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ASSESSING THE INFLUENCE OF INTERSEEDED COVER CROPS ON BENEFICIAL ARTHROPOD ABUNDANCE IN A NORTHEASTERN AGROECOSYSTEM

by

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A Thesis Submitted in Partial Fulfillment
of the Requirements for a Degree with Honors
(Ecology and Environmental Sciences)

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ABSTRACT

Conservation agriculture approaches are gaining traction as the planet's food system grapples with climate change, oil depletion, and rampant environmental degradation (Palm et al., 2014). Cover cropping is an integral practice of conservation agriculture. Ground dwelling arthropods play an important role in agroecosystems, providing ecosystem services including seed predation and nutrient cycling. Because the relationship between cover crops and arthropod abundance are likely influenced by management conditions, I investigated arthropod abundance in a field interseeded with cover crops on a research farm in Maine, United States. Interseeding is an emerging practice in the northeastern United States, with potential to address the barriers to more typical cover cropping. Such barriers are primarily economic and ecological in nature. For example, it can be difficult to achieve sufficient biomass when cover crops are planted late in the growing season, diminishing potential ecosystem service benefits. The influence of interseeded cover crops on beneficial arthropods has not been researched in this bioregion.

In this study, arthropods were sampled using pitfall traps three times during the 2023 fall growing season. I sampled from plots that were either cover-cropped or not cover-cropped (the latter being the control treatment), with 4 replicates per treatment. *Harpalus rufipes* DeGeer (Coleoptera: Carabidae) was the most abundant groups sampled, with members of the *Gryllus* genus (Orthoptera: Gryllidae) also highly abundant. *H. rufipes* and G. species are granivorous, providing seed predation services to regulate weed seedbanks. No significant difference in abundance or diversity was found between treatments, though other conditions observed in the experiment likely influenced

this outcome. A moderate positive linear relationship was found between canopy cover, which included both cover crops and weeds, and arthropod abundance. Both cover crops and weeds provide habitat for beneficial arthropods. Suitable habitat was less available when intercrop space was left bare. These findings show that cover crops provide the valuable habitat for beneficial arthropods, without the management complications and yield losses associated with high weed pressure. The findings prompt further research on the myriad factors influencing beneficial arthropod abundance in agroecological systems.

DEDICATION

For Jackie Cooper, my mom, for her endless care and support.

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TABLE OF CONTENTS

LIST OF FIGURES/TABLES

INTRODUCTION

Cover Crops

Cover Crops Uses and Purpose

Ecosystem service management is vital to the sustainability of farms. Ecosystem services are emergent processes from properly functioning ecosystems that are beneficial to humanity (Kumar, 2012). A range of ecosystem services can be tapped by farmers, including carbon sequestration, the promotion of biodiversity, and water regulation. The utilization of ecosystem services not only boosts sustainability for farmers, but also reduces externalities downstream of farm operations, like producing cleaner effluent and reducing air pollution (Palm et al., 2014). Conventional agriculture has been shown to provide many of these ecosystem services (Vidaller & Dutoit, 2022). However, conservation agriculture approaches go further to support the ecosystem functions providing services through the intentional integration of sustainable management practices. The reliance of conventional agriculture on chemical inputs, machinery, and high-intensity management practices reduces the short-term need to access ecosystem services on the farm level. Conservation agriculture approaches seek to maintain ecosystem stability which enables service utilization (Palm et al., 2014).

Cover crops have the potential to provide valuable ecosystem services to farms. However, adoption of cover cropping is limited in the United States, covering about 5.1% of cropland nationwide as of 2017 (Wallander et al., 2021). The majority of cover crop adoption is concentrated in the Mid-Atlantic region. For example, Maryland farmers use cover crops on about 33% of farmland (Wallander et al., 2021). New England is among the regions with marginal cover-crop adoption, raising questions about means to adapt the practice to the unique needs of the region. Economic, cultural, and climatic barriers hinder widespread adoption of cover cropping (Crézé & Horwath, 2021; Roesch-McNally et al., 2018).

One of the primary services cover cropping provides is reduced soil erosion. Tons of topsoil are lost each year due to erosion resulting from conventional agriculture practices. Approximately 57.6 billion metric tons of topsoil has eroded in the American Midwest alone since the beginning of agriculture by American colonists in the region (Thaler et al., 2022). Topsoil is vital to the growth of crops, providing a growing medium and nutrients. Historically, topsoil erosion has created major problems in food systems. The Great Depression of the 1920s was partially fueled by the American Dust Bowl. The Dust Bowl was in large part due to intensive cultivation of the land (Hurt, 1981). Without the stabilizing and water retaining properties of plant roots, the soil was highly susceptible to wind erosion. Cover crops reduce erosion by maintaining root biomass on the soil surface. In soils populated by roots, water is absorbed and infiltrates rather than mobilizing large volumes of soil through runoff. Cover cropped soils exhibit increased water infiltration compared to fallow soils (Lee & McCann, 2019), and serve as a critical component of multifaceted erosion control and drought resilience plans.

Cover crops can also help increase soil organic matter (SOM) of cultivated land. SOM is carbon-based material in soils derived from the tissues of organisms in various stages of decomposition (Simpson & Simpson, 2017). SOM aids in the retention of nutrients and water. Cationic nutrients like potassium, magnesium, and calcium adhere to the slight negative charges of organic molecules (Lehman et al., 2015). Water is also bound in the macrostructures of organic matter particles. leading to increased water holding capacity (Hudson, 1994). However, the water available to plants is limited to about a 1.16% volumetric increase for each 1% increase in SOM mass (Minasny & McBratney, 2018). Toxic elements, including aluminum, can be immobilized by SOM, reducing their uptake by crop plants (Hatten & Liles, 2019). Increasing SOM in soils is a means to increase carbon in soils, which is an increasingly important consideration in the context of climate change. Cover crops have the potential to be an important tool to trap and retain carbon in soils (Rejesus et al., 2021).

Organisms in the soil require SOM for habitat and food. Micro and macrofauna residing in the subsurface hold nutrients in their tissues, which may become available upon decomposition (Wade et al., 2015). Decomposers break down organic matter and liberate these nutrients for use by plants (Hatten & Liles, 2019). They also contribute to porosity of topsoil, enabling water infiltration and air exchange. High biomass yielding varieties are needed to produce a net gain in SOM (Mohler & Johnson, 2009). Such varieties tend to be grasses, such as sorghum sudangrass (*Sorghum × drummondii*) or annual ryegrass (*Lolium multiflorum*). When managed for biomass production, cover crops can increase SOM, thereby improving conditions for the organisms that reside in soil. This effect is contingent on several factors, including cover crop species selection, tillage regime, termination and incorporation method, and environmental conditions, such as temperature and precipitation (Blanco, 2023).

Species of cover crops must be carefully selected to meet the farmer's needs. For example, if a grower wishes to reduce nitrogen fertilizer costs, then they should opt for a legume or legumes-grass mix. Such plants make nitrogen available via a symbiotic association with nitrogen fixing bacteria in their root nodules. A bacterial inoculant is needed to maximize nitrogen fixation by leguminous cover crops unless a crop of the same family has been planted in the last 2 years (Clark et al., 1988). Inoculants are a product that must be purchased alongside seed, posing additional costs (Escobar Ortega et al., 2021).

