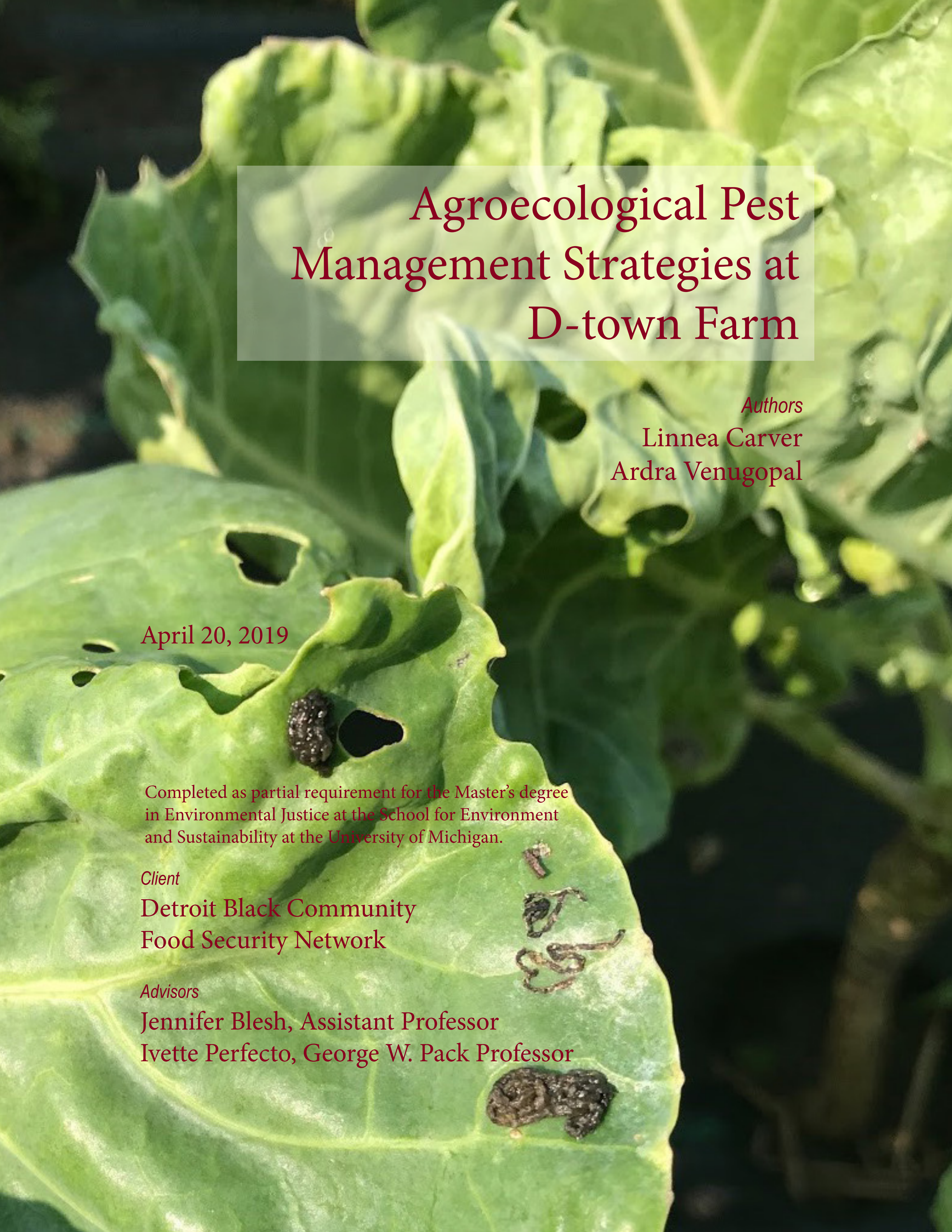

Agroecological Pest Management Strategies at D-town Farm

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April 20, 2019

Completed as partial requirement for the Master's degree in Environmental Justice at the School for Environment and Sustainability at the University of Michigan.

Client

Detroit Black Community Food Security Network

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Abstract

This project partnered with the Detroit Black Community Food Security Network to test pest management methods that are safe for both people and the environment. We conducted plot-scale experiments at D-town farm to determine which organic, agroecological methods are most effective at deterring caterpillars and aphids from brassica species. The experiment was implemented in kale and collard green crops on the farm. The pest management strategies tested included a weekly application of a neem oil-dilution, and a physical exclusion barrier in the form of a net that covered the crop rows, both compared to a control with no pest management. Our response variables included 1) abundance of aphids, 2) abundance of caterpillars, 3) percentage of leaves per plant with damage due to herbivory, 4) and percentage of leaf lost due to herbivory. We observed an increase in aphid abundance across both crop types in the net treatment, but this effect was only significant in the kale. Caterpillar abundance did not show any significant difference among treatments but tended to be lower in the net treatment for both crops. The percentage of leaves with damage from herbivory was significantly lower in the net treatment in both crops and in the neem treatment in the kale. However, percentage leaf loss was significantly greater in the net treatment for both kale and collard greens. In summary, our findings show that while the net treatment reduced damage from herbivory as well as caterpillar abundance in kale and collard greens, it caused the aphid population to grow. The neem treatment reduced caterpillar abundance and damage from herbivory in kale, but not in collard greens. Further experimentation is needed to find a pest management approach that is feasible and effective for reducing both aphids and caterpillar pests in brassica crops at D-town Farm.

Acknowledgements

Funding for this project was generously provided by the School for Environment and Sustainability (SEAS) at the University of Michigan, Ann Arbor. We would like to thank DBCFSN, Malik Yakini, D-town Farm staff, and Shakara Tyler for kindly welcoming us into their community and supporting us through this project. Our academic advisors at SEAS, Professor Jennifer Blesh and Professor Ivette Perfecto, graciously offered assistance and guidance throughout project design and report development. Without their mentorship, this project would not have been possible. We also acknowledge Adam Hall from the University of Michigan's center for Consulting for Statistics, Computing, & Analytical Research (CSCAR) for his contributions and support in our data analysis.

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Project Introduction

Detroit Black Community Food Security Network (DBCFSN) is a non-profit organization founded in 2006 that works to strengthen food sovereignty and community. Since 2006, the organization has grown in its influence and scope. Today, DBCFSN is a coalition of organizations that work together under the mission of building food security in Detroit's black community. Through its many partnerships and programs, DBCFSN influences public policy, promotes environmentally sustainable urban agriculture, fosters co-operative businesses, offers educational programing on healthy eating habits, and facilitates collective action amongst its members. A primary focus of the coalition is supporting the transformation of vacant lots into community spaces for urban agriculture in Detroit to boost food security. DBCFSN uses a community-based approach that increases access to healthy food while cultivating healthy lifestyles, collective work, and activism (White 2011).

Our partnership project with DBCFSN was located at their growing site, D-town Farm. This multipurpose 7-acre farm is used for growing crops, educational programming, community events, and agricultural experimentation. Currently, D-town Farm is the organization's only farming location. The produce that is grown on the farm is sold on-site and at a few farmers' markets in the Detroit area including Eastern Market. The top income generating crops for DBCFSN are from the Brassica genus of the mustard family (*Brassicaceae*). Brassicas include a variety of plants such as rutabaga, turnips, kohlrabi, cabbage, collard greens, kale, cauliflower, broccoli, brussel sprouts, mustard seed, and rapeseed (Nikolov et al. 2019). Plants from this genus are sometimes known as cole crops. Together, Brassica crops constitute an important source of revenue for D-town Farm and contribute to DBCFSN's mission. These crops are not only important for their economic value, but also for their nutritional and health benefits (Šamec et al. 2019). Brassica vegetables have high amounts of fiber, sulforaphane, selenium, 3.3'-diindolylmethane, and vitamin C (Abellán et al. 2019). Therefore, these crops are a central aspect of healthy eating habits and educational programing at D-town farms.

