Evaluating the Efficacy of Pesticides and Pesticide Application Timing Against Elongate Hemlock Scale and Cryptomeria Scale in Western North Carolina

ST 542 Statistical Consulting Project Report

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GitHub Repository: https://github.com/rlhardy2/ST-542-Consulting-Project

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1 Background

Elongate hemlock scale (EHS) and Cryptomeria scale are introduced pests originating from Asia. Though commonly associated with hemlocks, EHS can feed on many species of conifers including firs, pines, spruces, cedars, and Douglas fir. In western North Carolina, hemlocks and true firs, including Fraser fir, are its most common hosts (Sidebottom & Bookwalter, 2016). Though EHS is the most common scale pest, the most damaging is Cryptomeria scale. Scales are found on the underside of needles and are round. Pest control for Cryptomeria scale and EHS are similar (Sidebottom & Bookwalter, 2016).

These pests are difficult to control for several reasons. (1) Their armored covering makes pesticide penetration difficult. (2) Their asynchronous life cycle means that all life stages are almost always present, meaning that insecticides can not be applied at any specific crawler emergence. (3) Since these pests feed in epidermal tissue instead of vascular tissue, they are not as easily controlled by systemic insecticides. (4) Additionally, as introduced pests, they have few natural enemies, though there are several that feed on them (Sidebottom & Bookwalter, 2016).

The continued rise of these pest-related issues has affected the pest management landscape for U.S. Christmas tree farmers. Strict regulations in the U.S. have resulted in a zero-tolerance policy for EHS-infested and/or Cryptomeria scale-infested trees (Bookwalter, 2024). Despite the massive economic impact incurred by farmers in scale-infested states, pesticide efficacy against these pests is still understudied, as pesticide efficacy experiments are often difficult to conduct due to the spotty distribution of the insects in the field and in the tree (Bookwalter, 2024).

2 Introduction

The study investigates the efficacy of pesticides and pesticide application timing against scale insects on Christmas trees in western North Carolina through three experiments.

In the first experiment, four sites with high levels of pest infestation were selected. Each site was located in a different county (Ashe, Avery, Mitchell, and Watauga). With a randomized block design, sections of the field were randomly assigned treatments with guard rows. The only pesticide used in this experiment was Acetamiprid. Each treatment consisted of sixteen trees (a 4 x 4 block) with data collected only from the innermost four trees, with these four trees being referred to as the treatment section. There were four treatments in total consisting of a control (no treatment) and three different pesticide application timing windows. Only EHS were in these fields. Figure 1 below shows the block design for Experiment 1.

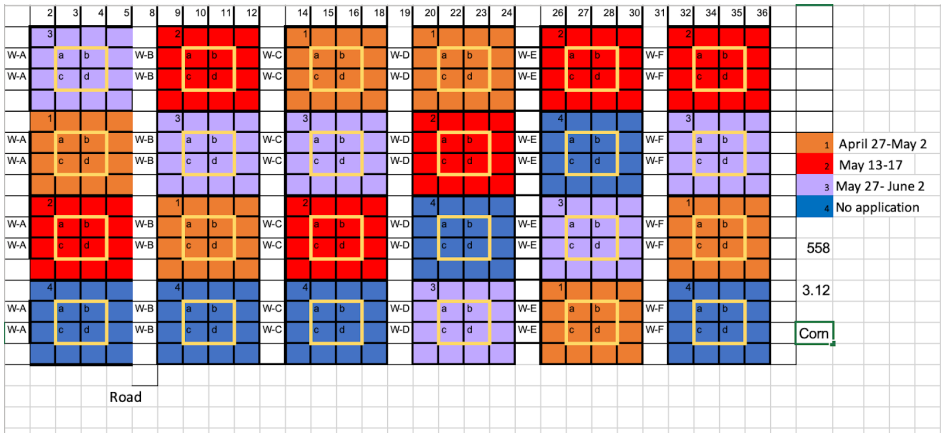

Figure 1: Block design for Experiment 1

The second experiment was implemented in Ashe county, specifically Doughton Mountain. The experiment utilized the same randomized block design seen in the first experiment. This experiment focused on two different pesticides contained in four treatments consisting of a control (no treatment), Acetamiprid, Pyriproxyfen, and both Acetamiprid and Pyriproxyfen (used simultaneously). Both EHS and Cryptomeria scale were in this field.