Seeding cover crops together in mixes can provide multiple ecosystem services simultaneously, increasing ecological and economic benefits to the farmer. For example, seeding a legume and a grass together enhance the benefits of each. Legumes are often climbers, and the grass serves as a structural support nurse crop (Ranells & Wagger, 1997). Such a planting scheme provides both biomass and nitrogen to soils. If the farmer seeks to optimize SOM, then they should select high-biomass varieties. Farmers managing for disease pressure consider including brassica cover crops for their suppressive properties of select pathogens (Townshend & Davidson, 1962). A comprehensive plan factoring in advantages and disadvantages of species selection, termination times, and management approaches is critical to a successful cover cropping practice.

Nutrient recycling is a key ecosystem service provided by cover crops. Plants hold nutrients in their tissues that might otherwise runoff, volatilize, or mineralize and become unavailable to cash crops. Nitrogen is especially susceptible to runoff and is often overapplied on crop fields. Globally, 60% of applied nitrogen is not used by crops (West et al., 2014). In the United States alone, 8.02 million tonnes of nitrogen are applied in excess, accounting for 11% of the global total (West et al., 2014). According to a survey of corn farmers in the Midwestern United States, farmers view N applications in excess of recommendations as a sort of insurance against poor yields (Houser, 2022;

Osmond et al., 2015). However, when nitrogen flows off the farm dissolved in effluent, it enters bodies of water like streams, rivers, ponds, lakes, and groundwater (Chislock et al., 2013). An influx of nitrogen can cause eutrophication, leading to hypoxic zones (Crawford et al., 2019). An often-cited example of this is the Gulf of Mexico, where N-loaded water from the Mississippi River watershed eventually flows. Much of the dissolved N in the Mississippi water was originally applied as agricultural fertilizer in the U.S. corn belt (Puckett, 1994.).

Cover crops hold some of this N in their tissues, reducing runoff potential. Though the N held in cover crop biomass can ultimately be made available to cash crops, it is released slowly over the course of a growing season as terminated cover crops decompose, with most varieties releasing plant-available nitrogen after 4-6 weeks (Sullivan & Andrews, 2012). Additionally, the overall need for applied N can be reduced by seeding leguminous cover crops. In an example of symbiosis, legumes develop nodules to provide habitat for Rhizobia nitrogen-fixing bacteria. Certain varieties of leguminous cover crops, such as hairy vetch (*Vicia villosa*) and berseem clover (*Trifolium alexandrinum*), can provide upwards of 200 kg of nitrogen per hectare (Lu et al., 2000). In an experiment conducted with organic broccoli cultivation, vetch-based cover crop mixes terminated prior to broccoli planting reduced nitrogen fertilizer requirements by 100–135 kg fertilizer equivalent N per hectare (Luna et al., 2020). Cover crops scavenge nutrients from the subsoil, which become available from the upon decomposition (Mohler & Johnson, 2009).

Cover crops can be used as an effective weed suppression tool. Cover crop canopies reduce sunlight infiltration to soil surfaces. Reduced sunlight hinders the germination and establishment of weed seed and seedlings (Lawley et al., 2012). When cover crops are established, they can outcompete weed seedlings for other resources as well, such as water and soil nutrients (Gerhards & Schappert, 2020). Some green mulches release allelopathic compounds as they decompose, inhibiting weed seed germination (Mennan et al., 2020; Weston, 1996). When cover crops are used for weed control instead of fallow periods, some can effectively disrupt the life cycles of weedy plants (Mohler & Johnson, 2009). Fallow fields are ideal habitat for weed colonization. A fallow field allows weeds to germinate, grow, and reproduce. Farmers may choose to address this by additional tilling or applying herbicides. Cover crops can reduce or eliminate the need for such interventions (Breech, 2018). Cover crops must be terminated before producing seed heads to prevent increased weed pressure in subsequent growing seasons. It should be noted that cover crops are not always effective as a sole approach to weed suppression, so they are best included as one element of a manifold approach to weed management (Fernando & Shrestha, 2023).

Biodiversity is a central tenant of agricultural sustainability. Cover crops can be a tool to increase biodiversity. Specifically, they provide habitat and food sources for generalist arthropod predators, which can reduce pest pressure through natural enemy relationships (Lu et al., 2000). Cover cropped plots have been shown to lower herbivorous insect populations. For example, a 2020 study showed lower thrip abundance in cover cropped fields versus those without (Bowers et al., 2020). Additionally, the nectar provided by cover crops can support pollinator activity by providing food sources over an extended time period within the growing season. By increasing biodiversity, cover crops can support natural enemy relationships, pollinators, and decrease pests in some circumstances (Appenfeller et al., 2022; Quinn et al., 2016; Carabajal-Capitán et al., 2021; McNeill et al., 2012).

Economics of Cover Cropping & Incentive Programs

Ecosystem services provided by cover crops can reduce management costs. Cover crops have been shown to provide economic benefits when planned and managed thoughtfully over several years (Myers et al., 2019). The practice is best characterized as an investment. Farmers should not necessarily expect cost reductions in the first year of use. One of the primary economic benefits associated with cover crop use is decreased spending on fertilizers, weed control, and erosion management. A Sustainable Agriculture Research and Education (SARE) survey estimated an average loss of $31.36 per acre of corn and $23.55 per acre of soybeans during the first year of cover cropping. However, the same study showed that after five years, cover crops can save between $33.90 and $50.90 per acre of corn and between $20.30 and $37.30 per acre of soybeans on cost of fertilizer, weed control, and erosion mitigation. This amounted to an average savings of $17.90 per acre of corn and $10.18 per acre of soy when input and management costs were factored in (Myers et al., 2019).

Cover crops provide a net positive return on investment in a shorter time frame when implemented to address specific on-farm issues, including: drought response, alleviating compaction, grazing livestock, conversion to no-till systems, and managing herbicide resistant weeds. Average net returns of cover crops implemented to target specific issues range between $33.10 and $110.45 per acre of corn or soybeans. The large range of cost savings is due to variability of losses caused by different problems and the efficacy of cover crops to address them. For example, cover cropping can increase yields during drought years, resulting in a net return of $110.45 per acre over five years, while the cost savings on fertilizer during the same five-year period amounts to only $33.10 (Myers et al., 2019). In no-till systems, legume cover cropping can increase yields greater than theoretically optimal fertilizing alone (Sarrantonio & Gallandt, 2003). While cover crops on their own can be a worthwhile investment for cost reduction and environmental sustainability, they are even more economically fruitful as a solution to acute problems.

Farmers must consider the cost-benefit ratio of cover cropping. Cover crops come with many additional costs. For example, seed must be purchased yearly. A survey for a SARE Technical Bulletin found the cost of seed ranged from $10 to $50 per acre during the survey years of 2012–2016. Seeding cost ranged from $5 to $18 per acre, and termination was $0 to $10 per acre. The survey showed a median cost of $37 per acre for seeds and seeding combined (Myers et al., 2019).

This study also showed that equipment needs differ between cover crop systems and conventional production practices. Seed drills ranging from 10 ft to 40 ft in length generally cost about $10 per acre or less to operate (Myers et al., 2019). Some cover crops can be seeded using the same or modified equipment as is used for common row crops, but not all. For example, a tillage tool can be modified with an air seeder to enable simultaneous tilling and seeding, reducing fuel usage associated with multiple tractor passes over a single field.

