just the abundance of flowers that matter, also the quality is important. For instance, pollen from Fabaceae plants are of particularly good quality to bumblebees (Goulson *et al.* 2005). The floral composition attracts different kinds of bumblebee species, for instance *T. repens* seems to attract *Bombus terrestris*, *B. lucorum* and *B. pratorum* (Norris *et al.* 2017).

Cultivated flowering crops such as *T. pratense* for seed production or *Brassica napus* could provide a temporary flower resource. Several studies have shown mass flowering crops to support bumblebee colony growth, either directly by increasing the reproduction by increasing birth of queens (Rundlöf *et al.* 2014) or indirectly by bolstering workers that could help provide for newly born queens (Westphal *et al.* 2009) and bring food back to the nest (Riedinger *et al.* 2015). The potential effect of flowering crops on bumblebee colony growth and reproduction depends on both its continuity as well as timing.

Lately, attempts have been made to elevate the abundance of food resources by using flower strips, consisting of mixes of flowering plants sown in field borders (Haaland *et al.* 2011; Uyttenbroeck *et al.* 2016; Ouvard *et al.* 2018). Positive effects of flower strips on pollinator abundance have been found in intensive managed landscapes (Ouvrard *et al.* 2018). It is not only the quantity but also the quality of food plants that determine the flower strip effect on pollinator abundance (Haaland *et al.* 2011). A boost of pollinator richness, density and diversity has also been found using strips of a floral mixture containing *Trifolium hybridum, T. incarnatum*, *Medicago lupilina* L, *Onobrychis viciifolia* L., *Lotus corniculatus* L. and *Malva moschata* L. in maize in UK (Norris *et al*. 2017). *Bombus terrestris/lucorum* and *B. lapidarius* were found to be most abundant.

3.3.4. Intercropping for pest management

The effects of intercropping on pest control have been studied for more than fifty years (Risch, 1983). Most of the studies were conducted in vegetables and fruits (Reddy, 2017), and only a few studies have been carried out in Europe (Chevalier Mendes Lopes *et al.* 2016). In northern Europe, there are even fewer studies. However, a few studies on the effect of intercropping on aphid control have been made. Spring-sown cereals intercropped with field beans in Denmark showed reduced damage by black bean aphids in intercrops compared to sole crops (Hansen *et al.* 2008). Damage on wheat caused by aphids could not be reduced by intercropping wheat with white clover *Trifolium repens* L (Mansion-Vaquié *et al.* 2019). Intercropping effects on pest management seem to vary depending on the weather in the year of study (Mansion-Vaquié *et al.* 2019).

The effect of mixing species with different vegetation architecture on predator population is called a habitat effect (Malézieux *et al.* 2009) and one way of doing this it to use flower strips. The results of a review shows that flower strips can be used for pollinators, but there are also some evidence for supporting predators of pests (Haaland *et al.* 2011). Species richness of generalist predators was often found to be greater in flower strip than in control treatment, but overall abundance was often shown to be more correlated with vegetation structure (Haaland *et al.* 2011). Generalist predators are thought to be less dependent on floral resources and the actual difference in habitat between the treatments with and without flower strips tend to be small. Therefore the actual factor causing difference has been hard to pin point. Apart from flower strips, studies concentrating on the effect of different grass mixtures in field verges on generalist predators have also been conducted. Agricultural field-margins have shown to enhance arthropod species richness similar to that of flower strips (Pollier *et al.* 2018). The vegetation structure seems to have a greater impact on insects like beetles than the presence of floral resources. For instance, if tussocky grass is used instead of fine grass in a mixture with herbs, the amount of beetles in verges could be elevated (Woodcock *et al.* 2005). A boost of abundance has been found for field margins on generalist predators such as carabids (Carabidae) and rove beetles (Staphylinidae) (Luka *et al.* 2006; Smith *et al.* 2008). Flower strips left over winter have also shown to be an important overwintering habitat for these predators, where the vegetation cover was the most important factor (Frank & Reichhart 2004). The presences of specific flowers have been shown to be related to the abundance of insects, e.g. *T. pratense* was positively correlated to the abundance of hoverflies but negatively correlated with leaf beetles (Pollier *et al.* 2018). How a crop is ended seem to affect the density of remaining arthropods, where mulching leads to a higher subsequent arthropod abundance than tillage (Rivers *et al.* 2018).

A recent review shows that intercropping, as a habitat manipulation technique, have positive effects on pest management in agro-ecosystems (He *et al.* 2019). It is not the crop diversity itself that leads to improved pest control, but the specific behaviour of the pest arthropod and the arthropod-plant interactions that determines if the pest thrives or not (Smith & McSorley, 2000). The outcome of the interaction is based on the microclimate suitability for the arthropods as determined by the vegetation structure (Landis *et al.* 2000). The arthropod-plant interaction determines the outcome of pest control. If the intercrops are competing strongly e.g. for resources, the effects on pests are poor due to high plant stress depending on the type of pest (Bukovinszky *et al.* 2004).

3.3.5. Intercropping cover crops

Cover crops can be sown in between cash crops, in order to be mulched or incorporated mechanically into the soil in preparation for sowing of the subsequent crop. The purpose of using a cover crop is to reduce erosion, add soil organic matter, retain nutrients in the cropping system and to contribute to biodiversity (SJV, 2021A). Keeping the soil covered with growing plants reduce nitrogen leaching (SJV, 2021B), provide carbon sequestration and enhance biodiversity by elevating food and habitat resources for pollinators and natural predators (SJV, 2021A). Common species to use as cover crops are different clover species, both perennial and annual, but also other legumes such as alfalfa (*Medicago sativa*) and hairy vetch (*Vicia villosa*), grasses such as perennial reygrass (*Lolium perenne*) and *Festuca rubra* and species within the Brassicaceae family, such as white mustard (*Sinapis alba*) and *Raphanus sativus* var. *oleiformis*

(Scandinavian seed, 2021A; Olssons frö, 2021A). These could be sown as sole crops or as mixed intercrops, but if the farmer is applying for EU funding's to limit nitrogen leaching in the autumn the amount of legumes in the seed mixture is limited to 15 % (SJV, 2021B). Intercropping cover crops could provide a continuity of ecosystem services (e.g. Bedoussac *et al.* 2015; Steen Jensen, 2015; Rundlöf *et al.* 2014) throughout the vegetation period, eliminate bottlenecks of arthropod food resources and make agro-ecosystems less vulnerable to climate change by elevating biodiversity using species adapted to the thermal and hydrological conditions of the cropping system (IAASTD 2009; Malézieux *et al.* 2009).

Trifolium species have a lot to offer an intercropping system. Their potential to be self-supporting of nitrogen (McKenna *et al.* 2018; USDA, 2020) might be the most important one, together with providing flowers as food for pollinators and thereby also enhanced pollination of crops like *Trifolium pratense* grown for seed production (Rundlöf *et al.* 2014) and providing suitable vegetation for natural predators (Landis *et al.* 2000; Hansen *et al.* 2008). They also increase soil organic matter content and improve soil aggregation (Kneble *et al.* 2015; Miller & Dick 1995), especially if such as *T. incarnatum* having a deep taproot (Olssons frö, 2021). Most of the studies of both application effects and biodiversity effects have been made on the most common species *T. pratense* and *T. repens*. Not much is known about annual clover species, such as *T. incarnatum, T. resupinatum* and *T. squarrosum*. *Trifolium incarnatum* is an intermediate producer of pollen and nectar, while *T. resupinatum* provides about the same amount of pollen but not as much nectar (Hansson 1991). *Trifolium incarnatum* can be sown late in the autumn as well as early in spring, flowering in late spring or early summer respectively late summer (Lindström, 2010). *Trifolium resupinatum* could also be sown in the autumn, flowering in late spring or early summer, or sown in spring flowering late in summer (Lindström, 2010). Leaflets from plant breeders and seed sellers provide the rest of what I found about these species: *T. incarnatum* reaches 50-70 cm in height, develops a deep taproot, produces a lot of biomass and is hardy against frost, heat, cold weather and drought (Olssons frö, 2021b). Further more, *T. incarnatum* might overwinter in southern Sweden, should not be used in easily saturated soils and is not a strong competitor against weeds (Scandinavian seed, 2021b). Further, according to Skånefrö AB (2021) *T. incarnatum* could be cut to prolong the flowering period to September. They also argue that *T. incarnatum* could be used to suppress weeds, which both Olssons frö and Scandinavian Seed do not recommend. *T. resupinatum* reaches 30-50 cm in height, is a good competitor against weeds, has good re-growth after cut but needs warm and moist soil to germinate. *Trifolium squarrosum* is not mentioned much, but has about the same re-growth after cut as *T. resupinatum* but a deeper root system (Olssons frö, 2021b). Olssons frö also provides a ranking system of the different clover species attractiveness to bees, ranging 0-4 were 4 equals high attractiveness (Olssons frö, 2021b). According to this system, *T. resupinatum* has bee attractiveness to nectar of 2 and to pollen 3. While *T. incarnatum* is ranked a 4 for both nectar and pollen, and *T. squarrosum* being not ranked at all. The source from which they got this information is not provided.

4. Method

In the spring of 2020, *T. incarnatum*, *T. resupinatum* and *T. squarrosum* were under-sown in oats in 14 fields, eleven located at organic farms and three at conventional farms (Table 1). The conventional farmers were all practising no-tillage and had to agree not to use pesticides in the experimental plots. The fields were located in the eastern part of Sweden, in the counties of Uppsala, Stockholm, Södermanland and Västmanland. The criteria to be met by the chosen fields were that they should have a clayey soil, be located within two hours of reach from Uppsala and that the farmer was able to grow oats intercropped with the clover mixture. Farmers that had practised growing one or more of the clover species in the past were favored in the selection process, whereas only a few farmers growing clover seed were selected due to elevated risk of clover disease affecting their seed production. Mainly farms without animals were interested in participating in the field study. One possible reason why farmers with ruminants might not be interested is that they already have much clover in their rotations, as part of the rotational leys. Twelve farmers participated in the project. Two of them contributed two sites and all the others one single site.

Table 1. The location and management methods for the field sites used in this study.

Site ID	Location (county)	Management	Row spacing
AN	Uppsala	Organic	12.5 cm
AO	Västmanland	Organic	25.0 cm
EN	Västmanland	Conventional	25.0 cm
ER1	Stockholm	Conventional	33.0 cm
ER2	Stockholm	Conventional	33.0 cm
HB	Uppsala	Organic	12.5 cm
KB	Uppsala	Organic	12.5 cm
KÖ	Västmanland	Organic	25.0 cm
NN1	Södermanland	Organic	12.5 cm
NN2	Södermanland	Organic	12.5 cm
SL	Västmanland	Organic	12.5 cm
TG	Södermanland	Organic	25.0 cm
UA	Uppsala	Organic	25.0 cm
VÅ	Västmanland	Organic	25.0 cm

4.1. Experimental design

At each site, the field experiment consisted of two plots: one containing row intercropped oats and clover, the other one a control with only oats. In four (AO, HB, AN and KB) of 14 sites, the farmer opted for the whole field (1.75-9.5 ha) to be intercropped, leaving just a small control plot without clover, while the opposite was the case at the other sites. The observation plots measured 50 m in length and 20-27 m in width, depending on the width of the sowing machine (Table 1). The plots were located at least 16 m from field edges, and positioned to ease the management and surveys. Five meters into each plot, two 40 m transects were placed (Figure 1). In total 18.7 kg/ha of clover seeds were sown as the clover treatment. The amounts of seeds used were: 2.25 kg/ha (46875 seeds/m^2) of *T. resupinatum*, 6.3 kg/ha (54688 seeds/m^2) *T. incarnatum* and 10.15 kg/ha (54688 seeds/m^2) of *T. squarrosum*.