The third experiment was also implemented in Ashe county, and utilized the same randomized block design seen in the first and second experiments. This experiment focused on four different pesticides contained in five treatments consisting of a control (no treatment), Acetamiprid, Dinotefuran, Flupyradifurone, and Sulfoxaflor. Both EHS and Cryptomeria scale were in this field.

For Experiments 1 and 2, scale insect damage was assessed in July 2024 and again in November 2024. For Experiment 3, scale insect damage was assessed in November 2024. There were two twigs from each of the four trees per treatment section collected, with each twig having three shoots. The following was recorded for each experiment:

1. The number of live and dead scale insects on the bottom five needles and top five needles from each of the three shoots.
2. The presence or absence of parasitism from each twig.
3. The presence or absence of entomopathogenic fungus from each twig.
4. The counts of natural parasitoid wasps (*Encarsia citrina*) on two sticky traps per treatment section were recorded in August 2024 in the first and second experiments only.

The second, third, and fourth items recorded for each experiment represent natural enemies (parasitoids, pathogens, and predators that reduce pest populations and associated damage). The application of pesticides can kill natural enemies and/or disrupt their advantageous activities.

3 Research Questions

The research questions differ slightly between the three experiments.

Experiment 1:

1. Is there a significant difference between the populations of scale insects across different Acetamiprid application dates?
2. How does the application of Acetamiprid across different application dates affect parasitism, entomopathogenic fungus, and *Encarsia citrina*?

Experiment 2:

1. Do the different pesticides (Acetamiprid, Pyriproxyfen, and simultaneous application of Acetamiprid and Pyriproxyfen) significantly affect the population of scale insects?
2. Is there a significant difference between the efficacy of applied pesticides?
3. How does the application of each pesticide affect parasitism and *Encarsia citrina*?

Experiment 3:

1. Do the different pesticides (Acetamiprid, Dinotefuran, Flupyradifurone, and Sulfoxaflor) significantly affect the population of scale insects?
2. Is there a significant difference between the efficacy of applied pesticides?
3. How does the application of each pesticide affect parasitism and entomopathogenic fungus?

4 Project Goals

The primary goal of our collaboration is to improve on our client's existing analysis (nonparametric modeling using the Kruskal-Wallis test). We will investigate two-factor alternatives that accommodate the blocking factor. We will also assess the suitability of parametric models. As the scale insect and *Encarsia* data is heavily skewed and contains high zero counts, we will explore Poisson and negative binomial regression and their zero-inflated variants. We will also investigate binomial regression for the presence/absence of parasitism and entomopathogenic fungus. For both techniques, we will estimate confidence intervals for treatment means and detect significant differences between treatments.

5 Data Collection, Pre-processing, and Exploration

5.1 Data Collection

All three experiments utilized the same framework, which consisted of a randomized block design with four trees per treatment section. Scale insect damage was assessed in July 2024 and again in November 2024 for Experiments 1 and 2, and only in November 2024 for Experiment 3. There were two twigs from each of the four trees per treatment section collected, with each twig having three shoots. For the first and second experiments, two sticky traps were placed in each treatment section with the intention of collecting natural parasitoid wasps (*Encarsia citrina*). *Encarsia* counts were recorded in August 2024. Data were collected by Dr. Jamie Bookwalter and her colleagues in the Extension Forestry Department at North Carolina State University.

5.1.1 Variables Recorded

For all three experiments, the following variables were recorded: the tree label, the twig the observation was taken from (A or B), whether parasitism was present, whether entomopathogenic fungus was present, and the number of live and dead scale insects for each of the three shoots (LiveScale1, LiveScale2, LiveScale3, DeadScale1, DeadScale2, and DeadScale3). For Experiment 1, the location (county) was also recorded. For Experiments 1 and 2, the date (July or November) and the count of *Encarsia citrina* found were also recorded.

Experiment 1 included fields where only EHS were present. Experiments 2 and 3 included fields where both EHS and Cryptomeria scale were present. In Experiment 2, separate observations were recorded for each twig depending on the type(s) of scale insects present (EHS/Cryptomeria/both). For Experiment 3, the number of live and dead EHS and Cryptomeria scale were recorded as separate columns within the same observation.