Specialized tractor implements are also needed for optimal termination and integration of cover crop biomass. Roll-and-crimpers are used in no-till systems to terminate the crop while maintaining soil structure. Such devices must be purchased outright, rented, or borrowed from equipment co-ops. Costs vary by sourcing method. Renting equipment restricts the window of cropping plan execution, adding yet other management consideration for farmers. Farmers must also consider the opportunity cost of cover cropping. A field in cover rather than cash crop is a field not producing income that season (Bergtold et al., 2019).

Despite significant ecosystem service benefits and the potential for economic returns, cover crops are not widely adopted on US farmlands, although their usage is growing (Zulauf, 2024). Less than 13% of farms nationwide use cover crops (Lee & McCann, 2019; USDA-NASS, 2019). About 15.4 million acres, or 5.1% of cropland, was cover cropped in 2017, increasing by 50% from 2012. (Wallander et al., 2021). The growth rate has slowed since, increasing by 17% to 18.0 million acres by 2022 (Zulauf, 2024). The majority of adoption is concentrated in the Mid-Atlantic states and Corn Belt. Maryland leads the pack in terms of percent coverage. In 2017, Maryland had 29% of cropland in cover, and Delaware had 20%. No other states reached above 20% land cover (Brown & Zulauf, 2019). However, Texas has the greatest total area of cover cropped farmland, with 1.5 million acres in 2022, increasing by 0.6 million in 2017 (Zulauf, 2024). Cover cropping is gaining in popularity nationwide, but the slowing growth rate is a concern to conservation agriculture advocates (Beeman, 2021).

Several government programs are available to increase the economic viability of cover crops. The National Resource Conservation Service (NRCS) is an agency within the United States Department of Agriculture (USDA), which manages the Environmental Quality Incentives Payment program (EQIP). EQIP provides grant funding to farmers to incentivize the implementation of conservation agriculture practices, including cover cropping. Payment rates vary depending on state and cover crop species mix. Rates are higher for conservation plans that entail using multiple cover crop species. Organic farmers may also receive higher payment rates, due to the relatively expensive cost of organic seed. Payments also cover a higher percentage of actual costs if farmers are categorized as historically underserved, or if they are beginning farmers (Myers et al., 2019). Payment rates per acre vary by state. In 2017, the lowest median payment per acre was $62.33 in Illinois, and the highest median payment rate was $92.27 per acre in Delaware (Wallander et al., 2021). About 2.4 million acres of cover crops were supported by EQIP funding in 2017.

The Conservation Stewardship Program (CSP), also administered by NRCS, provides five-year compensation contracts to farmers instituting conservation practices on their land, such as cover cropping. In the program, an NRCS representative works with the farmer to enhance their conservation practices. Farmers must already be utilizing practices to promote land conservations, so this program may not be right for all farmers. Only small to medium sized farmers are eligible, those making $900,000 or less of annual revenue. Most enrolled farmers receive $4,000 minimum payments annually (NRCS, 2023). CSP funded cover crops span about 2 million acres in the United States in 2015. Payments are much lower than that of EQIP. The median subsidy ranged from the lowest per acre of $7.96 in Arizona to the highest payment per acre of $14.65 in Wyoming (Wallander et al., 2021). However, the majority of USDA payments received by farmers for cover crops came from CSP in 2019 (Chami et al., 2023). Technical assistance from the NRCS is available to provide information and aid needed to successfully implement cover cropping practices through both EQIP and CSP.

Although funding from federal and state government agencies can play an important role in increasing the economic viability of cover crops, they are not without shortcomings. Some requirements of the programs diminish farmers' abilities to gain all possible benefits from cover crops. For example, the EQIP program does not allow for cover crops to be harvested for seed (Wallander et al., 2021). If farmers were able to harvest cover crops for seed, they could potentially reduce their costs even further. Restrictions imposed on management decisions by these programs may cause the farmer to feel they are losing autonomy of their farm (Stock & Forney, 2014).

Why farmers do or do not participate in federal programs is a topic worthy of further consideration. A 2016 survey showed that a majority of cover crop users (63%) did not receive financial support. Of farmers surveyed, 47% did not believe they qualified for federal or state funding (Dunn et al., 2016). This demonstrates that, while programs like EQIP and CSP are important for incentivizing conservation practices like cover cropping, farmers also utilize this practice independent of incentive programs.

As with any emerging or under-utilized agricultural practice, economic, cultural, and knowledge barriers hinder cover crop implementation. Managing cover-crops is a complex process requiring not just equipment, but also crop and region-specific knowledge. Knowledge barriers also play a role in cover cropping decisions. A 2022 survey of Ohio farmers showed knowledge of the practice and importance of cover crops influenced the decisions of 17% of farmers. The same study showed that of survey respondents, only 4% reported knowledge barriers and 9% reported lack of information on the importance of cover crops in Maryland. The state of Maryland has a robust cover crop outreach and support program, indicating that government support programs may dramatically reduce these cultural barriers (Duke et al., 2022). Incentive programs, either state or federally administered, can help introduce a farmer to cover cropping, making them more likely to continue use at the end of their contracts. Farmers who enroll in cover crop support programs on average used cover crops on 37.2% more acreage than before enrollment (Chami et al., 2023). Cover cropping practices can be boosted by farmer-farmer networks which provide farmers an opportunity to learn and collaborate with other practitioners (Kelemen, 2022).

There is room for improvement in the policies and literature on the economics of cover crops. For example, labeling schemes offer potential to improve consumer access to information regarding the conservation practices used by the farm producing their food (Daryanto et al., 2019). Certification programs for cover crop use may provide access to premium markets that are currently inaccessible to large scale conventional farmers. Such programs may increase farmers' willingness to use cover crop. However, this approach relies on consumer education and willingness to pay a premium, and therefore may not be the most effective approach to increasing conservation practices. The success of current government subsidy programs can be expanded on to further decrease fallow land. Of farmers not currently using cover crops, a majority of respondents said they would be more likely to use cover crops if there were cost sharing programs, tax credits for adoption, soil carbon sequestration credit payments, and discounts on crop insurance premiums (SARE, 2020). With climate change and the unsustainability of modern agriculture taking a front seat in the conversation about food system challenges, cover cropping will be a key component of transforming agriculture to meet the needs of the future.

Interseeding Cover Crops

Interseeding cover crops is a subcategory of cover cropping which seeks to address specific challenges farmers encounter when integrating cover crops into temperate cropping systems. In interseeding, cover crops are seeded alongside the cash crop after it is already established. The cover crop grows among the cash crop. Interseeding cover crops can allow farmers to access some benefits of living mulch while their cash crop is in the ground (McConnell et al., 2023; Peterson et al., 2019). The benefits are limited to those provided for while the cover crop is living, including the mitigation of soil erosion, supporting of soil organisms, uptaking a portion of nutrients from fertilizers applied in excess, and soil temperature regulation. Some benefits from cover cropping only become realized following their termination and the decomposition of their biomass, such as the release of nitrogen from legumes, the liberation of other nutrients bound in crop tissues, and the potential increases in soil carbon. Interseeding is unable to provide those benefits to the cash crop among which they are seeded, although these benefits can be accessed by subsequent plannings (McConnell et al., 2023). In traditional cover cropping regimes, the cultivation of cash crops in a field is temporally separated from a cover crop. Farmers may seed a cover crop in the spring and terminate it before planting a summer crop. Cover crops may then be turned into the soil or left on the surface as a mulch. For spring crops, cover crops are seeded following the harvest of the cash crop in the late spring or summer (Mohler & Johnson, 2009). In interseeded systems, a living green mulch covers the field during the growth of the cash crop. This provides the benefits of living ground cover for a greater portion of the season (Caswell et al., 2019; Curran et al., 2018).