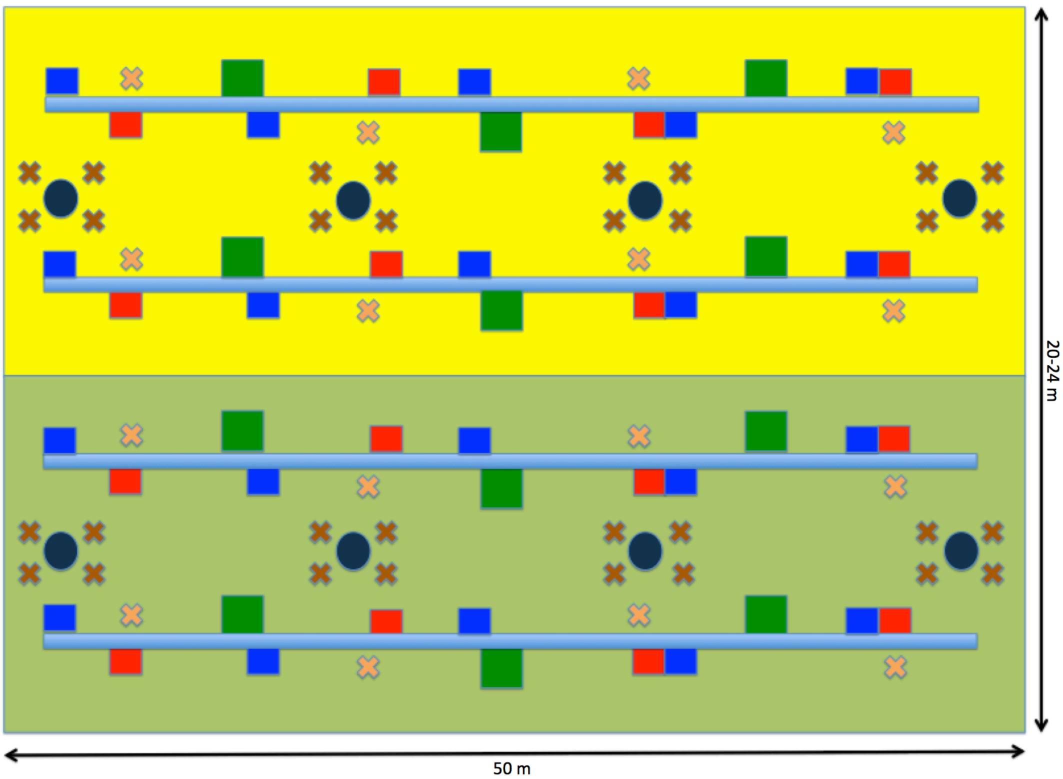

Figure 1. A map of the sampling points for measurements of yield of biomass and grains (bright crosses), crop emergence (blue quadrats), weed coverage (green quadrates), flower abundance (red quadrats), ground-dwelling predators using pitfall traps (dark circles) and predation of aphids on cards (dark crosses) in relation to the transects used for pollinator surveillance (blue lines). The two treatments are shown as two coloured rectangles: green for the intercropping treatment and yellow for sole cropped oats as control treatment.

The fields were sown between the 7th and 27th of April. At five sites the clover seeds were broadcasted from a separate seed hopper in front of the coulters sowing the oats and mulched with the coulters and the light harrow on the back of the sowing machine. At the other sites, the sowing of clover was done in a separate operation within two weeks from the sowing of oats, except in one case when the sowing was done 49 days after the sowing of oats. Half of the sites were sown using row spacing for the oats between 25 cm and 33 cm, while the other seven used 12.5 cm (Table 1). In all but three sites, the clover was broadcast drilled. In the sites where the clovers were drilled in rows, the rows sometimes overlapped with the rows of oat.

4.2. Crop emergence

About a month after the sowing of clover, the oat and clover emergence was estimated. The 40-m transects were used to place five 0.5 * 0.5 m quadrats, at distances of approximately 0 m, 10 m, 15 m, 25 m and 35 m (Figure 1). The plants of clover and oats were counted, each plant that got the stem within the sampled area was included (Figure 2). The quadrats were placed so that two (25-33 cm distance between rows) or four (12.5 cm distance between rows) rows of oat were centred inside. When clover was sown in rows between the rows of oat, there were two rows of oat and two rows of clover in each quadrat.

*Figure 2. A 50 * 50 cm quadrat was used for counting emerging shoots at ten spots in each treatment.*

4.3. Weed coverage

The ground cover of weeds were estimated ocularly according to pre-set evaluation templates showing 2-50 % coverage (Braun-Blanquet *et al.* 1932). One observer did all the estimations, to avoid one source of error. The overall abundance of weeds was estimated to 2 %, 5 %, 10 %, 20 %, 40 % and 50 % weed cover according to the template. The noted estimations were set as no more than the percentage chosen. For instance, an estimation of 15 % was noted as no more than 20 % in the field protocol. Three, 2 * 2 m, inventory plots were used in each transect and placed randomly within the distances of 10 m, 20 m and 30 m (Figure 1), resulting in total of six inventory plots in each treatment and 12 inventory plots at each site.

4.4. Grain and biomass yield

The harvests of the field experiments were made in the beginning to the middle of August, when the oats had reached at least BBCH 85 (soft dough, attempted pressure of the grains results in no liquid emerging) when the assimilation had stopped and the grains had started to dry up. The biomass of oats, weeds and each clover species were estimated from samples cut in four 0.5 m * 0.5 m quadrats randomly placed at distances of 5 m, 15 m, 25 m and 35 m measured by walking along the same transects used for the pollinator surveys (Figure 1).

The shoots of every plant within the quadrat of sampling, were cut as close to the ground as possible. Small plants were easily pulled from the ground together with their roots, in contrast to larger plants that were generally cut from their roots. Lastly, the ground of the quadrat was raked by hand and small leaves together with small parts of oat straw were collected. The quadrats were placed in such a way that lodged oats was avoided. All biomass above ground were cut, and the oats were separated from the rest already at sampling. Clover and weeds were separated at lab, only the clovers were sorted down to species level. All the samples on each 0.25 m^2 were cut, stored separately in paper bags and transported to the lab to be dried in 65 °C for 48 hours and weighed.

4.5. Yield nitrogen content

The harvested biomasses of the three different clover species as well as oat grains, threshed from the oat biomass samples, were analysed for total nitrogen content by dry combustion and using the infrared non-dispersive technic LECO CN928. Samples were weighed on a 5-decimal scale and ceramic boats were used as containers. All elemental nitrogen was converted into nitrous gas (N_2) and nitrous oxides (NO_x). The nitrogen content was obtained by measuring N_2 flow by voltage from a TC cell. Calibration of the machine was done using substrates with known nitrogen values and control samples were used roughly every 10 samples.

4.6. Pollinators and flower resources

In each treatment, two parallel transects were used for surveying pollinators, such as bumblebees, solitary bees, honeybees and butterflies (Figure 1). Only pollinators noted as having contact with the fertile parts of a flower were considered. The width of each surveyed transects was two meters, one meter on each side of the transects and the length was 40 m. The survey duration was 10 min, the pace was 2.1 km/h and each m^2 was observed in 7.5 s. A stopwatch controlled the timing. The stopwatch was paused for taking notes and if the crop was thick to locate buzzing bees. The pollinators were noted to species, caste e.g. worker bees and queens and the species of the flower visited was also noted. The transects were always walked avoiding shadowing the surveyed surface. If the bumblebees could not be identified through the net, they were collected and identified later in a lab.

After surveying pollinators, a survey of flower resources was made in four 0.5*0.5 m quadrats within each transects: at 0 m, 13.3 m, 26.6 m and 40 m (Figure 1). The squares were randomly placed within these locations. One flower unit equals to a flowering flower head (for example Rosaceae), a cluster of smaller flowers (for example Brassicaeae), a flowering spike (for example Fabaceae) or a flower stem (for example Lamiaceae). The size of each flower within a unit was calculated through a mean from five randomly measured flowers of each species. Also, the numbers of flowering flowers of each flower unit of clover were noted: a clover unit were noted as flowering if any of the flowers within the unit flowered.

The two surveys were done during July and August, between 8 AM and 8 PM. Morning and afternoon sampling was switched between the two survey rounds at each site. It had to be at least 16 °C, no rain within the last hour and preferable dry vegetation. The wind speed was less than 7.9 m/s (Beaufort 4). The weather was noted when first arriving to the field.

4.7. Pitfall trapping of ground-dwelling arthropods

Pitfall traps were used to measure the population of ground-dwelling arthropod predators: carabids (family Carabidae), spiders (order Araneae) and rove beetles (family Staphylinidae). In each treatment a new transect of 50 m were placed between transects used for survey of pollinators (Figure 1). In every transect four pitfall traps were randomly placed by walking a distance about 0 m (trap one), 13.3 m (trap two), 26.6 m (trap three) and 40 m (trap four). In total two rounds of pitfall data was collected, the first one in the beginning of July and the second one in the beginning of August. The pitfall traps were filled to about ¾ with water and a few drops of unscented soap and left for one week in the field. After that, the arthropods were collected and stored in ethanol until they were identified down to species level. The pitfall traps were placed in abundant vegetation; places of poor establishment and wheel tracks were avoided (Figure 3).

Figure 3. Four pitfall traps were placed in each treatment to catch ground-dwelling predators.

4.8. Aphid predation

Aphid cards were used to estimate the predation of aphids when the aphid population of *Rhopalosiphum padi* in the beginning of July usually reaches its maximum number. Sandpaper cards with the size of 42 cm^2 (6*7 cm) and six aphids on each card were used (Boetzl, 2020). Four aphid cards were pinned down next to each pitfall trap and inside the vegetation avoiding wheel tracks (Figure 1; Figure 4). The distance between the cards was 0.5-1 m and they were a maximum 1 m from the pitfall traps. The aphid cards were removed after 24 hours +/- one hour in the field. The remaining aphids on each card were counted at site when collected and noted in a field protocol. The aphids were grown in chambers at Swedish University of Agricultural Sciences in Uppsala. Adult aphids larger than 1 mm were put in a freezer no less than 15 min and then glued on to the cards with egg white. Even though the aphids had been stored in the freezer some managed to survive, especially when left in the freezer as short as 15 min but a few survived even when left several hours. To prevent them from escaping from the cards, the cards were put back into the freezer as soon as possible. They stayed in the freezer no more than three days before using them.

Figure 4. Four aphid cards were pinned down next to each pitfall trap, in total 16 cards per treatment, to estimate the aphid predation. The cards were placed on the soil surface inside vegetation.

4.9. Statistical analyses

I used Microsoft Excel for Mac 2011 (version 14.7.7) to sort and summarize data, which I then analysed using linear mixed models in R (version 3.4.3) and Lme4 package. Field-, transect- and replicate identities were included as random factors, to avoid measuring effects within sites. Transformations were used based on information about distribution pattern provided by residual plots (QQ-plots), to transform data into normal distribution. The models were based on four different analyse methods: mean values of treatments per site, summed values of treatments per site, pooled samples of treatments per site and random factors using R. The effects were determined comparing clover treatment with control treatment (sole crop of oats). The explanatory variable was if clover was intercropped or not. The response variables are listed in Table 2. Aphid predation was obtained by subtracting the remaining aphids on the cards, after being gathered from the fields, by the total amount of aphid glued to the card.

Two sites originally chosen for the study were excluded during the surveys. At site VÅ, the drilling of clover in oats was done later than the others and had a poor emergence (Figure 6). For that reason this site was excluded from the study in an early phase. Comparing SL with HB, EN and AO, the drilling results seem to be similar between sites (Figure 6). However, the biomass yield of the clover species was the lowest for SL and did not match the others for comparison (Figure 10). For that reason SL was also excluded from this study.

Vetches (*Vicia spp*.), a common cover crop, appeared in patches throughout the field of ER2 and were controlled with herbicides outside the experimental plots. This could potentially impact the presence of weed in treatments in a patchy manner and highly impact the randomized replicates. Weed coverage and biomass were therefore analysed twice, with and without site ER2, and compared.

Table 2. The data gathered from the clover and control treatments were analysed using different statistical models.