Each tree has a unique label indicating its specific location within the experimental field, which also identifies the treatment applied to it. A treatment variable is derived from the label variable, reflecting the treatment assigned to each tree. This variable is represented by integer values.

5.2 Data Pre-processing

5.2.1 Creation of New Variables

A shared goal among the three studies was to assess the average count of live and dead scale insects across the shoots on a twig. Each observation (a twig) had 3 shoots, though many samples were missing one shoot. We took the average of the available shoots to create MeanLiveScale and MeanDeadScale, representing the per-shoot average of live and dead scale insects across each twig. The raw data for Experiments 2 and 3 divided the counts for EHS, Cryptomeria scale, and both EHS/Cryptomeria into separate observations or columns. We summed the disparate counts into per-shoot totals before creating MeanLive/DeadScale.

The occurrences of parasitism and fungus were recorded as yes/no variables, PresPara and PresFungus. We converted PresPara and PresFungus to binary (0/1) variables, where 0 indicated undetected presence and 1 represented confirmed presence. Study 2 also divided the presence of parasitism/fungus into separate observations per scale insect subtype. We regarded parasitism or fungus as present if any observation for a given twig was marked as 1.

Because the average per shoot produced decimal values, we preferred the integer per-twig total for count models. However, many samples were missing data from one shoot, preventing us from using the observed sum for each twig. We therefore multiplied MeanLiveScale and MeanDeadScale by 3 to estimate the twig total, creating SumLiveScale_From_Mean and SumDeadScale_From_Mean.

Finally, we extracted the block from the treatment label.

5.2.2 Exclusion of Data

Multiple people collected samples, and occasionally, a sample was lost or not collected due to time constraints. Additionally, each twig collected (two per tree) was intended to have three shoots, but there were cases where a collected twig only had one shoot. To prevent imbalanced and/or misleading results, samples with only one shoot were removed. Observations without scale insects present were dropped for the analysis of fungus and parasitism, as these phenomena cannot occur without insects.

In Study 2, data was collected in both July and November. The data has several missing values for the counts of live and dead scale insects for the month of July only, due to an increased proficiency in twig collection in the month of November.

5.3 Preliminary Exploration of Treatment Means

In this section, we will conduct a preliminary exploration of treatment means for the three different studies. All means were taken across samples of 3 shoots (each shoot with 10 needles).