The Brassica crops at D-town farm have experienced an increase in pressure and damage from insect pests. The management and staff at D-town Farm identified two primary pests, aphids (superfamily *Aphidoidea*) and cabbage moths (*sp. Mamestra brassicae*), and asked us to focus our research project on this pest problem.

There are roughly five thousand species of aphids, four hundred of which have been identified as agricultural pests (Foottit et al. 2008). These sap sucking insects weaken plants by drawing out fluids and nutrients through the phloem with straw like mouth parts, called stylets. Aphids can also be vectors of disease and fungus, which can severely damage plant populations and destroy crops. Cabbage moths, in their larval stage as a caterpillar, feed on Brassica crops as well as many other plants. These pests cause serious damage by skeletonizing crop leaves, which reduces growth rates, nutrient content, and devalues the plant, in many cases making produce unfit for sale at market. Historically, the pest problem at D-town Farm has depleted revenue. In order to address this problem, D-town Farm experimented with row covers and the application of neem oil-dilution to combat pest infestation. After conversation with Malik and the farm staff, we decided to design an experiment that tests the effectiveness of these two pest management strategies. The fact that row covers and the application of neem oil-dilution were previously implemented on the farm was a primary rationale for selecting these treatments. The strategies were familiar, feasible, and scalable for DBCFSN's budget and labor resources. Empirical testing of these two pest management strategies would assess their efficacy and help farm management evaluate whether or not they should continue investing in neem-oil and row covers.

The goal of the project was to support D-town Farm's efforts to investigate feasible agroecological practices for future growing seasons that address the severe aphid and cabbage moth pressure. Our project supported this goal, provided experimental evidence, and produced baseline data for the efficacy of pest management strategies previously explored on the farm. We ran two plot-scale experiments with a net row cover treatment and neem oil-dilution treatment to determine which strategy was most effective in deterring aphid and cabbage moth populations to reduce herbivory. We hypothesized that the abundance of aphids, caterpillars, and herbivory would be dependent on the pest management method, and that subplots with net barriers would have lower pest abundance and herbivory compared to control plots.

Background on Pest Management

Agroecology is based on harnessing biodiversity and natural processes to reduce risk and create resilient agricultural systems (Altieri and Koohafkan 2013, Rawlinson 2016). The main principle of agroecology is to mimic the functioning of natural ecosystems by maintaining species richness and composition, thereby reducing external inputs (Pimbert 2018). An agroecological approach to agriculture imitates natural system processes rather than depending on external inputs to achieve sustainable outcomes and increase productivity. For example, mimicking closed nutrient cycling and promoting native biodiversity can spread risk and build resilience to shocks and stress. Agroecological systems use ecological interactions such as predation to manage pest prevalence (Pimbert 2018). In agroecological pest management, chemical inputs are replaced by broader management strategies (Palomo-Campasino 2018) including soil conservation, cover crops, intercropping, predator release, and crop rotation.

D-town Farm has experimented with two primary types of agroecological pest management: physical barriers and an organic input, neem oil extract. The farm has experimented with predator release of mantids and Coccinellidae lady beetles, but they have noted that these methods had minimal effect. Over the last two summers, the farm implemented physical weed barriers in their crop beds to reduce the time and labor and spent weeding. Forms of agroecological pest management that have not been tested on the farm include trap crops, border crops, and cover crops.

Neem Oil

Farmers have used plants and plant extracts to protect against insects, repel agricultural pests, and reduce herbivory for more than 3000 years (Isman 2006; Benelli et al. 2015, Pavela et al. 2016). Today, neem oil is the most commonly used plant extract in agriculture. Neem oil is produced from the seeds of the Azadirachta indica tree (Benelli et al. 2015b, Isman 2006, Sidhu et al. 2003). The oil serves as an organic and natural botanical insecticide for controlling pests. The active component in neem oil that provides these properties includes azadirachtin and its derivatives. Azadirachtin has been shown to work as an insecticide, antifeedant, antiovipositant, and repellent (Pavela et al. 2016). These chemicals inhibit cell division, neural activity, and block the release of hormones in insects (Campos et al. 2018, Dwivedi 2008, Pavela et al. 2016). In aphids, neem oil can reduce longevity, fecundity, and molting of aphids (Tang et al. 2002). Neem oil has been shown to work as an effective method of controlling caterpillar infestation in crops (Nagendra 2008). The application of neem oil-dilutions on crops inhibits oviposition, egg-hatching rates, and the feeding and development of larval lepidoptera; these effects can last up to three weeks after spraying (Hassan et al. 2018, Seljåsen & Meadow 2006).

Physical Exclusion Barriers

Row covers are commonly used to physically exclude pests and protect agricultural crops from predation and herbivory (Dib et al. 2010, Mukherjee et al. 2019, Sideman 2017). These physical exclusion barriers are typically marketed as agro-fabric products or garden netting made of polypropylene or polyester materials.

Exclusion systems have been an effective, organic protection device for the vast majority of key pests (Boiteau 2001). By reducing the abundance of pests, exclusion systems can also provide positive effects by reducing the spread of diseases and fungi (Chouinard et al. 2017). Additionally, these systems can reduce abiotic damage from the environment such as frost or hail events. Nets and agro-fabrics exclude pests but can unintentionally alter the interior microclimate affecting plant growth and yield (Vidogbéna 2015, Yang et al. 2018).

Research Methods

Treatment Design

Our project team ran two pest management experiments on lacinato kale (Brassica oleracea) and collard green (Brassica oleracea) crops. These two crops were the most abundant Brassicas at D-town Farm in summer 2018 and have historically experienced high pressure from aphids and caterpillars. The farm earmarked four beds of lacinato kale and one bed of collard greens for our experiments. The four beds of lacinato kale were approximately 3'x 24' each. The collard greens bed was 3'x 63'. The crop beds were divided into 4 replicate blocks with 3 subplots each, and a random number generator was used to assign a treatment or control group to each subplot. Kale subplots were 3'x6' and contained 12 individuals. Collard green subplots were 3'x4.5' and contained 9 individuals each. The subplots were separated by one buffer row each. Fewer collard greens were grown on the farm compared to kale, hence the collard green subplots had fewer individuals. In both the kale and collard green beds, individual crops were spaced 18" apart from one another in a staggered pattern (Figure 1 and 2).

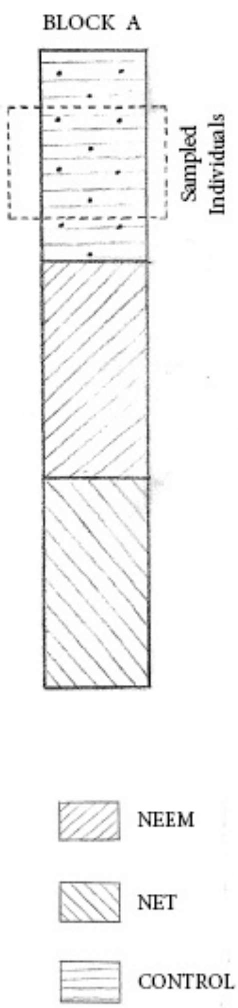

Figure 1. Diagram of randomized complete block design, experimental layout, and sampling in kale.