Explanatory variable	Response variable	Analyzing method	Random factors in R	Transformation
Clover/no clover	Emergence of oats	Random factors	Site, treatment, transects	Square root
Clover/no clover	Oat grain quantity	Random factors	Site, treatment, transects	Log
Clover/no clover	Weed biomass	Random factors	Site, treatment, transects	Square root
Clover/no clover	Flower resources	Random factors	Site, treatment, transects	Log
Clover/no clover	Oat harvest index	Mean values	Site	None
Clover/no clover	Oat grain nitrogen	Pooled sample	Site	None
Clover/no clover	Weed coverage	Mean values	Site	None
Clover/no clover	Pollinator abundance	Summed values	Site	Log
Clover/no clover	Bumblebee abundance	Summed values	Site	Log
Clover/no clover	Carabid abundance	Summed values	Site	Log
Clover/no clover	Spider abundance	Summed values	Site	Log
Clover/no clover	Rove-beetle abundance	Summed values	Site	None
Clover/no clover	Predator abundance	Summed values	Site	Log
Clover/no clover	Aphid predation	Mean values	Site	None

5. Results

5.1. System application

5.1.1. Crop emergence

The crop emergence of oats did not differ between the treatments (p=0.748; Table 3). The mean abundance of oats in the clover treatment was 376 plants/m^2 and 380 plants/m^2 in the control treatment. *T. incarnatum* had the highest mean abundance (87.3 plants/m^2), followed by *T. squarrosum* (80.5 plants/m^2) and with the lowest abundance *T. resupinatum* (49.1 plants/m^2) (Figure 5). The range of emergence was 11.2-147.2 plants/m^2 of *T. incarnatum*, 20.8-144.8 of *T. squarrosum* and 5.6-106.8 plants/m^2 of *T. resupinatum*.

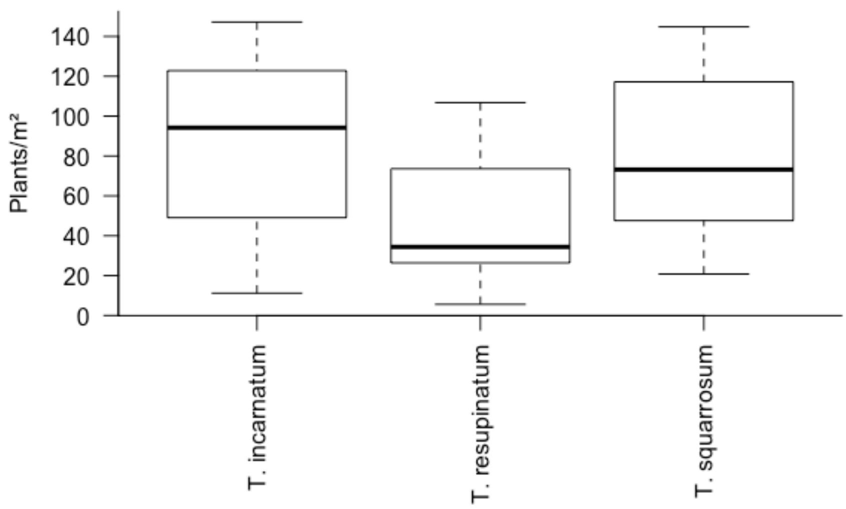

Figure 5. Boxplots showing the drilling results of the clover species, counted as emerged plants per m^2. T. incarnatum had the highest mean abundance of 87.3 plants/m^2, followed by 80.5 plants/m^2 for T. squarrosum and 49.1 plants/m^2 for T. resupinatum.

Figure 6. The emergence of clover treatment per site differed and site VÅ had the lowest abundance of all clover species.

T. incarnatum and *T. squarrosum* showed a pattern with resembling density of plants/m^2 in all but one site, whereas the density of *T. resupinatum* had a different pattern (Figure 6).

5.1.2. Crop yield

The oats grain yield of the control treatment was on average 4.77 Mg/ha and 4.61 Mg/ha in the clover treatment (Figure 7). No difference could be found for grain yield between the treatments (p=0.24). The biomass of oats in the control treatment was on average 9.27 Mg dw/ha and for the clover treatment 8.64 Mg dw/ha. The harvest index mean for the control was 0.344 and for the clover treatment 0.345. The harvest index (HI) of oats was not affected by the presence of clover (p=0.85; Table 3; Figure 8).

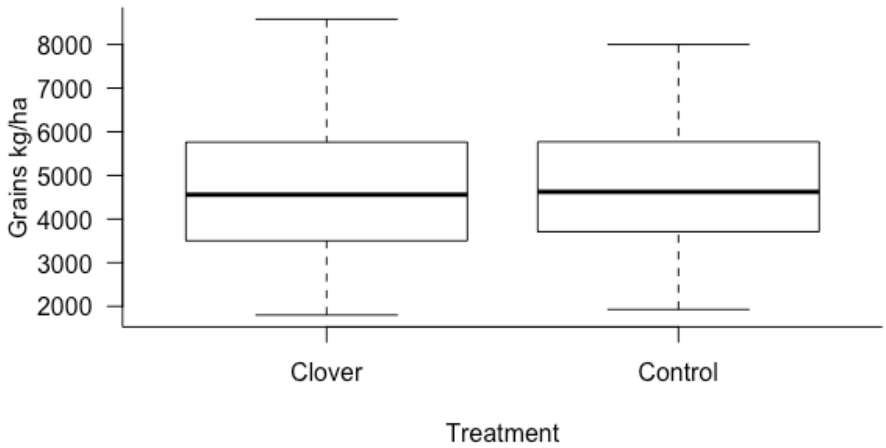

Figure 7. No difference (p=0.24) was found in grain yield between clover treatment and control treatment

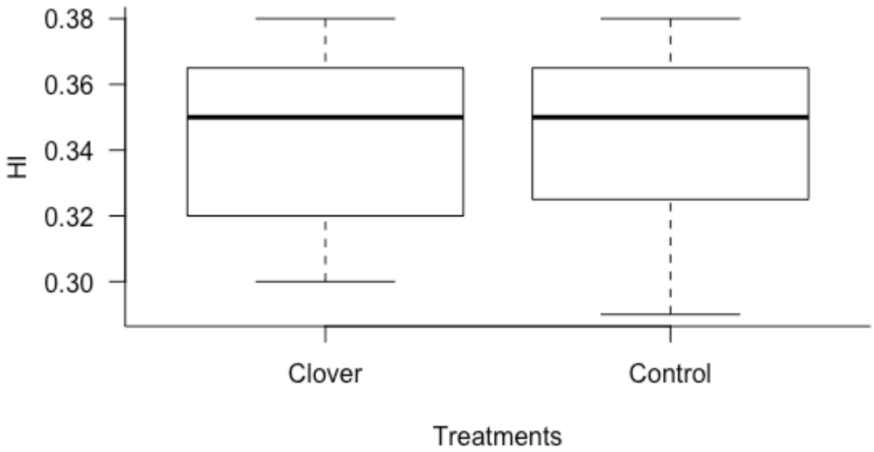

Figure 8. No difference was found in harvest index of oats between clover treatment and control treatment (p=0.85).

T. squarrosum had the highest mean biomass 226 kg dw/ha, followed by *T. incarnatum* and *T. resupinatum* with 175 kg dw/ha and 128 kg dw/ha, respectively. The range of biomass was 8.80 – 703 kg dw/ha of *T. incarnatum*, 0.00-601 kg dw/ha of *T. resupinatum*, and 0.8-1004 kg dw/ha *T. squarrosum* (Figure 9-10).

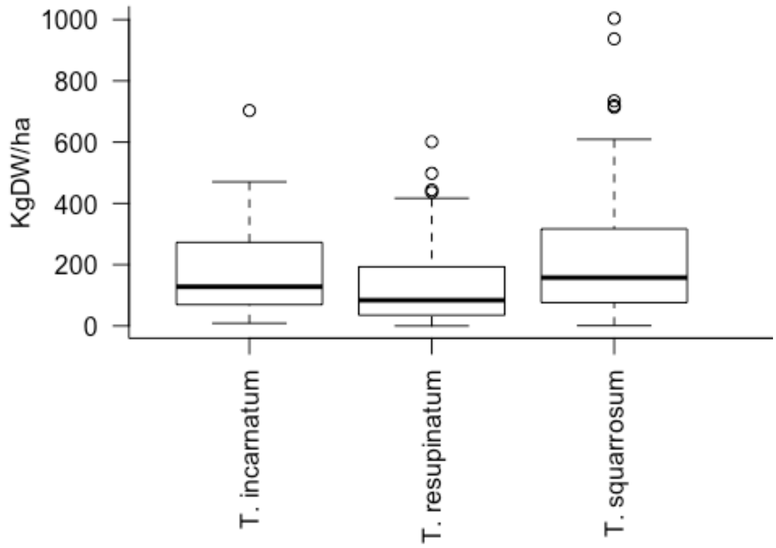

Figure 9. The range of dry weight of the Trifolium species biomass. T. squarrosum had the highest mean biomass of 226 kg DW/ha, followed by T. incarnatum of 175 kg DW/ha and T resupinatum of 128 kg DW/ha.

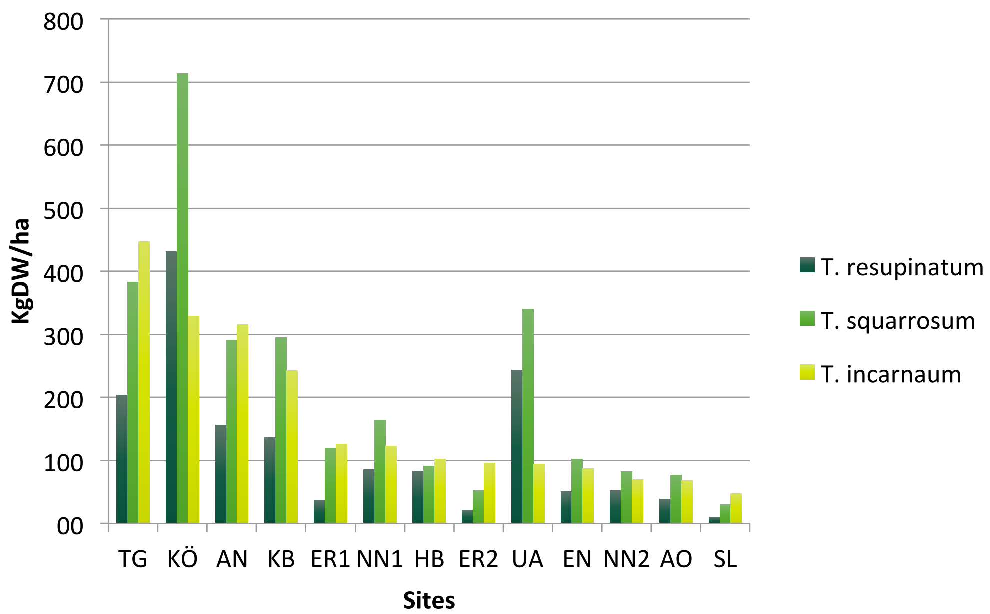

Figure 10. The biomass of the different clover species varied between sites. Site SL had the lowest clover biomass of all sites and all species.

The mean nitrogen content of oat grains was 17.70 g nitrogen/kg oat grains of the control and 16.97 g nitrogen/kg oat grains of the intercropped clover treatment. The control treatment had on average 0.73 g nitrogen/kg oats higher nitrogen content than the intercropped clover treatment (p=0.043; Table 3; Figure 11). The nitrogen content was 17.46 g/kg clover in *T. incarnatum*, 20.80 g/kg clover in *T. resupinatum* and 22.05 g/kg clover in *T. squarrosum.*

Figure 11. The nitrogen content of oat grains differed between treatments. The control treatment had higher nitrogen content than the clover treatment (p=0.043).