Interseeding introduces tradeoffs which must be considered by farm managers. Cover crops can compete with cash crops for nutrients, water, and sunlight, potentially reducing cash crop yields. Cover crops must be seeded within narrow windows to minimize competition with cash crops, which varies by crop species (McConnell et al., 2023). Cover crops may serve as habitat for pest species (Appenfeller et al., 2022). Cover crops prohibit weeding practices, such as mechanical cultivation. Physical methods of weed suppression, such as scuffle hoes, tine cultivators, flaming, etc, cannot be utilized without disrupting the cover crop. Chemical herbicides used to target weeds often also affect cover crops, and their application regimes must be changed or eliminated in interseeded systems.

Interest in interseeding has grown recently among farmers, academics, and agricultural advisors as cover cropping has become more widespread (Rees & Thompson, 2021). However, the practice is not new. In 1913, interseeding of crimson clover among corn crops was recommended by the USDA to increase yields (Brooker et al., 2020; Westgate, 1913). Cover crops, though not known by the name at the time, were used in the United States as far back as the colonial period. George Washington utilized “crops grown to replenish the soil” as part of his rotation with stable crops (Groff, 2015). Interseeding is based on the same ecological principles as those used by indigenous peoples in North America for centuries. The Three Sisters method, which seeds corn, beans, and squash among each other for the mutual benefit of each crop, exemplifies these principles, with squash providing living ground cover akin to a cover crop (Lewandowski, 1987).

Challenges of cover-crop management very greatly by USDA climate zone. The climate and bioregional characteristics of the northeastern United States constraints its agroecosystems. Maine has a humid continental climate, and the majority of the state is classified as *Dfb* using the Köppen climate classification model (Beck et al., 2018). Regions within the *Dfb* zone have temperatures below 0 ºC for at least one month of the year, no dry season, and warm summers (Köppen, 2011). The region has warm summers and cold winters. Summer average temperatures range from 16 ºC to 21 ºC, and winter temperatures range from -9 ºC to -4 ºC on average (Kunkel, 2022). Precipitation is relatively evenly distributed throughout the year, averaging about 1065 mm annually in central Maine (*US Climate Data*, 2024). The last frost dates in central Maine generally occur in late May, and first frost dates occur in mid-September or early October (Griffith, 2022). In Bangor, the ground freezes to a depth of about 1.9 m (NOAA, 2024).

Farmers in the northeastern US are limited by short growing seasons. Seeding time is therefore very important in these zones. Spring seeding must avoid frosts to ensure adequate germination and establishment. Late season seeding must be done early enough to attain sufficient biomass yield (Snapp et al, 2021). The management requirements of late season cover crops is a challenge to farmers operating in colder climate zones (Roesch-McNally et al., 2018). Late-season crop fields often must be left fallow during the winter due to insufficient time for cover crop establishment (McConnell et al., 2023). Interseeding has limited adoption in North America, with most use occurring with production in Quebec and British Columbia (Curran et al., 2018). Interseeding has promising potential to address the climatic barriers to cover cropping in the Northeast.

Arthropods and Cover Cropping

Arthropods provide an array of ecosystem services and disservices in agroecosystems. For example, arthropods store and cycle nutrients from plant matter, detritus, and soil organic matter. Ground-dwelling arthropods provide ecosystem services of pest control and seed predation. Herbivorous arthropods are pests that reduce crop yield and quality. Predator species act as natural enemies to pests. Arthropods require sufficient habitat for foraging, dwelling, and reproduction. Several factors influence arthropod abundance, namely trophic availability, edge proximity, habitat availability, and pesticide use (Labruyere et al., 2016). Spatial proximity to minimally disturbed habitat across landscape scales also influences carabid activity density. A study on Northeastern wild blueberries found that arthropod abundance increased with proximity to the field edge (Loureiro et al., 2020).

Many groups of arthropods are granivorous and provide weed seed predation services, such as ground beetles (Coleoptera: Carabidae) and field crickets (Orthoptera: Gryllidae) (Bohan et al., 2011; Carmona et al., 1999). *Harpalus rufipes* DeGeer has been found to have the capacity to significantly regulate weed seed banks through seed predation in Maine (Birthisel, 2013; Zhang, 1993). Granivorous carabids regulate seedbank abundance, with the impact dependent on carabid density (Bohan et al., 2011). Studies have shown positive correlations between activity of carabids and high seed predation rates. Beetle community composition influences seed predation rates.

Some arthropods are natural enemies to pest species, meaning they find and consume them throughout the growing season (Lami et al., 2020). Field crickets prey on a range of pest species, including adult flea beetles (Tribe: Alticini) and grasshopper

(Suborder: Caelifera) eggs (Barney et al., 1979; Carmona et al., 1999). The golden ground beetle (*Carabus auratus*) (Coleoptera: Carabidae), a ground dwelling beetle, consumes snails (Class: Gastropoda) and herbivorous insects in Maine (Lewis et al., 2015). More diverse and abundant predator assemblages correlate to greater rates of pest predation. Farm practices can either support or undermine these assemblages. For example, the practice of cover cropping in a Chinese tea plantation increased both predatory arthropod and herbivorous arthropod abundance (Chen et al., 2019).

In contrast to the well understood impacts of these factors, the impact of tillage and cover cropping on arthropod activity is less clear. Cover crops serve as suitable habitat for larger and diverse beetle communities (Inveninato Carmona et al., 2021; Quinn et al., 2016). The canopies of cover crops provide protection from avian and mammalian predators. Based on a simulation from a Maine study, without the protection of cover crops, 17% more weed seeds enter the seedbank due to lack of predation from loss of carabids to predators (Birthisel et al., 2014). Some studies show greater natural enemy activity and abundance in reduced tillage systems compared to full tillage (Appenfeller et al., 2022). Conversely, reduced tillage in an acorn squash field did not significantly affect abundance in most treatments and reduced in one treatment compared with traditional tillage (Quinn et al., 2016).

The existing literature discussing the benefits of arthropod presence and cover crops is highly variable. Generally, beneficial arthropod diversity increases and pest arthropod abundance decreases in systems that include cover cropping compared with those that do not (Inveninato Carmona et al., 2021). However, seasonal or site-specific factors may play a role, as some scientists have found increases in the abundances of both beneficial arthropods and pest arthropods in response to cover cropping (McNeill et al., 2012). Seasonal management and climate contexts also play a role. For example, in Georgia early season cover crops were demonstrated to increase natural enemy abundance and decrease thrips populations in a cotton production operation (Bowers et al., 2020). No studies have investigated the relationship between arthropod abundance and specifically interseeded cover crops in the Northeastern US. The influence of interseeded cover crops may influence arthropod dynamics differently than traditionally cover cropped systems, as the arthropod communities exist alongside the cash crop.

In the present study, I investigated the relationship between interseeded cover cropping practices and arthropod populations, within the context of agroecosystems of the northeastern United States. Farmers can benefit from practical knowledge of their local arthropod ecology to optimize their ecosystem services management in the context of conservation agriculture. The literature discussing the benefits of arthropod presence and cover crops is highly variable, therefore further research is warranted. The services provided by arthropod presence in interseeded cover crop systems may have different impacts than that of traditional cover cropping practices. Through this study, I aimed to 1) investigate the influence of interseeded cover crops on arthropod abundance and diversity, 2) identify dominant arthropod groups to understand what services they may provide, 3) generate locally applicable information for farmers in Maine and the northeast United States.