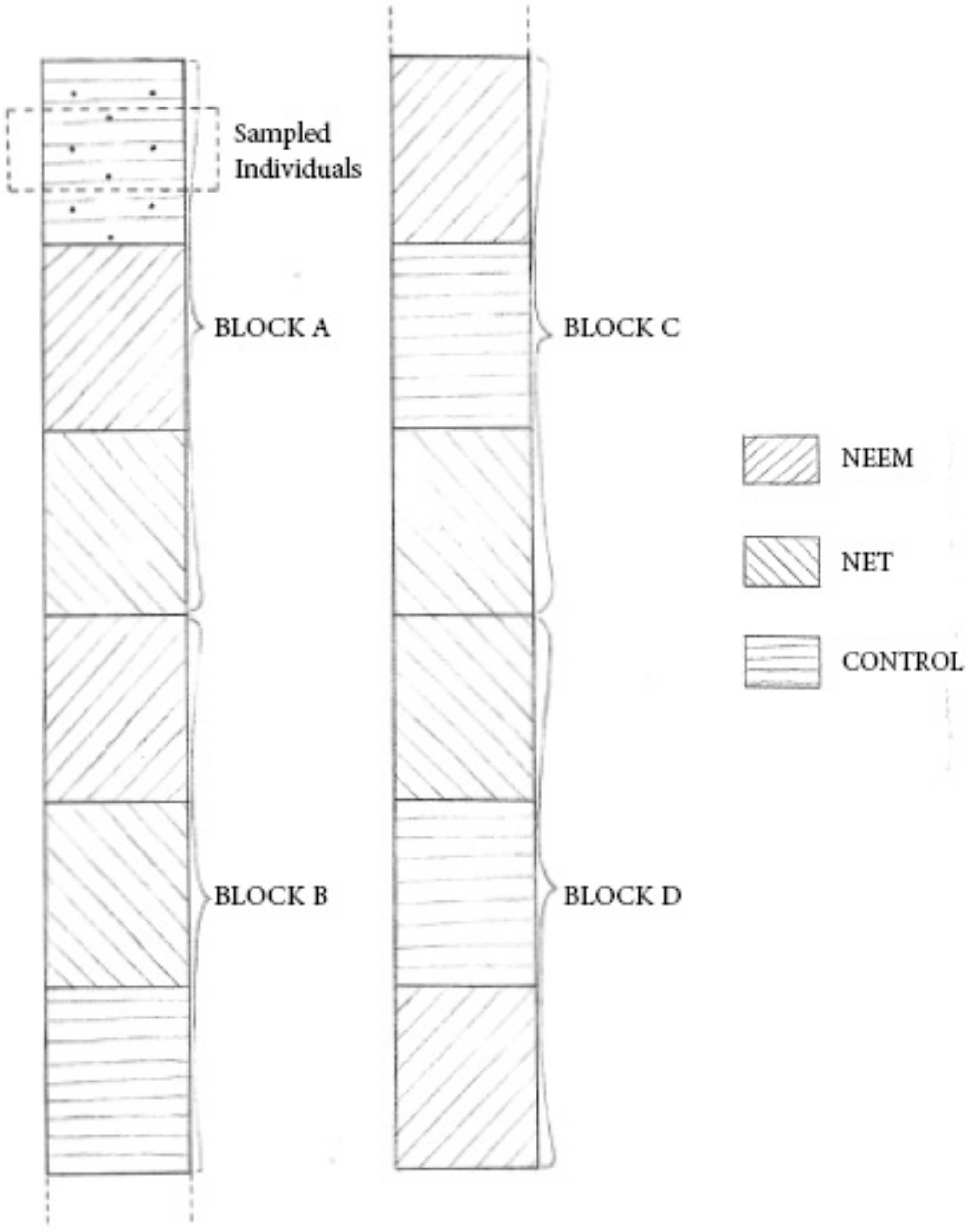

Figure 2. Diagram of randomized complete block design, experimental layout, and sampling in collard greens. The collard green bed is continuous, but the diagram has been split for representation.

Our experiment consisted of two treatment types, "neem" and "net," and a control. We did not apply a pest management strategy in the control group. The neem treatment consisted of a pest-repellant spray, which was a dilution of 2 tablespoons of neem oil and 1 tablespoon of cayenne pepper per gallon of water (Photo 1). To give the neem oil the chance to take effect before data collection we sprayed the neem subplots twice prior to the first data collection event on 26 July 2018. The two presprays occurred on the 12th and 19th of July 2018. We continued to treat the neem subplots by spraying them at the conclusion of each data collection event (Table 1). The spray was carefully applied to each individual plant in the neem subplots by coating the undersides of leaves and spraying from opposite sides of the crop-bed. When applying the neem treatment to the corresponding subplots, care was taken to ensure that individuals in neighboring subplots were not sprayed. The "net" treatment type was a mesh exclusion barrier supported by 6' PVC pipes that were hooped over the 3' wide plant beds. We used 18" rebars driven into the ground to install the PVC pipes at the ends of each net treatment subplot (Photo 2 and 3).

Photo 1. Sprayer for neem oil dilution treatment along with the neem oil and cayenne pepper used for our experiment.

Photo 2. Subplots in the Lacinato kale (*Brassica oleracea*)

Photo 3. Subplots in the collard greens (*Brassica oleracea*)

Data Collection

We collected data for from late July to early September 2018 at D-town Farm (Table 1). Some data collection events required multiple days to finish recording observations. Factors that influenced the number of days necessary to collect data included weather, the farm's operational hours, and number of team members available to collect data. In the kale beds, we collected data from six individuals in each subplot in the two most central rows (Figure 1). We chose the central rows to minimize border and edge effects. In the collard green subplots, we collected data from the four most central individuals out of nine (Figure 2). The discrepancy in the number of individuals we collected data from in the collard green versus the kale is due to the fact that less collard greens were planted on the farm in comparison to kale on the farm in summer 2018. This meant we had fewer individuals to work with and less individuals per subplot for the collard greens. However, the number of subplots and replicates remained the same across crop type.

Table 1. Data collection events shown with corresponding date and crop type analyzed.

Collection Event	**Date**	**Crop Collected**
1	26 July	Kale
	30 July	Collard Greens
2	11 August	Collard Greens
	12 August	Collard Greens
	13 August	Kale
	14 August	Kale
3	18 August	Kale
	19 August	Collard Greens
4	25 August	Kale
	26 August	Collard Greens
5	31 August	Kale and Collard Greens
6	9 September	Kale and Collard Greens

During each data collection event, we measured the extent of herbivory and the abundance of caterpillars and aphids. To assess the extent of damage from herbivory, we calculated the overall percentage of leaves with herbivore damage for each plant sampled. Henceforth, this metric is referred to as "percentage of leaves with damage." As an additional measure on the extent of herbivory, we estimated percentage leaf loss due to herbivory for the two most damaged leaves on the plant (Photo 4). This metric is referred to as "percentage leaf loss." To measure pest abundance, we found the two leaves on the plant with the most aphids present and counted the total number. We repeated this procedure for the caterpillars and found the two leaves with the greatest number of pests, and then counted and recorded their abundance. This means that we did not necessarily record the same two leaves for the abundance of caterpillars and aphids. A set of two leaves may have had the most caterpillars while a set of two different leaves may have had the highest aphid abundance on the same plant individual. Caterpillars and aphids are difficult to identify by sight, particularly when they are small in earlier stages of development. We decided to record the number of pests from the two leaves with the greatest abundance of each pest to ensure our data did not systematically underestimate pest pressure in our subplots. Choosing to record data from the leaves with the highest pest abundance reduces the chances of overestimating the effect of treatments on our response variables. For plants we collected data from, we recorded the number of morphotypes for caterpillars, aphids, and other general pests present on the plants from which data was collected. We also recorded the day, weather, and time for each collection event.