5.1.3. Weed coverage and biomass

The weed biomass in the control treatment was on average 586 kg dw/ha including ER2 and excluding ER2 583 kg dw/ha. In clover treatment the mean value was 494 kg dw/ha including ER2 and excluding ER2 444 kg dw/ha. No effect (p=0.13) was found of clover intercropping on the biomass of weeds when including ER2, but when ER2 was removed from the analysis, the weed biomass was lower (p=0.015) in the clover treatment than in the control (Table 3; Figure 12)

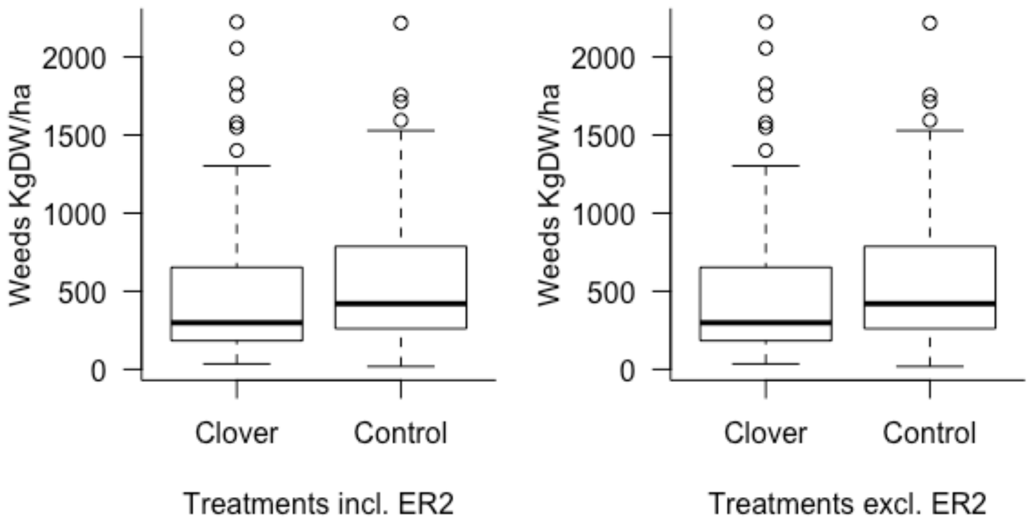

Figure 12. The biomass of weeds did not differ between clover and control treatments. However, if the replicate of ER2 was removed than the weed biomass becomes (p=0.015) lower in the clover treatment.

There was no difference in weed coverage between clover treatment and control (p=0.25; Table 3; Figure 13). The weed coverage varied between sites, ranging from 4.6 % to 50.0 % (Figure 13). A correlation was found between weed biomass and weed coverage (p= 0.048), which was stronger without site ER2 (p=0.005).

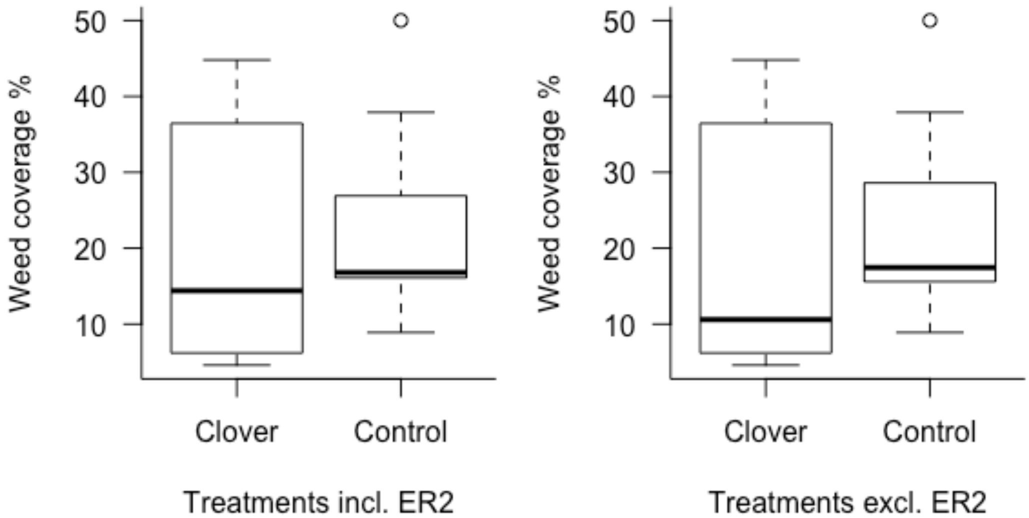

Figure 13. No difference was found between treatments in weed coverage (p=0.25) including ER2. The excluding of ER2 did not affect the outcome (p=0.15).

Table 3. The statistical results of system application comparing the intercrop clover treatment with the sole crop control treatment. One site had a patchy appearance of weeds and analyses were therefore made both with and without this site.

Response variable	**F-value**	**df**	**P-value**	**Transformation**
Emergence oats	0.108	12.505	0.748	Sqrt
Grain yield	1.587	10.080	0.236	None
Harvest Index oats	0.036	10.000	0.852	None
Biomass weeds	2.713	8.857	0.134	Sqrt
Biomass weeds without ER2	9.405	8.203	*0.015*	Sqrt
Weed coverage	1.491	9.759	0.251	None
Weed coverage without ER2	2.517	8.819	0.148	None
Nitrogen content	5.372	10.078	*0.043*	None
Biomass weeds: weed coverage	5.202	9.248	*0.048*	Sqrt/None
Without ER2: Biomass weeds: weed coverage	14.262	8.636	*0.005*	Sqrt/None

5.2. Effects on biodiversity

5.2.1. Flower resources

The treatments differed in the presence of flower resources. Both surveys showed higher amounts of flower resources in the clover treatment ($p<0.001$; Table 6; Figure 14). *Trifolium incarnatum* had the highest abundance of flowers in the first survey (802 flower units), followed by *T. resupinatum* (152 flower units) and *T. squarrosum* (26 flower units). The second survey *T. resupinatum* had the highest flower abundance (883 flower units), followed by *T. incarnatum* (453 flower units) and *T. squarrosum* (279 flower units) (Table 4).

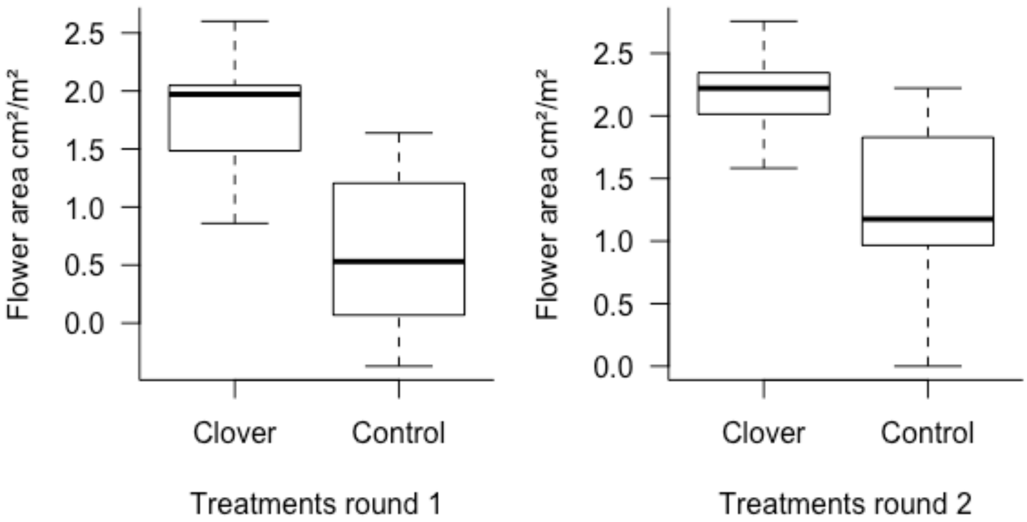

Figure 14. A higher ($p<0.001$) abundance of flower resources was found, for each round, in the clover compared to the control treatment. To the left: the abundance of flower resources in round one. To the right: the abundance of flower resources in round two.

Table 4. The flower units and flower areas in cm² of the clover species found within the clover treatment.

Survey	Species	Flower units	Total flower area cm²
1	*T. incarnatum*	802	1689
1	*T. resupinatum*	152	297
1	*T. squarrosum*	26	81
2	*T. incarnatum*	453	1218
2	*T. resupinatum*	883	2304
2	*T. squarrosum*	279	484

5.2.2. Pollinators

The abundance of pollinators was higher in the clover treatment than in the control treatment, in both round 1 ($p=0.01$) and round 2 ($p<0.001$) visible in Table 6. In the control treatment, 8 and 17 individual pollinators were found in survey one respectively two. In the clover treatment 53 respectively 106 individual pollinators was found in survey number 1 and 2. Furthermore, a higher abundance of bumblebees was found in the intercropped clover treament in both rounds ($p=0.005$ and $p=0.022$, respectively) (Table 6; Figure 15-16). The wild pollinators accounted for 106 out of 159 pollinators, 104 bumblebees and two butterflies and the rest belonged to honeybees, *Aphis mellifera* (Table 5). A strong correlation was found between the abundance of pollinators and floral resources for both survey rounds ($p=0.009$ and $p<0.001$, respectively) as well as between bumblebee abundance and floral resources ($p=0.002$ and $p=0.005$, respectively).

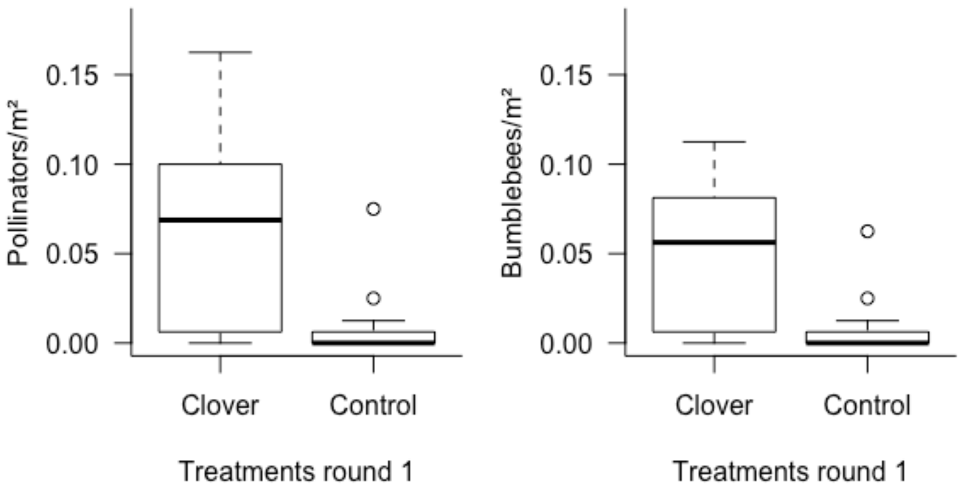

Figure 15. A higher abundance of pollinators (p=0.01) and bumblebees (p=0.005) was found for the intercropped clover treatment compared to the control in survey number 1.

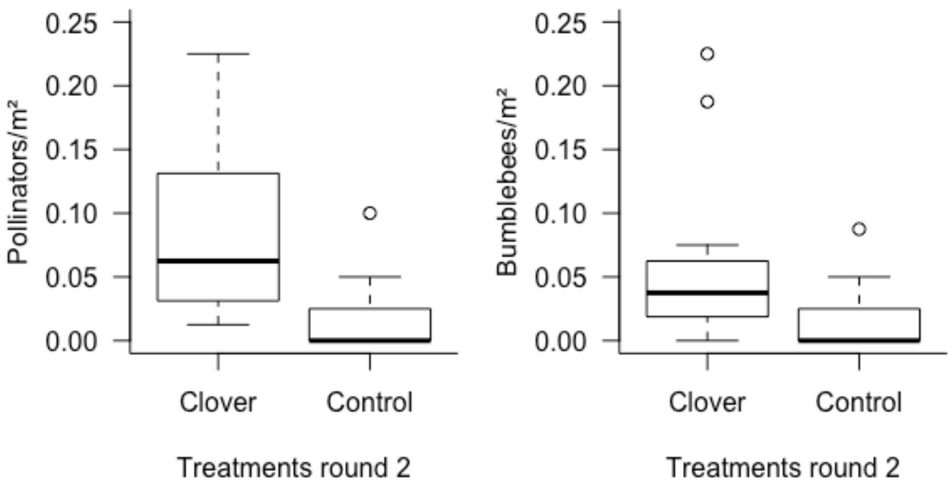

Figure 16. A higher abundance of pollinators ($p<0.001$) and bumblebees ($p=0.022$) was found for the intercropped clover treatment compared to the control in survey number 2.