METHODS

This study was conducted within the context of a larger research project that investigated the effects of interseeding cover crops on brassica and corn yield. The larger study was led by Jason Lilly, Assistant Extension Professor at the University of Maine, and Dr. Rachel Schattman, Assistant Professor of Sustainable Agriculture at the University of Maine. The study was funded by USDA Northeast Sustainable Agriculture Research and Education (NE-SARE), project #LNE22-451R-AWD00000495. In the following description of the materials and methods, I use "we" when referencing the larger study, and "I" when referencing my honors research. "We" refers to the project team which included the principal investigators, myself, a PhD student (Gladys Adu Asieduwaa), and two undergraduate research technicians (Chelsea Gilgan and Megan Smith).

Site Characteristics

We conducted this study on Rogers Farm Forage and Crop Research Facility in Stillwater, Maine. The site coordinates were 44.927698, -68.695855. The soil type was Pushaw-Swanville complex, with 0 to 8 percent slopes (NRCS, 2023). The region fell in USDA Plant Hardiness Zone 5a (USDA, 2023). The project was initiated in 2022, and replicated in 2023, at which point I included the carabid study within the larger project. In the past agriculture research in the field was managed conventionally.

Interseeding Study Design

Trial plots were planted with green cabbage (*Brassica oleracea*) as a cash crop. Cabbage was planted 45.7 cm (18 in) apart in two equally staggered rows such that the second row was aligned with the midpoint of the first. The field was divided into 4 blocks. Each block was subdivided into four main treatment plots, differentiated by the planting date of the cover crop: (a) cover crops seeded 10 days after cabbage transplant, (b) 21 days after transplant (DAT), (c) 30 DAT, and (d) post-harvest of cabbage. The 4 blocks served as trial replicates. The plots were subdivided further into 3 subplots for three different seed incorporation methods: (a) drilled, (b) broadcasted, and (c) broadcasted with incorporation. Main plot level treatments and incorporation method subplot treatments were randomly assigned within each block. Subplots were 1.8 m by 2.7 m (6 ft by 9 ft) in dimensions. A mixture of annual ryegrass (*Lolium multiflorum*) and crimson clover (*Trifolium incarnatum*) served as the cover crop. Cover crops were seeded at a rate of 0.103 lbs per subplot in a ratio of 60% annual rye grass to 40% crimson clover by weight.

Due to the extensive nature of the study design, I decided to select a reduced number of conditions in which to compare arthropod abundance and diversity. Specifically, arthropods were sampled in two main treatments: cover cropped treated plots (21 DAT only) and non-cover cropped control plots (post-harvest). The rationale behind selecting 21 DAT seeded by the broadcast and incorporate method was to compare the hypothesized “optimal” interseeding timing method to a non-cover cropped control. Based on results of a preliminary study, the 21 days after transplant cover crop seeding date was hypothesized to optimize the tradeoff between cover crop ecosystem benefits and cash crop yield (Schattman and Lilley, 2022). The post-harvest plots served as the non-cover cropped control. Post-harvest plots were not seeded during the duration of arthropod sampling, rendering them suitable to act as a non-cover cropped control for the purposes of this study. The cover crop was seeded by the broadcast and incorporation method for both treatments because this was hypothesized in prior research (Adu Asieduwaa et al., 2022) to achieve the most even cover and successful germination rates.

Arthropod Sampling

I used pitfall traps to sample ground beetles, arachnids, and other arthropods in both cover cropped and non-cover cropped plots during three time periods over the season. Each trap consisted of a 16-oz Deli-Cup™ buried in the ground so the top of the cup was flush with the surface of the soil. Traps were filled with 100 ml of dispatch solution (antifreeze), and were covered with a 17.8 cm by 17.8 cm (7 in by 7 in) sheet metal roof supported by nails 2.5 cm (1 in) above the soil surface. One trap was randomly placed with each subplot in each block. In each of the four blocks, two traps were placed, one in the cover crop treated subplot and one in the non-cover crop subplot. There were eight total sample traps. The distance of each trap from the field's edge was recorded (for cover cropped plots: mean = 7.91 m, standard deviation = 2.86 m; for non-cover cropped plots: mean = 8.52 m, standard deviation = 4.24).

Each trap was sampled three times approximately three weeks apart. Traps were set out in the field for 10 days each. The first sampling event began on 8/14/23. The second began on 9/5/23. The third began on 10/2/23. These sampling dates were chosen to correspond with pre-cover crop establish stage, early cover crop growth stage, and cover crop maturation stage respectively. The same location was used for each trap across sampling events The physical location of each trap was marked with a blue flag. Traps were removed from the field in between sampling events. I conducted three sampling events throughout the growing season to account for temporal variation and cover crop growth stage influence on arthropod abundance and diversity.

Arthropods were collected, strained out of the dispatch solution, and preserved in 70% ethanol. Captured arthropods were identified to the family. Genus and specific epithet were recorded for notable groups.

Analysis

Abundance and richness were calculated for each same plot. Abundance is the sum of individuals of a given group. Richness is the number of groups observed per plot. Multiple diversity indices were used. Shannon-Weiner diversity value was calculated using the following formula:

$$H' = - \sum_{i=1}^{s} p_i \ln p_i$$

where H' is the diversity index, *s* is group richness, and p_i is the proportion of abundance of each group belonging to the *i*th group of the total abundance (Shannon, 1948). The Shannon-Weiner index was used as a standard assessment of alpha diversity.

Simpson's dominance index was also calculated for each plot. The formula for Simpson's dominance is as follows:

$$D = \sum_{i=1}^{S} (n_i/N)^2$$

where n_i is the abundance of group *i*, N = total abundance of all groups, and n_i/N = the proportion of individuals of group *i*, S refers to group richness, and D = dominance index number (Simpson, 1949). Simpson's dominance index assesses if a given group composes the majority of individuals in a community. The index was used to investigate if the dominant group differed between the two treatments and if conclusions could be draw about the ecosystem services provided by the dominant group(s).

Many variables in the dataset violated parametric assumptions and were not correctable by transformation, therefore I used the nonparametric Mann-Whitney U rank test to compare means between cover cropping treatments (Mann & Whitney, 1947). The effect of edge proximity on the results was evaluated using a linear regression. Linear regressions were used to assess the influence of vegetative matter present (i.e., biomass and canopy cover), which influences both habitat and food availability, on abundance in each plot. Vegetative matter included both cover crop and weeds. Biomass data were measured by collecting above-ground plant matter in a randomly placed 1 m by 1 m quadrant within the sample plot. Biomass was sorted by type, either cover crop or weed, and dried. Dry biomass was massed and recorded. Biomass was collected for block 1 on 11/9/23, block 2 data was collected on 11/13/23 and block 3 and 4 data collected on 11/14/23. Canopy cover was determined by photographing 1 m by 1 m quadrats and processing the resulting images using Canopeo (Patrignani & Ochsner, 2015). Data were analyzed using Excel. Box plots were constructed using R (R Studio Team, 2020).

RESULTS

Community composition

Total arthropods presence and abundances varied among samples. The majority (61.4%) of arthropods sampled were *H. rufipes* when treatments, blocks, and sampling dates were taken in aggregate. Gryllids were the second most abundant, comprising 24.1% of total specimens. Carabids of the *Pterostichus* genus were the third most abundant, comprising 5.2% of total specimens. All other groups sampled comprised less than 1% of total specimens sampled. The groups identified are represented in Table 1.