Data Analysis Models

We analyzed the effect of treatment type and time on aphid and caterpillar abundance using a zero-inflated negative binomial model. The variable for time corresponded to each data collection event, an interval variable that ranged from 1-6. The nominal variable for treatment included neem, net, and control. When there are excess zeros in a dataset, a model that does not account for zero-inflation will predict negative observations. Therefore, the zero-inflated model was necessary to account for the large number of zeros in our data, where no caterpillars or aphids were observed.

We analyzed the effect of treatment type and time on the mean percentage of leaves damaged and percentage leaf loss using a linear mixed effects model. Again, the variable for time corresponded to each data collection event 1-6. Linear mixed models can analyze panel data that is non-independent, hierarchical, or correlated. This was necessary as we were sampling the same individuals, treatments, and subplots across time. Our model used treatment type and data collection event as fixed effects. Subplots were included as a random effect in our model.

Results

Aphid Abundance

The abundance of aphids was significantly higher in the net treatment compared to the control and neem treatment in kale (p-value 0.001). The same trend of increasing aphid abundance in the net treatment is present in the collard green crop, it was not statistically significant (p-value > 0.1). There was no statistically significant difference in aphid abundance between the neem and control treatments (Table 2).

Table 2. Statistical results of the zero-inflated negative binomial generalized mixed model for aphid abundance across all data collection events.

Crop Type	**β**	**Estimate**	**Std. Error**	**z-value**	**Pr (>$\lvert z \rvert$)**
Kale	(Intercept)	0.6396	0.3580	1.79	7.40E-02 .
	Neem	0.4384	0.4135	1.06	0.2890
	Net	1.3939	0.459	3.04	0.0024 **
	Data Collection Event	0.3635	0.0487	7.47	8.09E-14 ***
Collard Greens	(Intercept)	1.0257	0.5704	1.80	0.0721 .
	Neem	-0.4584	0.7329	-0.63	0.5317
	Net	0.5253	0.7571	0.70	0.4878
	Data Collection Event	0.2363	0.0755	3.13	0.0018 **

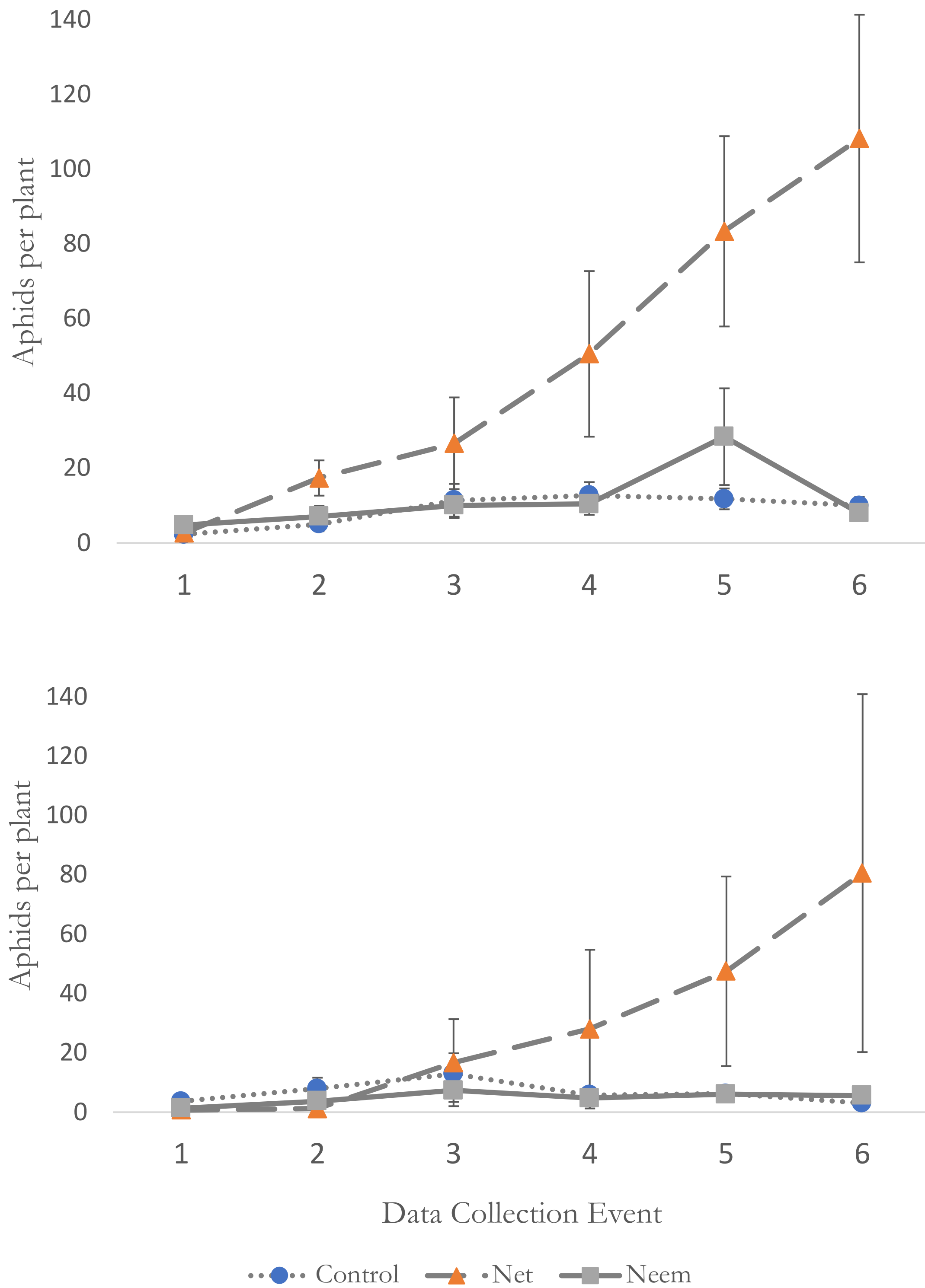

Figure 3. Mean aphid abundance in the two crop types (with standard errors): kale (top) and collard greens (bottom). The x-axis shows data collection events 1- 6. There were significantly more aphids in the net treatment than in the control and neem treatment for the kale. There was no statistically significant difference among treatments in the collard greens.

Caterpillar Abundance

There was no significant difference in caterpillar abundance between the treatment types (Table 3). Although not statistically significant, the neem and net treatments had lower caterpillar abundance on average in the kale crops. In the collard greens, the net treatment had a general trend of lower caterpillar abundance, while the neem treatment had no impact on the caterpillar population (Figure 4).

Table 3. Statistical results of the zero-inflated negative binomial generalized mixed model caterpillar abundance across all data collection events.