Of all the 159 individual pollinators found in all the clover treatments, 102 of them were found on the clover species. *T. squarrosum* and *T. incarnatum* was mainly visited by bumblebees, while *T. resupinatum* was only visited by honeybees (Table 5). *T. resupinatum* was found to be visited by *Bombus pascorum and B. lapidarius*, while *T. incarnatum* was visited by eigth different species shown in Figure 17. In the control treatment, eight different bumblebee species and one butterfly were found and they visited mainly *Cirsium spp., Vicia spp., Trifolium spp*. and *Lamium spp.* (see Appendix).

Table 5. Plants visited by pollinators in clover treatment.

Plant	Bumblebees	Honeybees	Butterflies	All pollinators
Trifolium incarnatum	45	7	1	53
T. resupinatum	0	43	0	43
T. squarrosum	6	0	0	6
Weed	53	3	1	57
Total	104	53	2	159

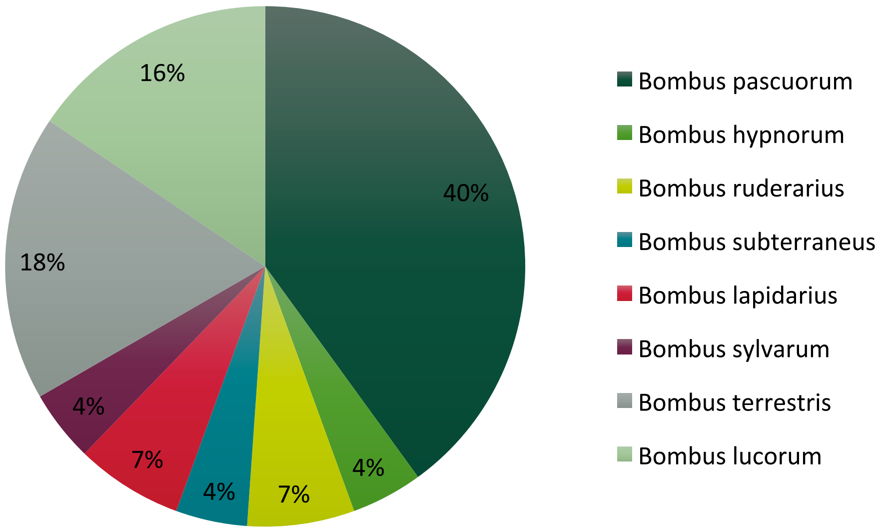

Figure 17. Eight different bumblebee species visited T. incarnatum in the clover treatment.

5.2.3. Ground-dwelling predators

Neither the total abundance of predators caught in the pitfall traps nor the abundance of spiders, rove beetles and carabids alone differed between treatments in any of the two surveys (Table 6; Figure 18-21). In survey round two, a positive tendency was found for predator abundance in clover treatment (Table 6). The general abundance of rove beetles was low (see Appendix). The species composition differed between treatments (see Appendix).

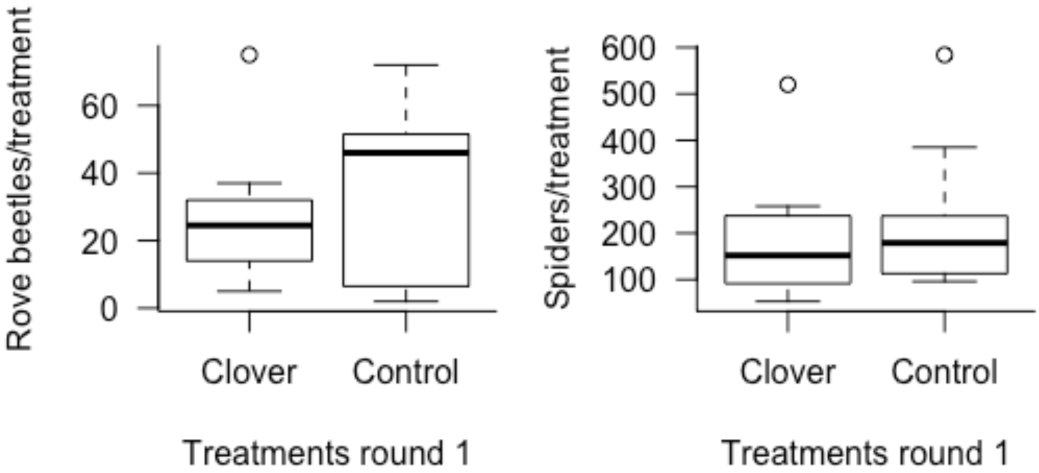

Figure 18. There was no difference in abundance of rove beetles (to the left) and spiders (to the right) in survey 1 between clover and control treatments.

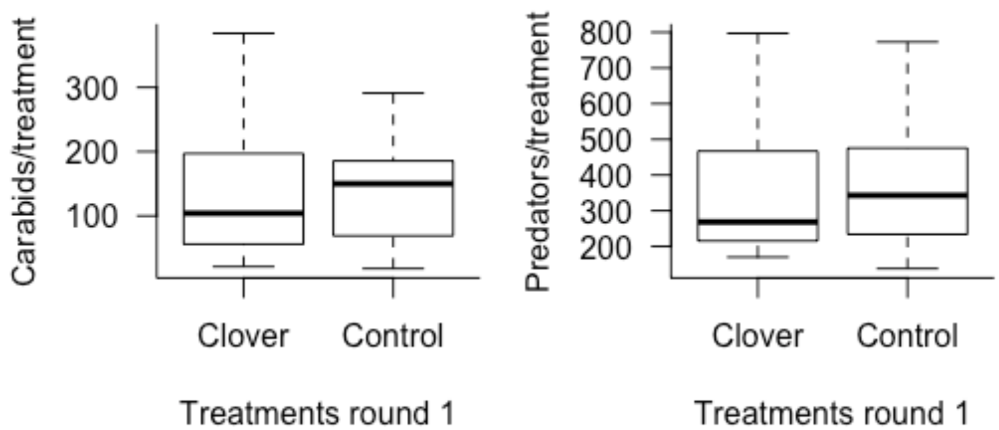

Figure 19. There was no difference in abundance of carabids (to the left) and overall predators (to the right) in survey 1 between clover and control treatments.

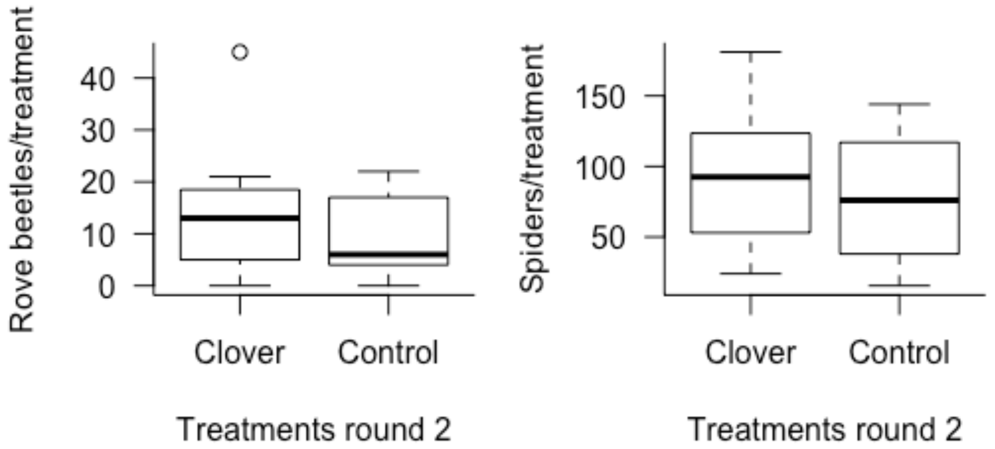

Figure 20. There was no difference in abundance of rove beetles (to the left) and spiders (to the right) in survey 2 between clover and control treatments.

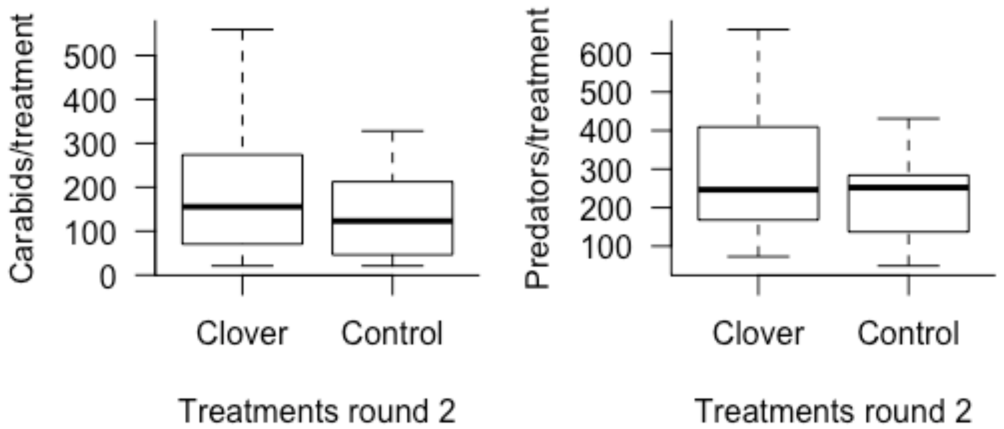

Figure 21. There was no difference in abundance of carabids (to the left) and overall predators (to the right) in survey 2 between clover and control treatments.

5.2.4. Predation of aphids

The predation of aphids was similar in both treatments (p=0.373; Figure 22). No correlation between aphid predation and number of natural predators was found (p=0.349; Table 6).

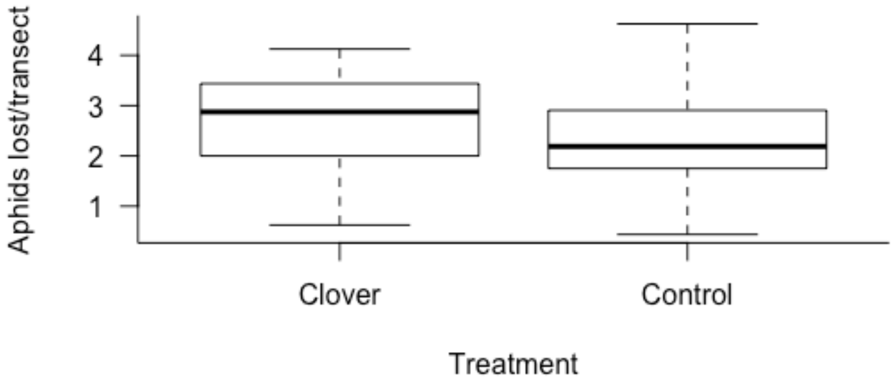

Figure 22. No difference was found in aphid predation between clover and control treatments.

Table 6. The statistical results of effects on biodiversity comparing the intercrop clover treatment with the sole crop control treatment.