					Treatment					
					Cover cropped			Non-Cover Crop		
Taxonomic Category					Sampling Date					
Class	**Order**	**Family**	**Genus**	**Species**	S1	S2	S3	S1	S2	S3
Insecta	Orthoptera	Gryllidae	*Gryllus*		15	33	31	7	52	85
Insecta	Coleoptera	Carabidae	*Harpalus*	*Rufipes*	178	211	23	54	75	26
Insecta	Coleoptera	Carabidae	*Pterostichus*		10	21	1	4	7	5
Insecta	Coleoptera	Carabidae	*Carabus*	*Auratus*	1	2	1	0	2	3
Insecta	Coleoptera	Carabidae	Unknown		2	0	0	2	1	0
Insecta	Coleoptera	Scarabaeidae			4	1	0	2	1	0
Insecta	Coleoptera	Elateridae			0	0	0	2	0	2
Insecta	Hemiptera	Lygaeidae			0	0	0	2	1	0
Insecta	Hemiptera	Reduviidae			0	0	1	1	0	1
Insecta	Hemiptera	Miridae			0	0	1	0	0	2
Insecta	Hemiptera	Alydidae			0	0	0	0	0	1
Insecta	Dermaptera	Forficulidae			0	0	1	0	1	1
Insecta	Hymenoptera	Formicidae			0	0	0	0	0	2
Insecta	Diptera				5	5	2	5	2	0
Malacostraca	Isopoda				0	0	0	0	0	1
Arachnida	Opiliones				5	0	3	1	5	1
Arachnida	Araneae				2	2	0	1	1	1
Insecta	Lepidoptera				1	0	0	0	0	0
Chilopoda					0	0	0	0	0	2

Table 1. Taxonomic rankings of specimens by treatment and sampling dates.

Abundance

Table 2 shows the average abundance values by treatment and sampling event. Total arthropod abundance did not differ significantly between the cover cropped and non-cover cropped treatments. Assuming an alpha level of 0.05, the critical U value is 37.

The U-wert value of 44.5 is greater than 37, therefore the results are insignificant (Mann & Whitney, 1947).

Mean Abundance Values by Treatment				
	Sampling Date			
Treatment	S1	S2	S3	Mean
Cover cropped	56 ± 25	69 ± 27	16 ± 8	47 ± 31
Non-cover cropped	21 ± 16	37 ± 20	33 ± 26	30 ± 26

Table 2. Mean arthropod abundance by treatment and sampling event with standard deviations.

Biodiversity

Diversity values for each plot by treatment, replicate, and sampling event are displayed in Table 3. Simpon's Dominance index values did not differ between cover cropped and non-cover cropped treatments. Assuming a p-value threshold of 0.05, the Mann-Whitney U the critical U value was 37. The U-wert value of 47 is greater than 37. Therefore, the difference of dominance between the two treatments is insignificant.

Mean Diversity Index Values by Sample Date												
	Shannon H-Value				Simpson's Dominance Value				Simpson's Diversity Value			
	Sampling Event											
Treatment	S1	S2	S3	**Mean**	S1	S2	S3	**Mean**	S1	S2	S3	**Mean**
Cover cropped	0.59 ± 0.17	0.74 ± 0.31	0.84 ± 0.57	**0.72 ± 0.37**	1.64 ± 0.27	1.67 ± 0.41	2.10 ± 0.89	**1.80 ± 0.57**	0.38 ± 0.10	0.37 ± 0.16	0.43 ± 0.30	**0.39 ± 0.19**
Non-cover cropped	0.74 ± 0.92	1.05	1.16 ± 0.66	**1.08 ± 0.59**	3.16 ± 0.59	2.18 ± 0.40	2.84 ± 1.67	**2.73 ± 1.69**	0.53 ± 0.27	0.53 ± 0.10	0.55 ± 0.24	**0.54 ± 0.20**

Table 3. Diversity Index values for Shannon-Weiner, Simpson's Dominance, and Simpson's Diversity by treatment and sampling event with standard deviations.

Changes over time

Average abundance peaked at the second sampling date on 9/5/24 for both cover cropped and non-cover cropped treatments. The second highest average abundance for the cover cropped treatment was captured on the first sampling event on 8/14/24, while the second highest average abundance for the non-cover cropped treatment was captured on the third sampling event on 10/2/24. Non-cover cropped plots maintained steadier levels of abundance throughout the duration of the experiment, while the average abundance of cover cropped plots declined precipitously on the third sampling event. Figure 1 shows the changes in average abundance for all replicates of each treatment over time.

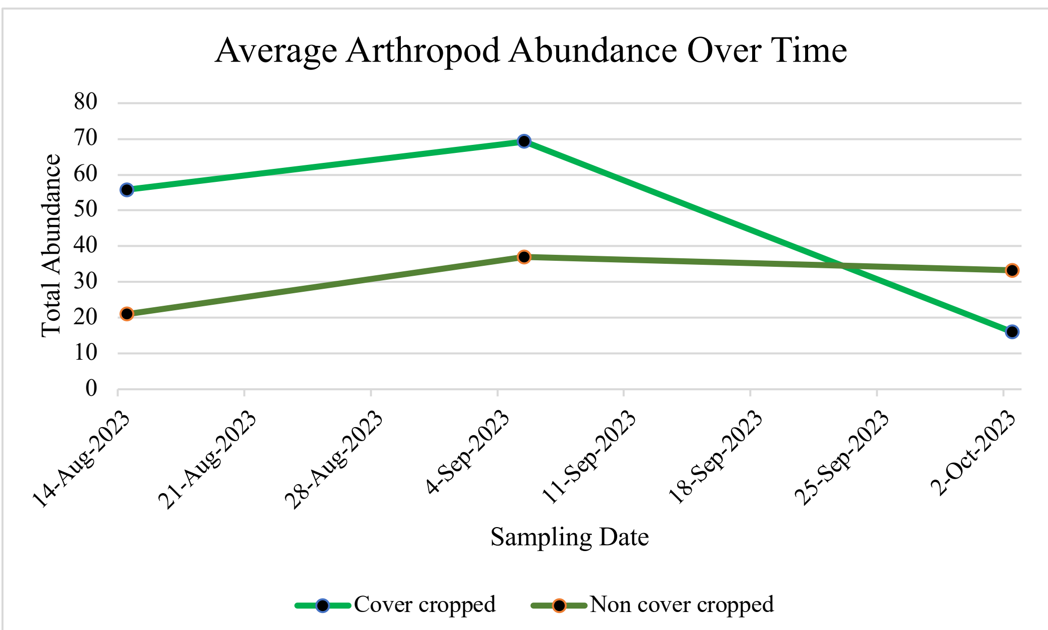
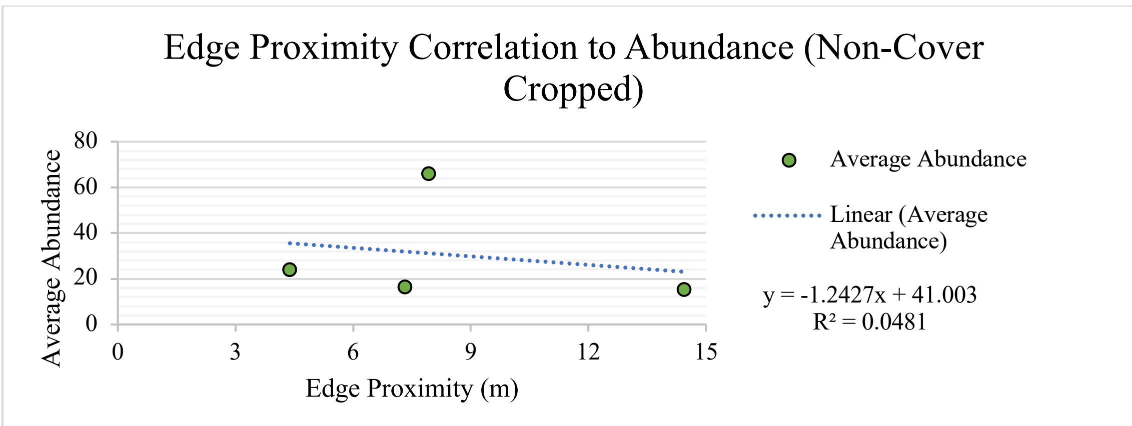


Figure 1. Average arthropod abundances over the course of the study separated by treatment.