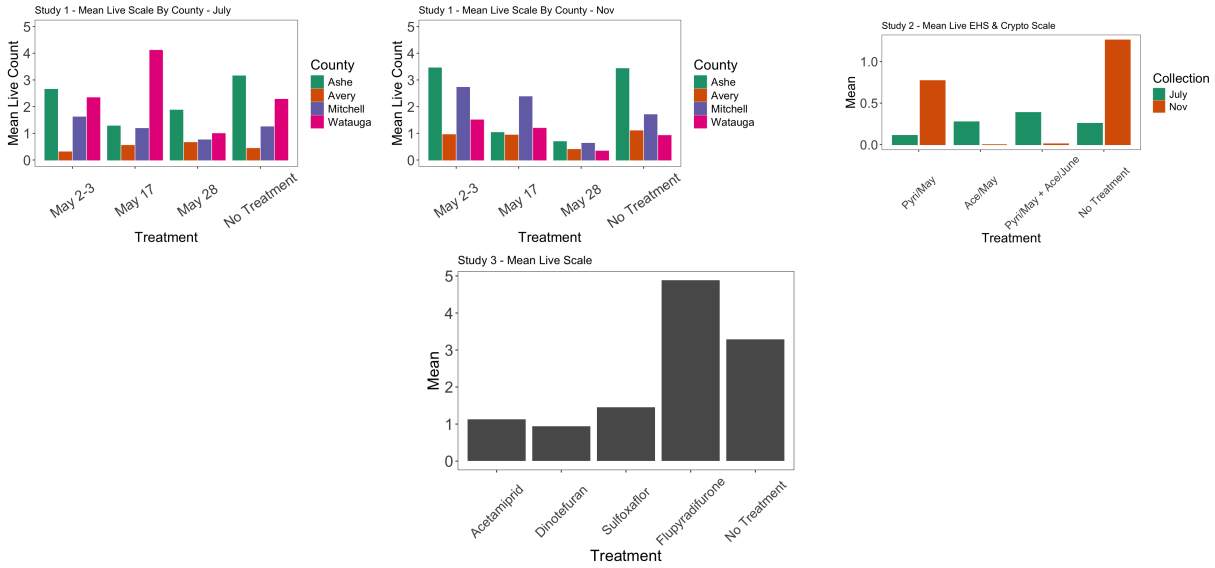

Figure 2: Counts of mean live scale insects by treatment and county by collection dates, and by treatment alone across both collection dates, per shoot

From a glance, we seem to observe higher mean live scale insect counts for the no-pesticide control.

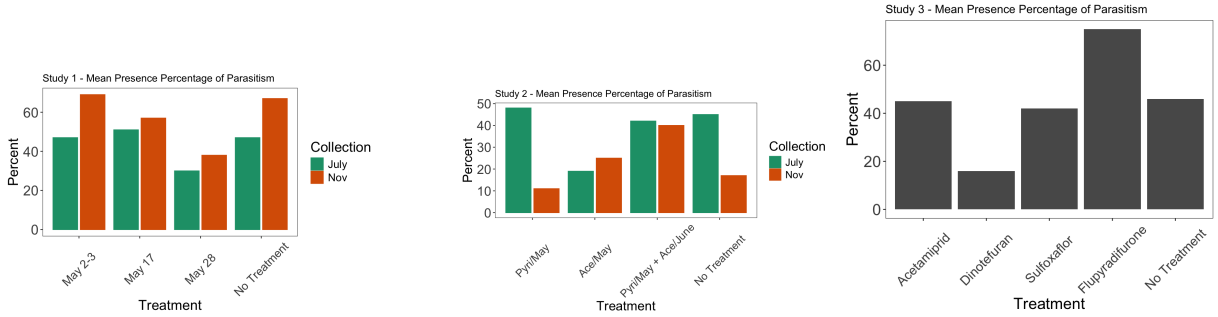

Figure 3: Presence percentages of parasitism per twig, across treatments

The mean presence of parasitism appears lower for the May 28th treatment in Study 1. For study 2, differences appear more ambiguous. Dinotefuron seems to impact parasitism significantly in Study 3.

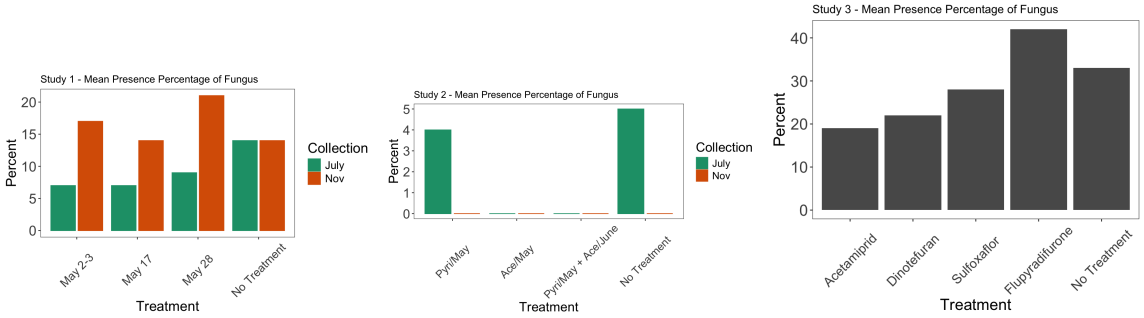

Figure 4: Presence percentages of entomopathogenic fungus per twig, across treatments

We see extremely low percentages in Study 2 for both July and November (<5% vs 5-20+% in the other experiments).

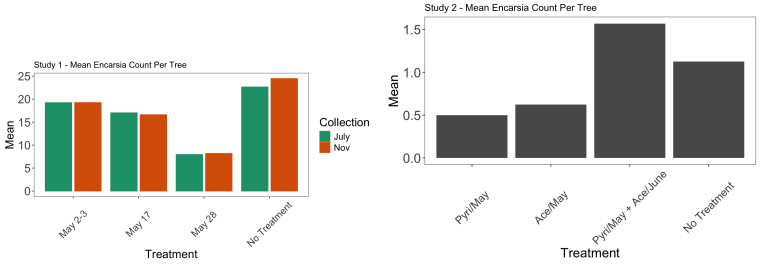

Figure 5: Mean Encarsia count for each tree

We seem to observe lower *Encarsia* counts for the May 28th treatment in Study 1, and for Pyriproxyfen in Study 2.