Crop Type	β	Estimate	Std. Error	z-value	Pr(>|z|)
Kale	(Intercept)	-0.0087	0.2384	-0.04	9.71E-01
	Neem	-0.3858	0.2789	-1.38	0.167
	Net	-0.5032	0.3152	-1.60	0.11
	Data Collection Event	0.0294	0.0320	0.92	3.59E-01
Collard Greens	(Intercept)	-0.0943	0.1315	-0.72	0.4734
	Neem	-0.1478	0.1888	-0.78	0.4339
	Net	-0.3462	0.2963	-1.17	0.2426
	Data Collection Event	-0.2101	0.0781	-2.69	0.0072 **

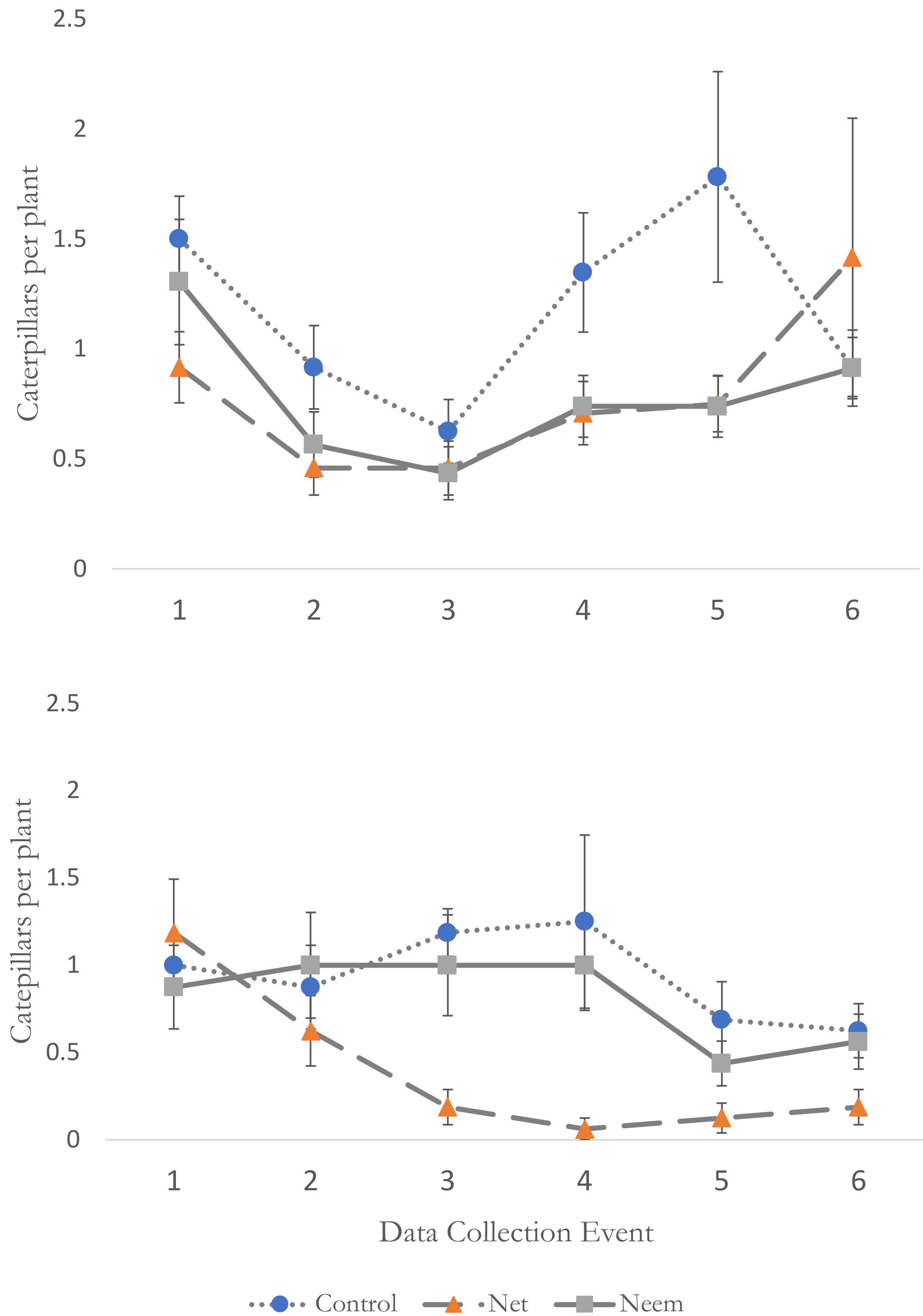

Figure 6. Caterpillar abundance in the two crop types (with standard errors): kale (top) and collard greens (bottom). The x-axis and markers remain the same as in figure 5. There was no statistically significant difference among treatments in either crop.

Percentage of Leaves with Damage

In kale crops, the percentage of leaves with damage was significantly lower in the net treatment (p-value 0.003) and neem treatment (p-value 0.04) compared to the control. In collard greens, only the net treatment had a statistically lower percentage of leaves with damage (p-value 0.001) than the control (Table 4).

Table 4. Statistical results of the linear mixed effects model on percentage of leaves with damage across all data collection events.