Response variable	**Round**	**F-value**	**df**	**P-value**	**Transformation**
Pollinators	Round 1	13.341	9.497	*0.010*	Log
Pollinators	Round 2	14.037	21.000	*< 0.001*	Log
Bumblebees	Round 1	12.948	9.614	*0.005*	Log
Bumblebees	Round 2	6.163	21.000	*0.022*	Log
Carabids	Round 1	0.039	10.130	0.848	Log
Carabids	Round 2	2.425	10.080	0.150	Log
Spiders	Round 1	3.412	10.239	0.094	Log
Spiders	Round 2	2.886	10.115	0.120	Log
Rove beetles	Round 1	2.148	10.279	0.173	None
Rove beetles	Round 2	2.425	10.488	0.149	None
All predators	Round 1	1.495	10.303	0.249	Log
All predators	Round 2	4.416	10.083	0.062	Log
All predators	Both rounds	0.002	10.208	0.963	Log
Aphid predation		0.858	11.621	0.373	None
Flower resources	Round 1	21.095	11.120	*< 0.001*	Log
Flower resources	Round 2	19.826	11.022	*< 0.001*	Log
Flower resources: Pollinators	Round 1	10.460	9.832	0.009	Log/Log
Flower resources: Pollinators	Round 2	15.363	21.000	*< 0.001*	Log/Log
Flower resources: Bumblebees	Round 1	12.482	21.000	*0.002*	Log/Log
Flower resources: Bumblebees	Round 2	13.333	9.572	*0.005*	Log/Log
Predators: Aphid predation	Round 1	0.961	10.708	0.349	Log/None

6. Discussion

6.1. Grain and biomass yield

No differences were found for oat harvest index and grain yield between treatments. The hypothesis of oat yield quantity being higher in control was therefore not supported. The nitrogen content of oat grains was higher in the control sole crop treatment compared to the clover treatment. The sole crop having higher nitrogen content than the clover treatment thereby confirms my hypothesis. Even though the difference between treatments was only about 4 %, the difference was consistent among sites. The result could be explained by a high nitrogen uptake from the soil by the clover species, possibly if these particular clover species are strong competitors for soil nitrogen (Dayoub *et al.* 2017). The highest nitrogen content was found in *T. squarrosum* which might be explained by this species having the highest biomass and thereby a high nitrogen fixating potential as well as high potential nitrogen uptake from the soil. The lower nitrogen content in oats could also be explained by a difference in nitrogen allocation of oats to kernels when intercropped with clovers, when oat straws increases in height as a result of competition for light.

The difference in plant emergence between sites could be a result of differences in sowing method and machinery, where machineries coping with one clover species better than the others, differences between machineries causing seeds to be drilled to deep or to shallow. *T. resupinatum* had the smallest seeds and is the most likely species to be sown to deep, but the ratio of seed used for sowing to plant emergence was similar for all three species. Dry weather following sowing could also impact by delaying or reducing germination, which was probably the reason for the poor clover emergence in site VÅ. Difference in biomass could originate in shoot emergence being affected by differing environmental condition between locations, e.g. to cold or dry for *T. resupinatum* to germinate (Olssons frö, 2021) and causing difference in competition, stressing clover before being self-supporting of nitrogen.

Clover is more likely to suffer from competition with oats due to oats being a stronger competitor for resources (Bedoussae *et al.* 2015). Since *T. incarnatum*, *T. resupinatum* and *T. squarrosum* have some documentation of different competiveness against weeds, however not conclusive (Verret *et al.* 2017; Ranaldo *et al.* 2019; Adeux *et al.* 2021; Scandinavian seed, 2021; Olssons frö, 2021), it is also likely that they have differences in traits used for competing for resources with oats. Together with slightly different environmental conditions for optimal performance, this might affect the species composition to vary among sites. If the clover species only was impacted by the competition with oats, given that environmental factors provides similar stress on these species, then the ratio between the species would follow a similar pattern e.g. a site with high biomass of oats would at the same time be low in clover biomass and vice versa. This is the case for site SL and EN, with an oat biomass between 10000-14000 kg oats biomass DW/ha but well under 100 kg DW/ha of all clover species. A thick and high oat canopy reduces the possibility for light interception for clovers. Site KÖ had the highest biomass yield of clover but belongs to the bottom five with the lowest oat biomass. In this site, oats might have been affected more negatively by weather conditions than clovers. However, site KB, UA, AN and TG belonged to the top eight sites of producing between 9000-14000 kg oats biomass DW/ha, but also to the top five of high clover biomass. These scattered results could mean that other factors such as competition with weeds, row width and different abilities of handling environmental impacts e.g. dry weather affected the dynamics between clover and oats competing for light and nutrients. Reports about difference in nitrogen uptake between legume species, especially early in development and growth (Dayoub *et al.* 2017), might be one of the factors impacting the competition dynamic between oats and clovers as well as between clover species. The faster the clover species can start to fixate nitrogen, the more independent it is supporting itself on nitrogen and thereby less affected by competition.

In the mix of clover species, *T. incarnatum* was the most abundant at eight sites followed by fours sites dominated by *T. squarrosum* and two sites by *T. resupinatum*. However, *T. resupinatum* was sown in relatively lower densities. Having the highest biomass, *T. squarrosum* has been found to correlate with lower weed biomass (Ranaldo *et al.* 2019) which might suggest that this species is competitive. The ratio between the clover species appears similar when comparing sites, except for site KÖ and UA. Even though high in *T. squarrosum* biomass (e.g. TG, AN and KB) the biomass of both *T. incarnatum* and *T. resupinatum* followed a similar pattern. This might suggest that the clover species competed similarly within the sites, *T. squarrosum* being the overall stronger competitor. *T. squarrosum* might be facilitating the other clovers having more flowers, and thereby indirectly support pollinator abundance. Intercropping several clover species elevates the chances of a higher biomass yield and higher efficiency in resource usage (Azam-Ali, 2003; Bedoussae *et al.* 2015; Malézieux *et al.* 2009) as well as a better insurance to achieve high biomass yield when one species can compensate for loss of another (Azam-Ali, 2003).

Half of the sites hade about double row spacing (25-33 cm) compared to the other half (12.5 cm). For instance, the site SL had a shoot emergence relative to HB, EN and AO but a low yield of clover biomass (as why SL was excluded). HB and SL had both 12.5 cm in row spacing, which means the competition with oats should be equal if environmental conditions were similar. But EN and AO had double row spacing, which means that the clover had a better chance of light interception (Bedoussac *et al.* 2015) in the competition with oats and therefore more likely to get a higher clover biomass yield. Because there was no difference in grain or biomass yield of oats between these sites, it is likely that wider row spacing elevates the chance of a higher clover biomass yield and reduces the impact of environmental conditions e.g. on competition for light during clover growth and development. Further more, three of the sites with wider row spacing also used row-hoeing equipment for under-sowing clover that might impact plant emergence and competition dynamics.

6.2. Weed biomass and coverage

No difference between treatments was found in the biomass of weeds when all sites were included in the analysis. However, if site ER2 was removed from the analysis, the biomass of weeds was reduced. This could be explained by the patchy appearance of vetches (*Vicia spp.)* used as a cover crop in years before and still present in the ER2 field. Using weed coverage data that was collected in larger areas, could be assumed reduce some of the effect of patchiness of vetches found in the small quadrats where the biomass was harvested. The stronger correlation between weed biomass and weed coverage excluding ER2, indicate that the biomass data without ER2 is more credible. However, even though the coverage of weeds did not differ between treatments and were not affected by the removal of ER2, the estimation was based on classes that might be less consistent with the true weed cover. Based on the analysis that excluded ER2, the hypothesis of weed biomass being lower in the intercrop compared to sole crop of oats is confirmed.

The difference in competiveness between *T. incarnatum, T. resupinatum* and *T. squarrosum* against weeds, might be explained by the interspecies competition highly depending on weather conditions, row spacing (Rathika *et al.* 2013) as well as competition with the main crop. Overlapping between niches of crops might cause facilitation, where the dominant crop early in development e.g. oats makes room for the slower growing e.g. clover by reducing available nitrogen for weeds and thereby providing space otherwise filled with non-Fabaceae weeds. The difference in results of the effect on weed biomass by intercropped *T. incarnatum*, *T. resupinatum* and *T. squarrosum* in the present study as well as in previous (Verret *et al.* 2017; Ranaldo *et al.* 2019; Adeux *et al.* 2021) might have to du with the early development of the clover species in these intercropping systems, especially their ability to compete for nitrogen (Dayoub *et al.* 2017). If the clovers are not able to be self-sufficient in nitrogen early in development (Andersen 2005; Haugaard-Nielsen *et al.* 2009), they might suffer from competition by weeds.

However, successfulness in limiting weed abundance could also be shown by reducing the soil seed bank (Reddy, 2017) when germinating seed fails to reproduce or completely fails to germinate (Anil *et al.* 1998). Furthermore, row spacing might impact the effect on weeds by intercrops (Rathika *et al.* 2013; Shah *et al.* 2011). Of all the sites with row spaces between 25-33 cm, three had a relatively large (ER2, AO and UA) and two (KÖ and EN) relatively low weed coverage in clover treatment. All of the other six sites with 12.5 cm drilling distance showed less variation in weed coverage of clover treatment. This could mean that intercrops with larger row distance are affected more by environmental impacts on clover development, and thereby weed interactions, than those with smaller row distance caused by less competition by oats. In intercropped cover crops, as long as they do not become a severe problem in succeeding crops, high weed diversity could also help to reduce nutrient leaching and elevate carbon sequestration (Baraibar *et al.* 2021) and indirectly also increase the abundance of decomposing arthropods by elevating plant biomass (Ebeling *et al.* 2014). However, if facilitated, highly competitive weed species such as *Elymus repens* L. or *Cirsium spp*. could be necessary to control by tillage or herbicides and thereby have negative effect on arthropod abundance, nutrient leaching and carbon sequestration.

6.3. Pollinators and flower resources

Both a higher abundance of pollinators overall as well as abundance of bumblebees was found in the clover treatment compared to the control. The hypothesis of the clover mixture elevating pollinator abundance could thereby be confirmed, which means that pollinators, especially wild bumblebees, are supported by the intercropped clover species. This is further supported by the correlation found between pollinator and flower abundance. For elevating pollinator density of the intercrop, *T. incarnatum* was the clover species that showed highest amount of visitations (Table 5). In contrast, *T. resupinatum* had no visitations of bumblebees but most of the honeybee visitors. This result might be explained by the difference in corollas of the flowers and the tongue length of the bees. The deeper corollas of *T. incarnatum* fitting better the tongue length of bumblebees than honeybees and vice versa (Goulson, 2010). Of the bumblebee species visiting *T. incarnatum,* 4 % belonged to the long tongued bumblebee

Bombus subterraneus, which means that this clover species also can support rare longue tonged bumblebee species (Goulson *et al.* 2005), and not only the previous recorded short tongued species such as *B. terrestris/lucorum* and *B. lapidarius* (Norris *et al.* 2017). Further, the diversity of flower visiting species of bumblebees was high for *T. incarnatum*, visited by eight species. There was an almost equal number of bumblebee visits of weed plants in both control and clover treatments. Although having the lowest amount of flowers, *T. squarrosum* also showed to be visited by bumblebees, however flowering later in season could have impacted the outcome of visitation in this study. The use of annual clover species, such as *T. incarnatum*, with different flowering time and as a cover crop not being harvested, elevates bumblebee abundance and species diversity.

The sites were located in different landscapes types, where some had a higher complexity, containing more forest and field verges. Because differences in pollinator abundance depend on the degree of landscape complexity (Tscharntke *et al.* 2002), this could explain the wide range of pollinator abundance found in clover treatment (Figure 15-16). Surrounding landscape features, such as abundance of field verges, pastures, woodland, the diversity of crops in crop rotations and field management intensity might have an impact on pollinator abundance (Norris *et al.* 2017; Westphal *et al.* 2009). Further, the use of intercropped clover for elevating food sources for pollinators could have an even larger effect if used not just once but more often in the crop rotation. Providing a continuity of floral resources during pollinator population growth and reproduction reduce the risk of bottlenecks (Schellhorn *et al.* 2015), which in turn will provide even more populations the upcoming years. Mass flowering crops have been shown to be a temporal flower resource for pollinators to enhance both abundance (Westphal *et al.* 2009) and reproduction (Rundlöf *et al.* 2014). Therefore, it is likely that flowering cover crops could have similar results on bumblebee population reproduction or even better depending on its continuity. These might be extra important for smaller bumblebee species with shorter dispersal range (De Luca *et al.* 2019).