Confounding factors

Edge Proximity

Edge proximity did not significantly affect total abundance. For the cover cropped plots, the $R^2 = 0.0735$, and for non-cover cropped plots, the $R^2 = 0.0481$. Both of these values are less than 0.2, indicating a very weak negative correlation. Figure 2 displays the linear model of the relationship between edge proximity and abundance separated by treatment.



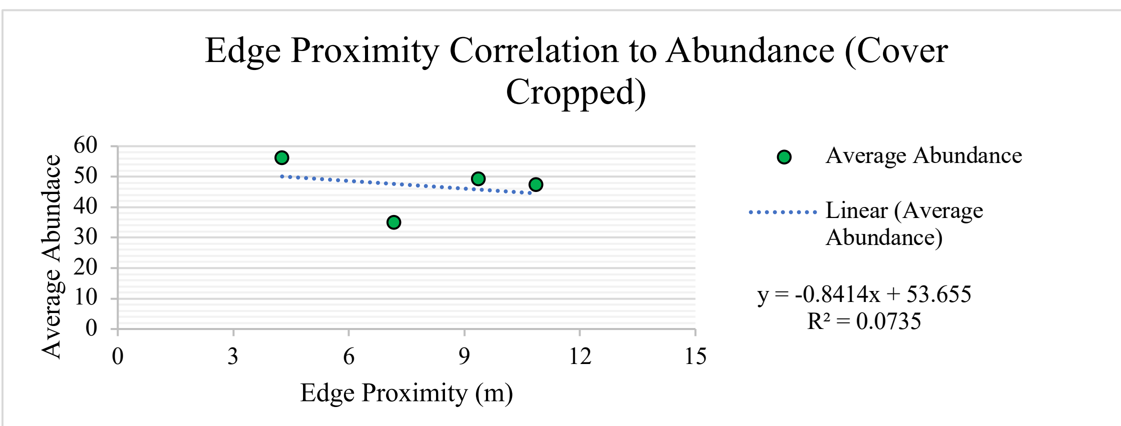


Figure 2. Edge proximity relationship to average arthropod abundance in a linear model.

Biomass

Dry biomass was not significantly correlated with arthropod abundance from the third sampling event. Only the third sampling event was considered in this model, as it was most representative of the final stage of growth of the cover crop. The regression model described in Figure X shows an of $R^2 = 0.0768$. The coefficient is < 0.2, indicating a very weak positive correlation.

Canopy Cover

Canopy cover, inclusive of weeds and cover crops, was found to have a moderate positive correlation with arthropod abundance across both treatments. Canopeo measurements of percent cover within a 1 m by 1 m quadrant were used for the linear model (Adu Adsieduwaa, 2023). The R^2 value for the linear model was 0.6924, which falls within the moderate correlation range of $0.3 < x < 0.7$.

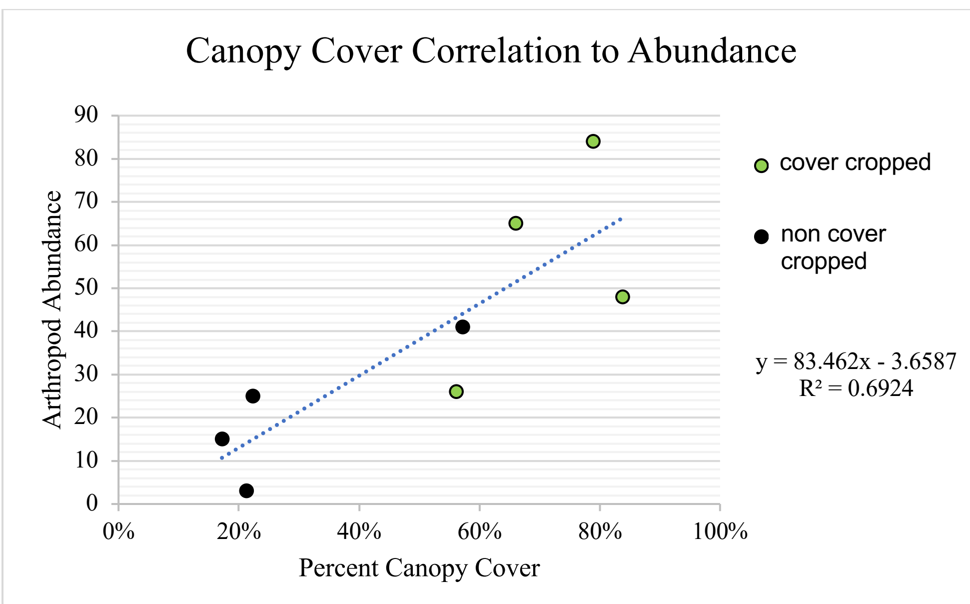


Figure 3. Linear model of the relationship between canopy cover and arthropod abundance of the 8/14/24 through 8/24/24 sampling event (S1).

DISCUSSION

Abundance Variability

This study contributes to a body of research which describes the complex dynamics of arthropods in agroecosystems, with specific relevance to the Northeast. Many of the groups found in sampling, most notably members of the Carabidae and Gryllidae family, are known seed predators. While previous research indicates that environmental conditions, such as amount of ground cover, influences populations of arthropods in these families, I found no significant difference in abundance or diversity between treatments. Counter to expectations, edge proximity did not play a significant role in abundance. Canopy cover was shown to have a relationship with abundance, affirming trends in the literature.

Total arthropod abundance did not differ significantly between cover cropped and non-cover cropped treatments. Confounding factors may have influenced the outcomes of this study. Weeds were present in plots of both treatments. Suitable habitat is necessary for any arthropod, though most of the arthropod groups sampled in this study were non-specific and did not demonstrate preferences for habitat consisting of weeds versus cover crops. Both treatments had prevalent vegetative cover, which increased over time. The vegetation in the cover cropped treatment was dominantly the seeded cover crop, annual ryegrass (*Lolium multiflorum*) and crimson clover (*Trifolium incarnatum*), while the vegetation in the non-cover crop treatment was mostly weeds. Weeds were not identified by species, eliminating the potential to assess the difference in effect on arthropods among weed species. However, cover crops can provide multiple ecosystem services, while weeds are problematic to efficient management of crop yields. Cover crops can provide sufficient habitat for beneficial arthropods while avoiding weed pressure.