<table>
<tr><th>Crop Type</th><th>β</th><th>Estimate</th><th>Std. Error</th><th>df</th><th>t-value</th><th colspan="2">Pr(>|t|)</th></tr>
<tr><td rowspan="4">Kale</td><td>(Intercept)</td><td>8.29E-01</td><td>3.50E-02</td><td>1.97E+01</td><td>23.654</td><td>6.28E-16</td><td>***</td></tr>
<tr><td>Neem</td><td>-9.19E-02</td><td>4.05E-02</td><td>1.30E+01</td><td>-2.268</td><td>0.04103</td><td>*</td></tr>
<tr><td>Net</td><td>-1.67E-01</td><td>4.27E-02</td><td>9.00E+00</td><td>-3.898</td><td>0.00364</td><td>**</td></tr>
<tr><td>Data Collection Event</td><td>6.35E-03</td><td>5.33E-03</td><td>4.07E+02</td><td>1.191</td><td>0.23434</td><td></td></tr>
<tr><td rowspan="4">Collard Greens</td><td>(Intercept)</td><td>9.62E-01</td><td>1.99E-02</td><td>2.84E+02</td><td>48.339</td><td>< 2e-16</td><td>***</td></tr>
<tr><td>Neem</td><td>4.58E-03</td><td>1.82E-02</td><td>2.84E+02</td><td>0.252</td><td>0.801</td><td></td></tr>
<tr><td>Net</td><td>-9.24E-02</td><td>1.82E-02</td><td>2.84E+02</td><td>-5.085</td><td>6.69E-07</td><td>***</td></tr>
<tr><td>Data Collection Event</td><td>-4.70E-03</td><td>4.34E-03</td><td>2.84E+02</td><td>-1.083</td><td>0.28</td><td></td></tr>
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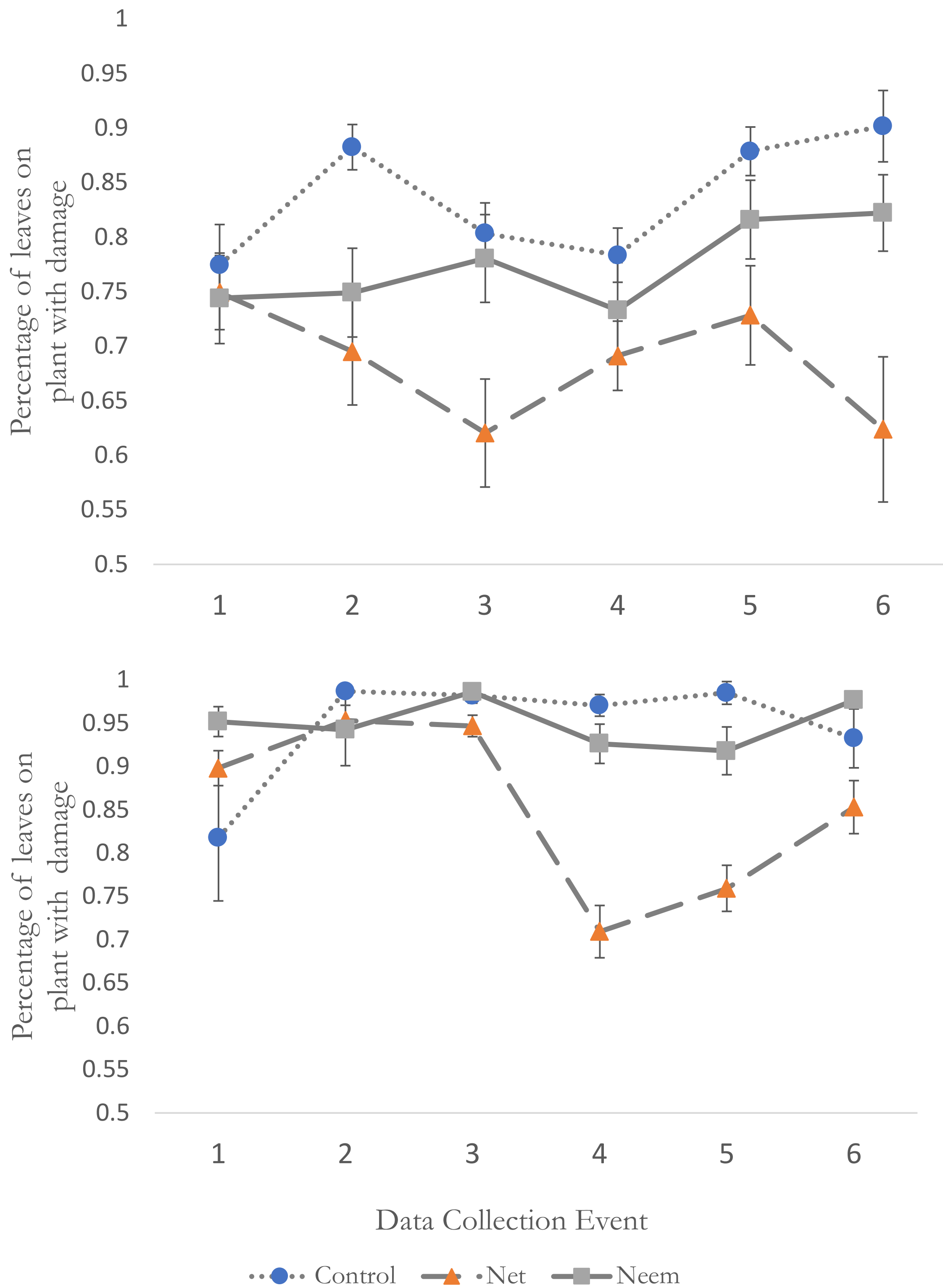

Figure 5. Percentage of leaves with pest damage (with standard errors) for kale (top) and collard greens (bottom). The x-axis and markers remain the same as in figure 3. There were statistically lower leaves with damage in the net and neem treatments in the kale crops. There were also statistically lower leaves with damage in the net treatment in the collard green crops.

Percentage Leaf Loss

In the kale, the percentage leaf loss for the net treatment was significantly greater than the net treatment or control (p-value 0.02). There were no other statistically significant differences in the percentage leaf loss across treatment types in either kale or collard greens (Table 5).

Table 5. Statistical results of the linear mixed effects model for percentage leaf loss across all data collection events.

Crop Type	**β**	**Estimate**	**Std. Error**	**df**	**t-value**	**$Pr(>\lvert t \rvert)$**
Kale	(Intercept)	1.80E-01	3.83E-02	1.92E+01	4.703	1.51E-04 ***
	Neem	1.20E-03	4.51E-02	2.15E+01	0.027	0.979101
	Net	1.35E-01	5.11E-02	1.09E+01	2.643	0.023049 *
	Data Collection Event	4.02E-03	4.64E-03	4.08E+02	0.867	0.386179
Collard Greens	(Intercept)	2.96E-01	6.34E-02	1.26E+01	4.669	0.000472 ***
	Neem	-7.04E-02	8.23E-02	9.00E+00	-0.855	0.414914
	Net	1.23E-01	8.23E-02	9.00E+00	1.492	1.70E-01
	Data Collection Event	2.28E-02	7.18E-03	2.75E+02	3.176	0.001664 **