5.3.1 Distributional Testing

There were significant zero counts across the samples, as is typical of insect population data.

Figures 6, 7, and 8 show mean live scale insects for each shoot, from each twig/sample of 3 shoots (10 needles per shoot). The mean is shown here because it is most pertinent to the research, but we will model with the estimated total sum across each twig, which is simply 3x the mean live scale. We note very high zero counts and right-skewed data.

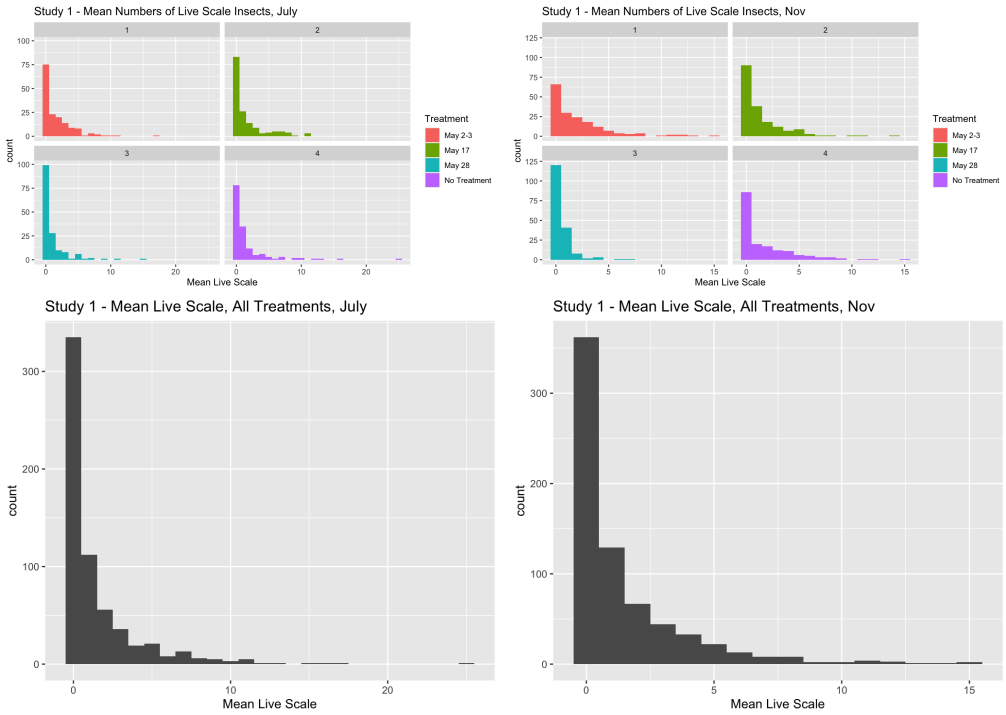

Figure 6: Distributions of live scale, Study 1

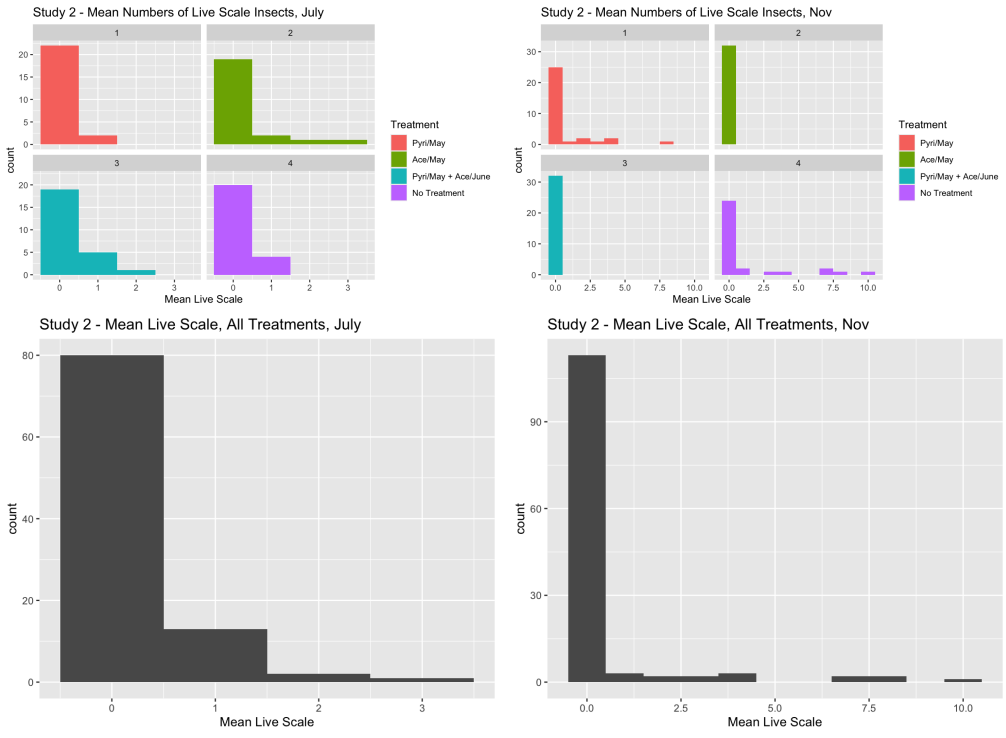

Figure 7: Distributions of live scale, Study 2

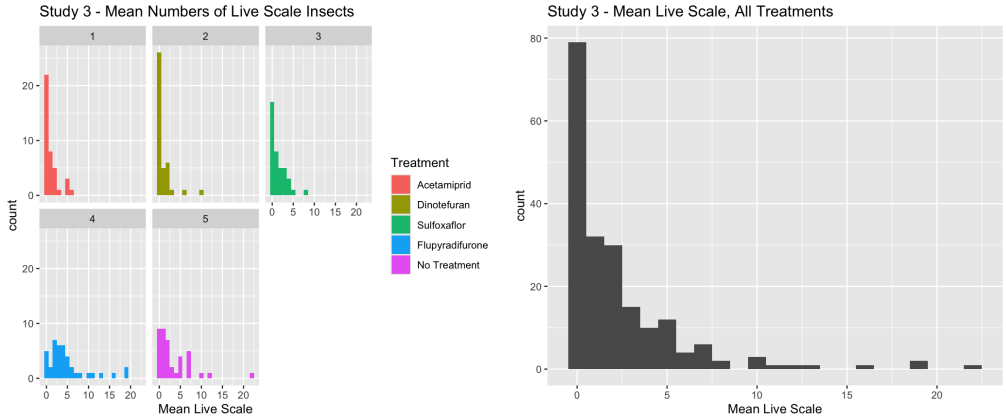

Figure 8: Distributions of live scale, Study 3

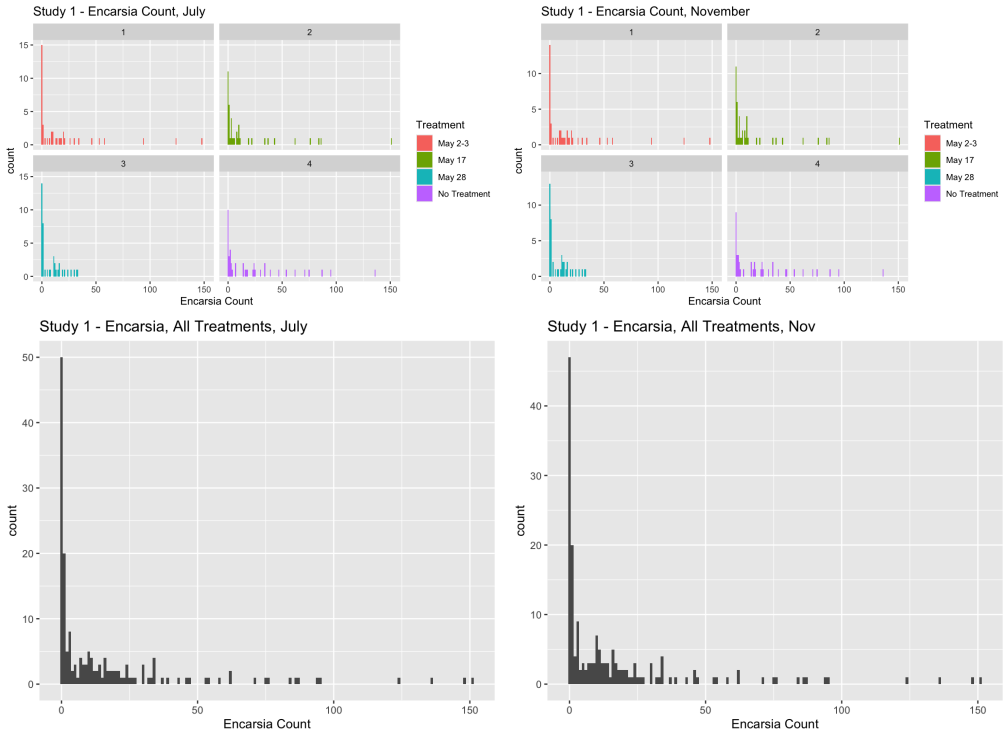

Figure 9: The distribution of Encarsia citrina counts across each tree, per treatment. As Encarsia presence is not contingent on scale insects, these counts include trees with all observed scale counts. In Study 2, we note lesser zero counts for certain treatments.

5.4 Normality Testing

The Shapiro-Wilk test for normality was performed for the mean live scale count and the counts of *Encarsia citrina*. The test was not performed for the variables signifying the presence of parasitism and entomopathogenic fungus, as these are binary variables. For all three studies, significant normality violations were present among all variables examined.