As previously stated, the majority of specimens sampled were in the Carabidae in order Coleoptera or the Gryllidae in order Orthoptera. Other orders and families within class Insecta were found, but not nearly as consistently or at comparable abundances. *H. rufipes*, a carabid, was present in 100% of pitfall traps. This species represented 61.4% of total individuals recorded. *H. rufipes* consumes weed seeds and can have a significant impact on reducing seed rain (Birthisel, 2013; Zhang, 1993). Crickets of the *Gryllidae*, also a significant seed predator, accounted for 24.1% of specimens documented (Carmona et al., 1999; MacKeil, 2021). Both of these arthropods have demonstrated this behavior in the northeast (Birthisel, 2013; MacKeil, 2021). Natural enemy species were recorded in low abundance, namely *Carabus auratus*, indicating the potential for biological control of pests like snails (Lewis et al., 2015). Notably, no major pest species recorded in significant abundance. This may be a product of the pitfall traps targeting ground-dwellers, whereas most pest species are aerially mobile and best targeted through other sampling methods (Naranjo, 2008)

Arthropod groups present in the central Maine bioregion may change as climate change progresses (Fernandez et al., 2020). This data can serve as a reference point in the literature tracking arthropod diversity changes over time. Climate change impacts the life cycles of arthropods (Halsch et al., 2021). Data from each time interval is useful for understanding where arthropod populations are in their life cycles at a given time, although confounding variables of temperature, precipitation, and ground cover must be considered. These findings provide a record of the arthropod community composition in this northeastern agroecosystem, which may be subject to shifts in arthropod abundance or range due to climate change.

Biodiversity

No significant difference in arthropod diversity was found between cover cropped and non-cover cropped plots. This, however, may not diminish the ecosystem services provided by arthropods, specifically seed predators such as *H. rufipes*. For example, a plot with many *H. rufipes* and a few individuals of other groups would have a lower diversity value than a plot with a small number of *H. rufipes* and many other groups in comparable abundance. If the farmer is managing for the maximization of weed seed predation rates, a greater abundance of a seed predator groups like *H. rufipes* provides a greater benefit than a more diverse community with fewer individuals overall, as fewer individuals consume fewer weed seeds (Trichard et al., 2013).

Influence of Confounding Factors

Edge proximity did not significantly impact arthropod abundance, another result that diverges from previously published studies. For example, Loureiro et al. (2020) found links between the edge proximity of traps and the abundance of *H. rufipes* in a wild blueberry (*Vaccinium angustifolium*) production system. The discrepancy between these findings from the current study suggest influence from a range of potential factors, including cropping system type, management regime, habitat characteristics, and experimental design. Future studies into edge proximity could account for past management of the land, temporal influence, and local carabid ecologies, among other potential factors. The cover cropped and non-cover cropped treatment subplots in the trial field were close in proximity, prohibiting spatial separation of treatments to control for dispersal of ground dwellers by ambulating. The suitability of habitat is defined by the landscape to a greater extent than the plot level (Birthisel et al., 2014; Tscharntke et al., 2007). Ultimately, the conditions of individual plots are not the best predictor of arthropod abundance.

Canopy cover was found to have a moderate positive correlation with arthropod abundance. Canopy cover as measured by Canopeo was a percentage of the quadrat covered by plant matter. It did not discriminate between cover crop and weed cover. The percent canopy cover of the random quadrat sample can be used to infer the total coverage of the entire plot. Canopy cover serves as a proxy for habitat availability to ground-dwelling arthropods. However, canopy cover data was only relevant to one sampling event, providing insufficient evidence to make strong claims regarding its influence on abundance. Canopeo data was collected on 8/21/23, during the first sampling event from 8/14/23 to 8/24/23. Future studies should measure canopy cover multiple times throughout the duration of the trial to properly control for its influence.

Biomass data serves as an additional proxy for habitat and food availability to ground-dwellers. No significant correlation was found between biomass and abundance. Biomass was collected once at the end of the season, approximately one month following the end of the third sampling event from 10/2/24 to 10/12/24. Therefore, the data could only reasonably be related to the third sampling event. Additionally, the time delay between biomass measurement and arthropod sampling reduces my ability to draw conclusions about the relationship between the variables.

Limitations

Environmental conditions may have influenced the outcome of this study. The 2023 growing season was characterized by abnormally high volumes and variability of precipitation. The total precipitation for the year was 20% to 50% greater than average in Central Maine (US Department of Commerce, 2023). The experiment field was frequently very muddy, potentially interfering with germination of cover crops. During August, when my arthropod sampling begun, rainfall ranged from 50% to 100% above average statewide. On August 13th, 2023, one day before the beginning of the first sampling event, a severe thunderstorm was recorded in Penobscot County. Precipitation changes predicted to worsen with climate change are associated with declines in arthropod abundance (Lee et al., 2014). Average temperatures exceeded baselines throughout the year, with 2023 landing as the 3rd warmest year on record in Bangor.

My study would have been improved by addressing specific design flaws. Spatial separation between the two treatments could increase the power of the study to draw conclusions about the influence of cover crops. Arthropods can disperse throughout the field by walking on the ground. The proximity of the sample plots allowed for arthropods in one plot to easily walk over to another, creating challenges when assessing the suitability of a particular plot for arthropods.

Since a relationship was detected between canopy cover an abundance, collecting more canopy data throughout the duration of the study would have been useful for analysis. Canopeo data was only collected once during my study, limiting the potential for drawing sound conclusions. Biological and structural differences in weed species may have played a role in arthropod abundance and diversity. Variability of weed species could have been controlled for by recording weed species.

The study did not address certain factors in the relationship between cover crops and beneficial arthropods. Cover crops species selection may play a role in influencing arthropod community compositions, which was not investigated in this study. Seed predation emerged as the primary ecosystem service of interest in this study. However, the rate of seed predation was not measured directly, rather abundance was used as a proxy for seed predation. To better understand the impact on the weed seedbank by beneficial arthropods in a cover cropped system, future studies should measure actual seed predation rates in addition to arthropod sampling.

CONCLUSION

This study investigated the relationship between interseeded cover crops and arthropod abundance. No significant difference in arthropod abundance was found between the cover cropped and non-cover cropped treatment. *H. Rufipes* and *Gryllus* species were found in high abundance consistently throughout the study, indicating the potential for utilizing their seed predation services for agricultural management. Canopy cover apparently influenced arthropod abundance, affirming the importance of habitat presence for supporting arthropod communities. The question of how cover crop species selection influences arthropod abundances and community compositions ought to be posed further research. The direct influence of cover cropping on seed predation rates was not investigated in this study, which could be researched further.

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Charlie Cooper was born and raised in Midcoast Maine. He has spent his life appreciating Maine's natural world through his hobbies of gardening, mountain biking, and skiing. He has worked on organic farms and homesteads for 5 seasons, one of which as a MOFGA apprentice. He believes in the importance of acknowledging the personhood of all beings in the beautiful ecological system we are embedded within. He is dedicated to communicating the ethics and practices necessary for cultivating sustainable agriculture systems through his roles as vice president of the UMaine Permaculture and Gardening Club and resident steward of the Terrell House Permaculture Living and Learning Center. He helmed a successful student-led divestment campaign, working with the UMS Board of Trustees to divert the University of Maine's finances from the fossil fuel industry.

After graduating from the University of Maine, he plans to work on a pastured livestock farm in the Midcoast. Later on, he hopes to pursue a graduate degree in ecological economics and build a career in reforming the sustainability issues of the industrial food system.