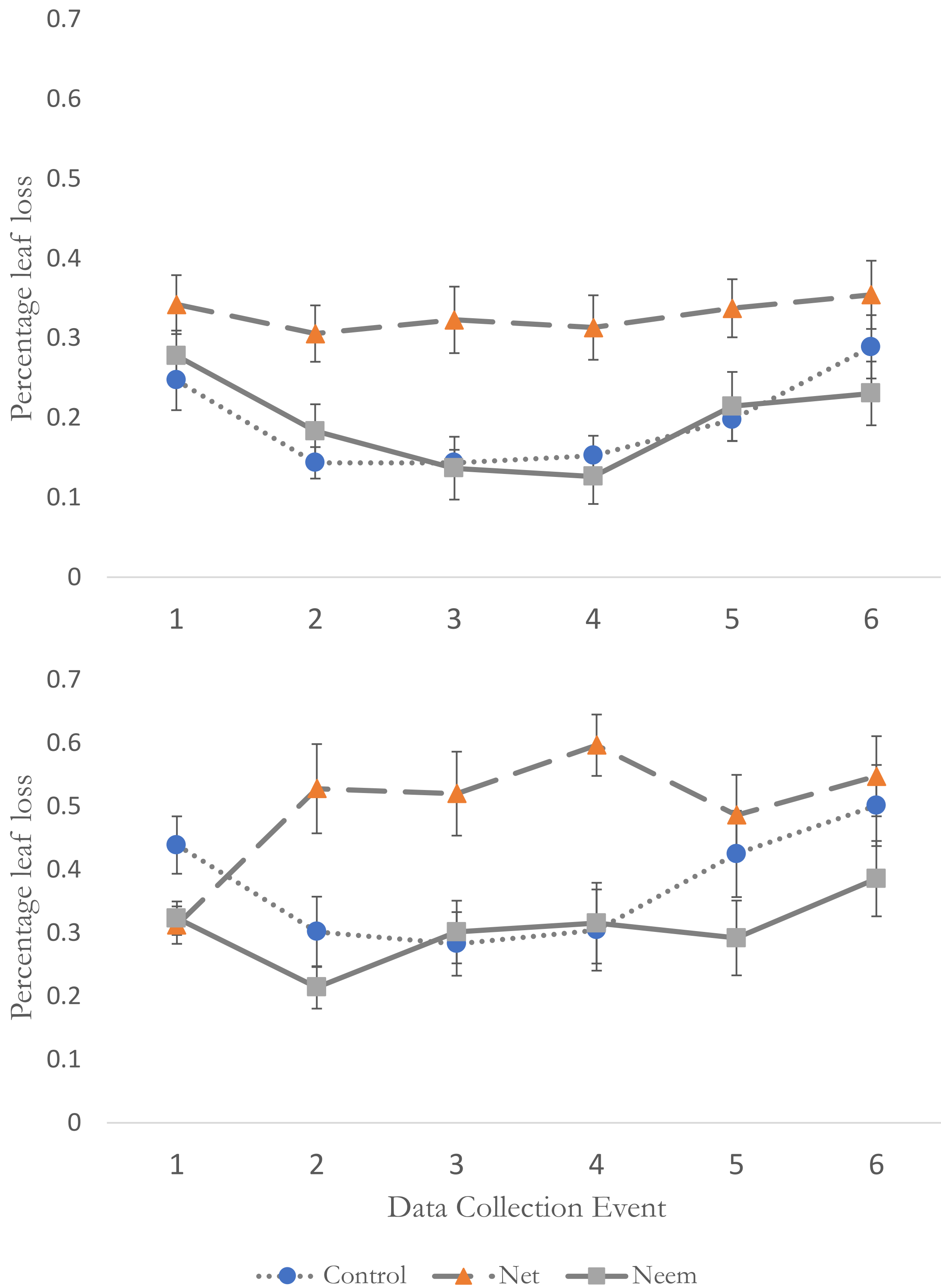

Figure 6. Mean percentage leaf loss (with standard errors) for kale (top) and collard greens (bottom). The x-axis and markers remain the same as in figure 3. The net treatment had significantly greater leaf loss in the net treatment for the kale crop. There were no other statistically significant differences among treatment types.

Result Summary

In summary, neither treatment had a significant effect on caterpillar abundance, and the net treatment worsened aphid abundance in kale (p-value 0.002) in contrast to our hypothesis. The net treatment reduced the percentage of leaves with caterpillar damage in kale (p-value 0.004) and collards (p-value < 0.001), while the neem treatment showed lower damage percentages in kale (p-value 0.04). The net treatment showed higher percentage of leaf loss in kale (p-value 0.02).

Discussion

This study examined the efficacy of a regular application of a neem oil-dilution and a physical exclusion barrier in the form of a net that covered crop rows. Both treatments were compared to a control with no pest management to assess the effect of neem oil and net barriers in brassica crops at DBCFSN's urban farm in Detroit. We conducted plot-scale experiments in kale and collard green crops on the farm. Our response variables included 1) abundance of aphids, 2) abundance of caterpillars, 3) percentage of leaves per plant with damage due to herbivory, 4) and percentage of leaf lost due to herbivory. Our results provide insights on the feasibility and efficacy of neem oil and exclusion barriers as agroecological pest management for brassica crops,

Aphid Abundance

Overall, neither pest method tested here was effective for controlling aphids. Aphid abundance was significantly higher in the net treatment than the control for the kale crop (p-value 0.002). Trends in aphid abundance for collard greens matched those in the kale, and the net treatment had more pests relative to the neem treatment and control (Figure 3). Previous studies have demonstrated that netting and row covers typically change the interior microclimate and increase the temperature, humidity, and soil moisture (Gogo et al. 2014). Another body of literature has demonstrated that these conditions can facilitate an increase in aphid population (Majumdar et al. 2011). It is possible that by changing in the microclimate, the net treatment created conducive conditions for aphid proliferation.

Predator exclusion is another possible explanation for the observed increase in aphid abundance in the net treatments. It is possible that the aphid population in the net treatments was protected from its natural predators and parasitoids (Woltz et al. 2012). If natural enemies were not well established in the subplots when the net cover was applied, the physical barrier could have a sheltering effect on the aphids by excluding predators

Predator prey population dynamics, where the population of the predator is dependent on prey abundance, are well studied in ecology (Curtsdotter 2019). The speed at which a predator population can respond is dependent on the length of their life cycle, environmental conditions, and interactions with other species. This creates a time lag as predator populations are constrained in the speed and extent to which they can respond to changes in prey populations (Woltz et al. 2012). Due to the time lag in the predator-aphid system, it is possible that aphids were established before predator populations in the net treatments. Such conditions would create a sheltered climate for the aphids without natural enemies (Kumar et al. 2019). Aphids were possibly established earlier than predator populations in our net treatments leading to the population increase in these subplots (Figure 3). For example, it is possible that we installed the nets after the aphids were established, but before predator populations were able to reach sustainable population levels. We see that when nets are installed later in the season, they are a counterproductive pest management strategy for aphids and ineffective to control caterpillar population in brassica crops. Further testing with earlier installation timing is needed to determine if physical barriers can be an effective management strategy when implemented earlier in the season.

There was no significant difference in aphid abundance between the neem and the control treatments in the kale and collard greens. There was a notable increase in aphid abundance during the 5th data collection event, where there were more aphids in the neem treatment compared to the control subplots (Figure 3). However, by the 6th data collection event the abundance of aphids decreases again, to approximately the same abundance as the control subplots. The cause for the increase in aphid abundance in data collection event 5 and decrease in 6 is unknown, but possible factors include predator control, disease, adverse climate conditions, or a decrease in food quality due to secondary compounds released by the plant. In conclusion, neither the net treatment nor the neem treatments were effective in controlling aphid populations in kale and collards, instead the nets were counter-productive.

Caterpillar Abundance

The net treatment had fewer caterpillars in both the kale and collard green crops, although this trend was not statistically significant (Figure 4). Previous studies provide evidence that row covers can reduce pest abundance, deter oviposition, and decrease caterpillar herbivory (Morishita et al. 1990, Rekika et al. 2008). The trend of fewer caterpillars in our net treatments may be explained by similar factors: the physical exclusion of pests and prevention of oviposition. Although the trend was not significant in kale, the neem treatment tended to have fewer caterpillars compared to the control. This trend was not observed in the collard green crop, where the neem and control subplots had similar caterpillar abundances. Anecdotally, we noticed that the neem oil-dilution seemed to adhere better to the kale leaves in comparison to the collard green crops due to the structural differences in the leaves. The kale had more textured leaves than the collards which perhaps led to a greater persistence of neem oil on the kale (Photo 4 and 5).

Photos 4. Lacinato kale leaves from D-town Farm, summer 2018

Photos 5. Collard green leaves from D-town Farm, summer 2018

Overall, caterpillar abundance decreased or remained steady across the six weeks, with one exception. We observed a spike in caterpillar abundance in net subplots for kale during data collection event 6. By the 6th data collection event, some of the kale crops were tall enough to press against the net of our row covers. The highest point of the hoops was approximately 21 inches off the ground. It is possible that the increase in caterpillar abundance during data collection event 6 was due to oviposition occurring through the net on leaves pressed against the net barrier. There was also an increase in caterpillar abundance measured in collards during data collection events 5 and 6. This was to lesser degree, possibly because the collard greens did not grow as tall as the kale and did not press against the net barrier as much. Structurally, the collard greens grew broader and closer to the ground while the kale crops grew taller. Future testing should be done to determine if earlier installation of taller net barrier exclusions would have a effect on reducing caterpillar abundance in both crops.

In sum, the net treatment has the potential to control caterpillar populations in kale and collards, while the neem treatment has potential to control caterpillars in kale. Further research on more spacious designs for the physical barriers and earlier installation dates is needed determine an effective treatment approach.