6.4. Ground-dwelling arthropod predators and aphid predation

No effect on abundance of ground-dwelling predators was found for the clover treatment, and the hypothesis of clover mixture elevating abundance was thereby not confirmed. The second survey, done in late July and beginning of August, showed lower probabilities for random effects causing higher abundance of carabids ($p=0.15$), spiders ($p=0.12$) and overall ground-dwelling predator abundance ($p=0.06$). Maybe if the number of replicates were higher, the higher abundance could be explained by the clover treatment. An increase of ground-dwelling predators in survey two compared to survey one, could be explained by a time-depending accumulation of predators coming from nearby habitats such as field verges. However, the difference shown in this study cannot with confidence be separated from the random effects. Neither was there any effect from the clover on aphid predation or correlation between predators and predation. My hypothesis of a higher aphid predation in oats under-sown with clovers is thereby not confirmed. The general abundance of rove beetles was low and therefore difficult to analyse.

The difference in range of ground-dwelling predators within both treatments (Figure 18-21), could be a result of surrounding landscape structure (Persson & Smith, 2013; Galloway *et al.* 2021), weed vegetation structure, no-till litter or tillage (Haaland *et al.* 2011), row-spacing and within intercrop competition (Bukovinszky *et al.* 2004). E.g. a high diversity and abundance of predators in field margins could affect the diversity of natural predators in this study. Where larger differences in heterogeneity of treatments have been used, between treatment and control, results have been more prominent. This might explain why a lot of the studies of ground-dwelling predators have been done in systems with high diversity in vegetation structure, such as vegetables and agroforestry. The effect on ground-dwelling predators could also be delayed, shown first after a few years as reduced pest reproduction by predator induced stress (Eubanks & Finke 2014). In the long run, differences in how the cover crop is terminated (Rivers *et al.* 2018), the following soil management practices (Landis *et al.* 2000) and the following crop´s vegetation structure (Landis *et al.* 2000) might affect if the predators return to the field. This could also explain the tendency of a higher abundance of ground-dwelling predators found during second survey.

The plot size of the control could also affect the number of found ground-dwelling arthropod predators by more or less accumulate their numbers when the ratio of edge to total plot area is too low (edge effects). Measuring ground-dwelling predators could be affected by the plot size (McSorley, 2000), row intercropping of a cover crop of the whole field might show higher effect than flower strips used on field edges on ground-dwelling predators. Due to the larger area of heterogeneity of the field potentially creating more habitats and thereby also more entering points from surrounding habitats e.g. field verges. After all, it seems to be the heterogeneity of the field and not the flower resources that is important to natural predators. To be able to measure abundance of ground-dwelling predators, the treatments have to be affected in the same way. Because four of the sites had the whole field intercropped, larger edge effects causing accumulation of predators in the control might have impacted the results. Using larger control treatments might reduce those effects if intercropping on larger scale.

6.5. Utility and future research

The management system, leaving litter and vegetation residues on the soil, might be more important than effect of clover on ground-dwelling arthropod predators. In the future, I suggest that *T. resupinatum* is changed for a grass that has a tussocky appearance to attract ground-dwelling arthropod predators. However, only perennials over time form a real tussock but under-sowing a broadcasted grass species with a more shrubbery appearance by having a lot of shoots might help, e.g. *Festuca rubra* which is not a heavy competitor in seed mixes (SJV, 2012). Low seed doses of *Lolium multiflorum,* which in the middle of Sweden may not survive winter, might be less of a problem for no-till farmers. In order to evaluate the effects on weeds and ground-dwelling arthropods, field experiments lasting longer than one year is needed as a complement. In combination with more surveys evenly distributed over the season the year of study, the tendency of a higher abundance of predators found in clover treatment might be possible to confirm and using more surveys later in season might capture potential accumulation effects. A field experiment carried out for several consecutive years might also be able to capture effects of weed soil seed banks, as well as of crop rotation e.g. effects of re-occurring flowering resources. Also potential long-term effects of elevated weed diversity might impact the competition dynamics of nitrogen and light by plant species and impacting vegetation structure for ground-dwelling predators. Future research should also focus on researching the effects on species diversity within the weed and ground-dwelling predator communities.

Effects of clover treatment on nitrogen availability for the subsequent crop is expected because of clover not being harvested but left mulched or tilled to enrich the soil. However, the potential pre-crop effects of adding nitrogen to the soil by clover are highly affected by the environmental conditions (McKenna *et al.* 2018).

To further study the utility of intercropping clover as a cover crop, some factors causing clover fatigue (growth problems in clover) needs to be investigated. The presence of clover root rot was not tested in this field study but affects the applicability of intercropping clover. The pathogen causing clover root rot *Sclerotonia spp.* has a wide host range, causing a decrease of plant survival during winters (Vleugels 2013; SJV 2004). This would not directly affect annual species because the clover plants are not meant to survive winter, but they might retain the pathogen affecting other crops in the crop rotation (Axelsson & Andersson 2017) especially if no-till management is used were *Sclerotinia spp.* spores are not broken down. No studies exist for infections of the annual clover species used in this study by *Sclerotinia spp.* Apart from clover diseases caused by fungi, other clover fatigue problems are nematodes (Serikstad *et al.* 2013).

Intercropping provides highly valuable diversity effects, as supporting future pollination of crops by enhancing abundance of intercropped flower resources e.g. intercropped clovers in oats by providing higher biodiversity today both within the fields and indirectly in the surrounding landscapes. Using a non-harvested flowering cover crop to enhance the flowering season is an important advantage to prolong the effects through out the season as well as to provide pre-crop effects such as higher nitrogen abundance and to elevate carbon sequestration by keeping the soil covered in-between crops. A cropping system supporting biodiversity is more likely to be resilient e.g. against climate change and also provide enhanced resilience of surrounding ecosystems. A 5 % reduction in oat grain nitrogen content, as found in the clover treatment, is probably a small price to pay for a cropping system able to produce food now as well as in the future. If every farmer intercropped a cover crop at least one field every year, this could create a heterogeneity and continuity much needed for supporting both the cropping system itself as well as the surrounding ecosystems.

7. Conclusions

This report shows that intercropped clovers in oats contributes to diversify the cropping system by elevating biodiversity within fields by increasing wild pollinator abundance, without at the same time reducing oat grain yield. Even though *T. incarnatum* stood for most of the bumblebee visitations, its abundance was enough to show differences in bumblebee abundance between intercropped clovers and oats compared to sole stand oats. *T. incarnatum* had most visitations by wild pollinators and second largest mean biomass yield. *T. squarrosum* provided the highest mean biomass yield and had a few visiting wild pollinators. *T. resupinatum* had the lowest mean biomass yield and no visitations by wild pollinators. To further understand the intercropping cover crop effects on ground-dwelling arthropod predator populations and weed abundance, field studies continuing over several consecutive years are needed. Also, potential effects of intercropped clover on pathogens such as *Sclerotonia spp.* on crop rotations need to be examined.

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Appendix 1

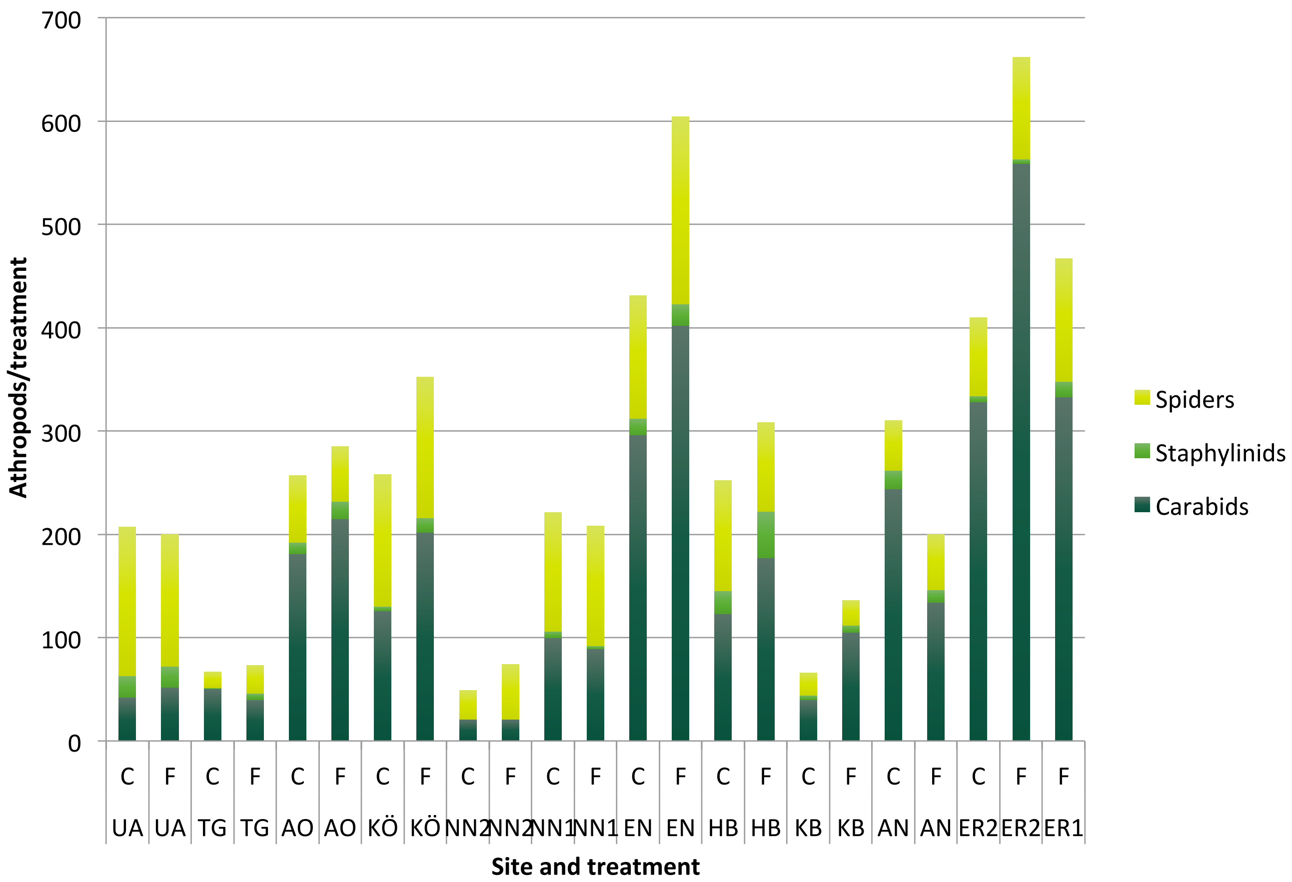

Figure A1. The distribution of ground-dwelling predators between treatments and sites. The abundance of staphylinides (rove beetles) was low. C stands for control and F stands for clover treatment.

Table A1. The species of ground-dwelling arthropods found in the clover and control treatments.

Group	**Genus/species**	**Control**	**Clover**	**Group**	**Genus/species**	**Control**	**Clover**
Rove beetles	*Aleochara*	37	28	Carabids	*Agonum assimile*	0	1
Rove beetles	*Amischa*	28	27	Carabids	*Agonum dorsale*	10	16
Rove beetles	*Anotylus*	41	24	Carabids	*Agonum muelleri*	0	0
Rove beetles	*Astibus*	1	4	Carabids	*Agonum obscurum*	8	2
Rove beetles	*Athea fungi*	41	28	Carabids	*Amara aenea*	0	1
Rove beetles	*Atheta gregaria*	370	412	Carabids	*Amara aulica*	36	40
Rove beetles	*Hypocytus*	4	3	Carabids	*Amara apricaria*	45	60
Rove beetles	*Ilyobates*	5	2	Carabids	*Amara bifrons*	1	0
Rove beetles	*Ischnosoma*	0	1	Carabids	*Amara brunnea*	0	1
Rove beetles	*Lathrobium*	7	15	Carabids	*Amara familiaris*	5	3
Rove beetles	*Lesteva*	0	1	Carabids	*Amara lunicollis*	1	1

Table A1 cont. The species of ground-dwelling arthropods found in the clover and control treatments.