Percentage of leaves with damage

The net treatment had a significantly lower percentage of leaves with herbivore damage in both kale (p-value 0.004) and collard greens (p-value < 0.001). The neem treatment also had a significantly lower percentage of leaves with damage, but only in kale (p-value 0.04). These effects correspond to the lower, but non-significant, trends of caterpillar abundance in the net treatments for both crop types, and in the neem treatment for the kale crop.

All plots were still used for harvesting kale and collards throughout the summer and duration of the experiment. A limited number of healthy leaves were harvested from crops to meet daily sale demands. We do not have data on harvesting events or the number of leaves collected per plant in our subplots. It is possible that harvesting may have skewed our measure of percentage of leaves with damage to some extent. Harvesting is often typically biased towards the leaves with the least herbivory for aesthetic reasons and marketability. Furthermore, severely damaged leaves were left on the plants. Therefore, it is possible that this measure reflects an underestimate of the effect of treatments on the crops as the leaves with lowest damage were selectively removed. It is also possible that there was differential harvesting across treatment types in our experiment. The farm staff may have been less likely to harvest from the net treatment subplots due to the physical barrier.

Overall, the net treatment tended to be effective for decreasing leaf damage (Figure 5). This supports the broader objective for pest control on the farm to grow marketable produce. The neem treatment could also be beneficial in managing leaf damage for kale crops.

Percentage Leaf Loss

The net treatment led to a significantly higher percentage of leaf loss in both crops. While the number of caterpillars was lower in the net treatment, we anecdotally observed that the individual caterpillars inside the net were larger in size than the ones in the neem treatment and control. Hence, the leaves on which caterpillars were present may have experienced more leaf loss from the fewer, but larger caterpillars. This is a possible explanation because we chose to sample from the two leaves with the maximum amount of leaf loss.

Further, while our team and the farm staff periodically removed older yellowed leaves, the leaves with maximum leaf loss often remained on the crops. Because highly damaged leaves remained and leaves with less herbivory were harvested for market, it is possible that we measured the same leaves with maximum herbivory across multiple data collection events. This is especially relevant in collard greens where newer leaves experienced more herbivory in comparison to kale where the maximum leaf loss was often observed on older leaves closer to the ground.

Despite statistically significant results for percentage leaf loss among treatments, this measure of herbivory may not best capture the effect of the treatments over time (Table 5 and Figure 6).

Additional Factors

External factors may have impacted the experiment and our results. The seedlings were obtained from an external supplier and pests were present on them. Further, the experimental setup took place during the second half of the season, at which point pest populations were already established in the crops. The number of days needed to complete data collection events varied according to farm working hours, labor available, and weather conditions. Population dynamics could have shifted during this period, especially if there was a rain event or another marked weather fluctuation such as a large temperature swing. If the spraying is followed by a rain event, the effect of the treatment may be diminished. Further, the neem treatment is non-targeted and could have decreased the abundance of natural predators to aphids and caterpillars.

The farm staff observed that pest pressure during the summer of 2018 when our experiments took place, was lower than the previous season. Apart from weather patterns and broader population dynamics that influence local abundance, our methods and research practice could have introduced factors that impacted our results. For instance, we removed yellowed leaves from the crops and deweeded the beds once a week. While these maintenance activities are regularly completed by farm staff, it is possible that we did so more regularly by comparison.

Plastic weed barriers were used on the beds for the lacinato kale and collard greens to limit the need for manual deweeding. It is possible that this practice altered the microclimate which inadvertently impacted the pest-predator dynamics, particularly of ground-dwelling varieties.

Conclusion

There are three primary takeaways from our plot-scale experiments. The net and neem treatment were not effective in controlling aphids, and the net treatment can counter-productively increase aphid abundance. Hence, if the focus of the farm is the management of aphids, a different pest management strategy will be necessary.

The net treatment was effective for reducing herbivore damage and caterpillar abundance in both lacinato kale and collard greens. The treatment could be more effective if installed earlier in the growing season, before the pest population is established. Growing seedlings on the farm itself may also deter the establishment of pest populations. Further, larger row covers for lacinato kale may better sustain the effect of the net treatment throughout the growing period. Further, the neem treatment was effective at reducing herbivore damage and caterpillar abundance in kale, but not in collards. All costs and benefits of these two pest management strategies should be considered. Although future research is needed for both of the neem and net treatments, the time, labor, and financial costs necessary to scale up both of these management strategies across the farm needs to be considered.

We hope to see the partnership between DBCFSN and the School for Environment and Sustainability (SEAS) develop further. Future Master's students could collaborate with DBCFSN and use our project as a baseline and continue to explore innovative and practical agroecological pest management strategies at D-town Farm. Further experiments could consider combining the neem and net treatments to investigate if the two methods have a greater impact when jointly implemented. Other agroecological management practices could also be considered for future exploration, including intercropping, cover crops, and crop rotation across the farm matrix.

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Photo Appendix

Photo 6. Severe herbivory on a collard green plant in the control plot.

Photo 7. Herbivory on a kale plant in the control plot.

Photo 8. Severe aphid infestation on a collard green plant in the net plot.

Photo 9. Cabbage Looper (Trichoplusia ni) on a collard green individual.

Photo 10. Imported cabbageworm (Pieris Rapae) chrysalis on a kale plant.

Photo 11. Caterpillars on a kale plant. Possibly an eastern tent caterpillar variety.

Photo 12. Caterpillar on a kale plant.

Photo 13. Caterpillar on a kale plant.

Photo 16. Michigan Green Caterpillar (Melanchra adjuncta) on a kale plant.

Photo 17. Slug on a kale plant.

Photo 18. Predator of caterpillars on a kale plant. Possibly a lacewing larvae..

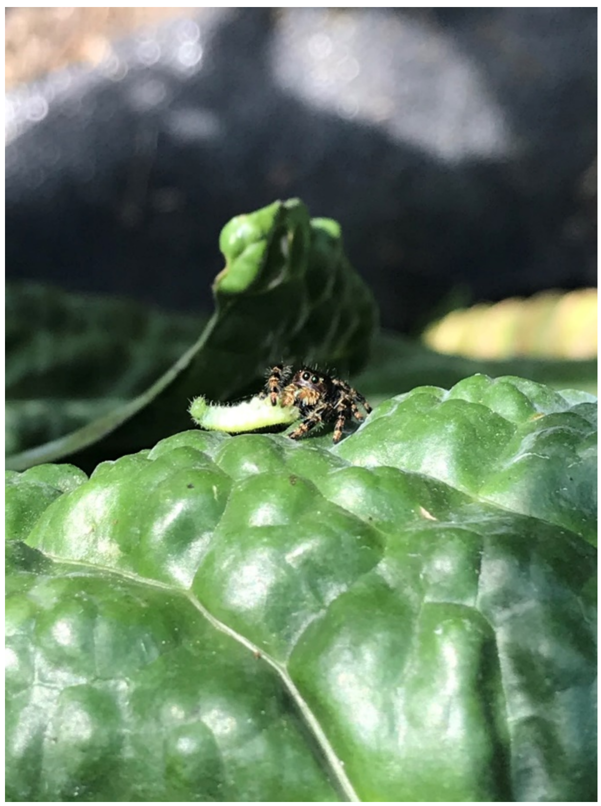

Photo 19. Predation of caterpillars on a kale plant by a jumping spider.