Group	**Genus/species**	**Control**	**Clover**	**Group**	**Genus/species**	**Control**	**Clover**
Rove beetles	*Mycetoporus*	27	34	Carabids	*Amara similata*	7	10
Rove beetles	*Oxytelus*	2	2	Carabids	*Bembidion aeneum*	3	9
Rove beetles	*Philonthus*	113	119	Carabids	*Bembidion guttula*	1	1
Rove beetles	*Quedius*	1	2	Carabids	*Bembidion lampros*	53	70
Rove beetles	*Staphlyinus*	11	18	Carabids	*Bembidion quadrimaculatum*	6	6
Rove beetles	*Stenus*	0	1	Carabids	*Calathus erratus*	9	10
Rove beetles	*Tachporus*	34	48	Carabids	*Calathus fuscipes*	73	39
Rove beetles	*Zantholinus*	17	32	Carabids	*Calathus melanocephalus*	4	2
Rove beetles	*Zyras*	0	1	Carabids	*Calathus micropterus*	16	17
Rove beetles	*Pselaphinae*	0	1	Carabids	*Carabus granulatus*	0	4
Carabids	*Acupalpus meridianus*	22	7	Carabids	*Carabus nemoralis*	1	0

Table A1 cont. The species of ground-dwelling arthropods found in the clover and control treatments.

Group	Genus/species	Control	Clover	Group	Genus/species	Control	Clover
Carabids	*Clivina fossor*	19	44	Carabids	*Stomis pumicatus*	1	1
Carabids	*Dolichus halensis*	0	0	Carabids	*Synuchus vivalis*	29	28
Carabids	*Harpalus affinis*	15	21	Carabids	*Trechus discus*	0	7
Carabids	*Harpalus distinguendus*	0	1	Carabids	*Trechus micros*	0	3
Carabids	*Harpalus latus*	0	4	Carabids	*Trechus secalis*	25	31
Carabids	*Harpalus rufibarbis*	0	1	Carabids	*Trechus quadristriatus*	380	453
Carabids	*Harpalus rufipes*	1387	1853	Carabids	*Coccinella septempunctata*	0	0
Carabids	*Lebia chrysocephala*	1	0	Carabids	*Propylea quattuordecimpunctata*	0	0
Carabids	*Licinus depressus*	0	1	Spiders	*Achaearanea riparia*	2	1
Carabids	*Loricera pilicornis*	1	3	Spiders	*Phylloneta impressa*	1	3
Carabids	*Metabletus foveatus*	0	1	Spiders	*Robertus arundineti*	0	2

Table A1 cont. The species of ground-dwelling arthropods found in the clover and control treatments.

Group	Genus/species	Control	Clover	Group	Genus/species	Control	Clover
Carabids	*Metabletus truncatellus*	3	0	Spiders	*Robertus neglectus*	0	2
Carabids	*Microlestes minutulus*	2	5	Spiders	*Theridion sisyphium*	0	1
Carabids	*Nebria brevicollis*	16	18	Spiders	*Theridion varians*	0	1
Carabids	*Notiophilus aestuans*	0	1	Spiders	*Agyneta rurestris*	225	283
Carabids	*Notiophilus aquaticus*	1	0	Spiders	*Bathyphantes gracilis*	21	22
Carabids	*Patrobus atrorufus*	4	4	Spiders	*Erigone atra*	239	198
Carabids	*Poecilus cupreus*	647	666	Spiders	*Erigone dentipalpis*	44	52
Carabids	*Poecilus lepidus*	2	2	Spiders	*Micrargus subaequalis*	12	7
Carabids	*Pterostichus melanarius*	1054	938	Spiders	*Microlinyphia pusilla*	1	1
Carabids	*Pterostichus niger*	299	453	Spiders	*Oedothorax apicatus*	639	689
Carabids	*Pterostichus vernalis*	31	25	Spiders	*Oedothorax fuscus*	7	6

Table A1 cont. The species of ground-dwelling arthropods found in the clover and control treatments.

Group	Genus/species	Control	Clover	Group	Genus/species	Control	Clover
Spiders	*Oedothorax gibbosus*	1	0	Spiders	*Pardosa fulvipes*	8	4
Spiders	*Oedothorax retusus*	0	1	Spiders	*Pardosa lugubris*	2	1
Spiders	*Pelecopsis parallela*	0	3	Spiders	*Pardosa paludicola*	0	3
Spiders	*Poecilonota gibbosa*	0	1	Spiders	*Pardosa palustris*	168	212
Spiders	*Porrhomma microphthalmum*	3	2	Spiders	*Pardosa prativaga*	107	118
Spiders	*Porrhomma pygmaeum*	2	1	Spiders	*Pardosa pullata*	8	17
Spiders	*Saaristoa abnormalis*	0	1	Spiders	*Pardosa sphagnicola*	0	1
Spiders	*Savignia frontata*	1	1	Spiders	*Pardosa subadult*	24	19
Spiders	*Tenuiphantes tenuis*	1	1	Spiders	*Pardosa juveniles*	27	37
Spiders	*Tenuiphantes zimmermani*	1	1	Spiders	*Pirata tenuitarsus*	0	1
Spiders	*Tiso vagans*	0	1	Spiders	*Pirata uliginosus*	1	7

Table A1 cont. The species of ground-dwelling arthropods found in the clover and control treatments.

Group	Genus/species	Control	Clover	Group	Genus/species	Control	Clover
Spiders	*Troxochrus scabriculus*	3	2	Spiders	*Trochosa ruricola*	32	43
Spiders	*Linyphiid subadults*	52	28	Spiders	*Trochosa subadults*	97	106
Spiders	*Linyphiid juveniles*	10	15	Spiders	*Trochosa juveniles*	78	73
Spiders	*Pachygnatha degeeri*	7	17	Spiders	*Xerolycosa minitiata*	3	1
Spiders	*Tetragnatha extensa*	0	1	Spiders	*Xerolycosa nemoralis*	0	1
Spiders	*Tetragnatha pinicola*	0	1	Spiders	*Lycosid spiderlings*	1299	947
Spiders	*Alopecosa cuneata*	3	0	Spiders	*Drassodes cupreus*	1	0
Spiders	*Alopecosa pulvurulenta*	1	0	Spiders	*Drassyllus lutetianus*	1	0
Spiders	*Alopecosa juveniles*	1	1	Spiders	*Drassyllus pumilus*	0	1
Spiders	*Pardosa agrestis*	242	223	Spiders	*Drassyllus pusillus*	4	6
Spiders	*Pardosa amentata*	4	2	Spiders	*Micaria pulicaria*	1	4

Table A1 cont. The species of ground-dwelling arthropods found in the clover and control treatments.

Group	Genus/species	Control	Clover	Group	Genus/species	Control	Clover
Spiders	*Zelotes latreillei*	3	2	Spiders	*Diapriidae*	23	14
Spiders	*Gnaphosidae subadults*	3	2	Spiders	*Ichneumonidae*	3	0
Spiders	*Clubiona reclusa*	2	3	Spiders	*Megaspilidae*	11	7
Spiders	*Clubiona subsaltans*	1	0	Spiders	*Mymaridae*	5	1
Spiders	*Clubiona juveniles*	0	1	Spiders	*Platygastridae*	112	89
Spiders	*Pisaura mirabilis*	0	5	Spiders	*Proctotrupidae*	2	4
Spiders	*Agelena labryrinthica*	2	3	Spiders	*Pteromalidae*	3	2
Spiders	*Thanatus arenarius*	1	1	Spiders	*Signiphoridae*	4	6
Spiders	*Micrommata virescens*	1	0	Spiders	*Chilopoda*	23	5
Spiders	*Ozyptila atomaria*	0	1	Spiders	*Braconidae*	19	19
Spiders	*Xysticus audax*	2	0	Spiders	*Ceraphronidae*	33	27

Table A1 cont. The species of ground-dwelling arthropods found in the clover and control treatments.

Group	**Genus/species**	**Control**	**Clover**	**Group**	**Genus/species**	**Control**	**Clover**
Spiders	*Xysticus bifasciatus*	0	1	Spiders	*Anistea elegans*	1	0
Spiders	*Xysticus cristatus*	1	4	Spiders	*Predatory Acari*	83	113
Spiders	*Xysticus juveniles*	0	3	Spiders	*Opiliones*	73	58
Spiders	*Zora nemoralis*	1	1	Spiders	*Formicidae*	36	27

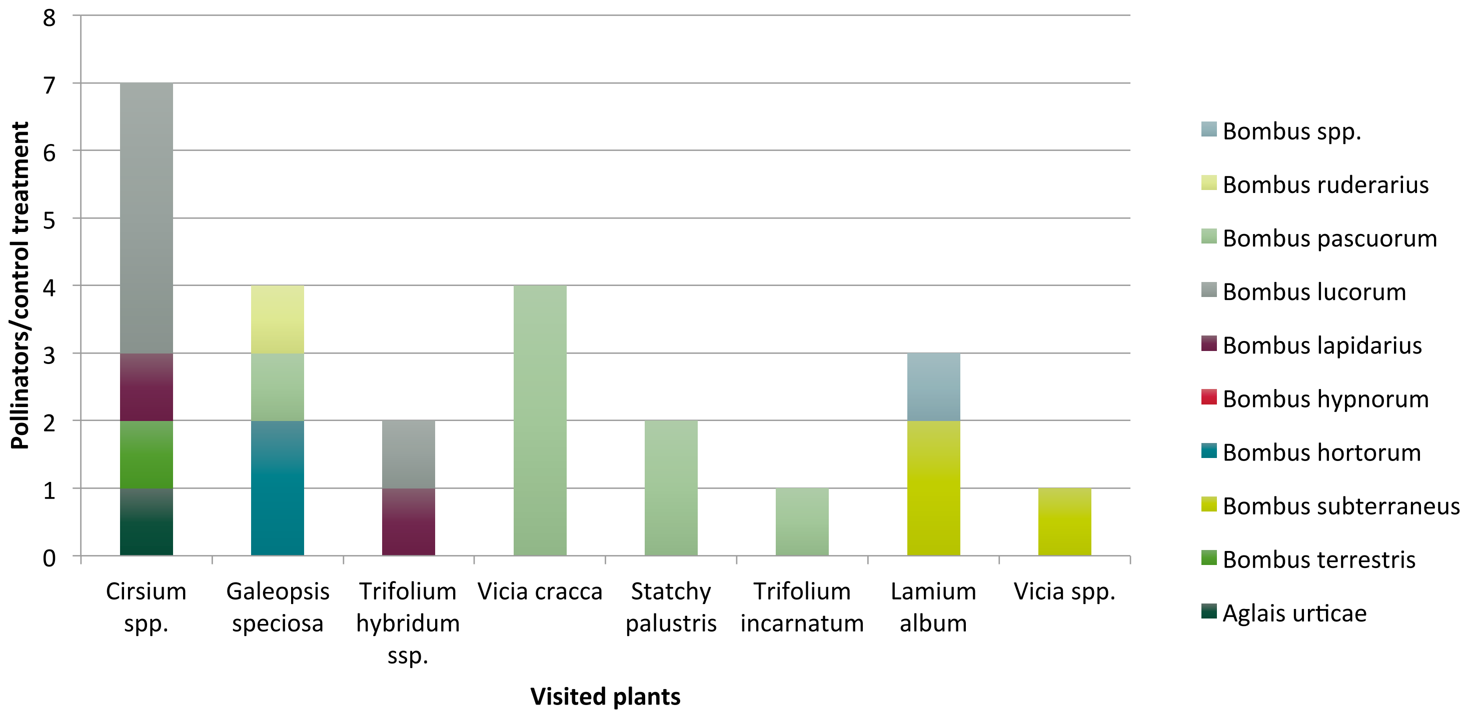

Figure A2. Plant species in the control treatment visited by pollinator species.