For the Shapiro-Wilk normality test, the null hypothesis is that the sample in question came from a normally distributed population. With a low p-value (less than 0.05), we will reject the null hypothesis and conclude that the sample did not come from a normally distributed population. Below are the results of this test across the three studies.

In all three studies, for the non-binary variables of interest (scale and *Encarsia* counts), we reject the null hypothesis and conclude that these variables are not normally distributed. See tables below.

Study 1: Shapiro-Wilk Normality Test Results			
Variable	**Month**	**p-value**	**Outcome**
MeanLiveScale	July	2.2e-16	Reject the null hypothesis
Encarsia	July	2.2e-16	Reject the null hypothesis
MeanLiveScale	November	2.2e-16	Reject the null hypothesis
Encarsia	November	2.2e-16	Reject the null hypothesis

Study 2: Shapiro-Wilk Normality Test Results			
Variable	**Month**	**p-value**	**Outcome**
MeanLiveScale	July	2.2e-16	Reject the null hypothesis
Encarsia	July	3.372e-05	Reject the null hypothesis
MeanLiveScale	November	2.2e-16	Reject the null hypothesis
Encarsia	November	1.109e-06	Reject the null hypothesis

Study 3: Shapiro-Wilk Normality Test Results			
Variable	**Month**	**p-value**	**Outcome**
MeanLiveScale	November	2.2e-16	Reject the null hypothesis

6 Methods

6.1 Nonparametric Methods – Friedman Test, Scheirer-Ray-Hare Test

Due to the non-normality of the scale and *Encarsia* counts, nonparametric methods will be utilized. For the nonparametric analysis, two techniques will be implemented. First, we will use the Friedman test followed by the post hoc Nemenyi test, if appropriate. Second, we will use the Scheirer-Ray-Hare test, which is an extension of the Kruskal-Wallis test to accommodate factorial designs. We originally planned to use the Kruskal-Wallis test followed by Dunn's test, but soon realized that a one-factor test was not appropriate due to the randomized block design that all three experiments employ.

6.1.1 Friedman Test

The Friedman test is a non-parametric test for analyzing randomized complete block designs. It is an extension of the sign test when there may be more than two treatments. In order to use the Friedman test, the data must be condensed to an unreplicated complete block design, meaning that there must be one observation for each treatment-block combination. In other words, this test assumes there are k experimental treatments with the observations arranged in b blocks. This test operates by summing the ranks to obtain

$$R_j = \sum_{i=1}^{b} R(X_{ij}) \tag{6.1}$$

where $R(X_{ij})$ is the rank assigned to X_{ij} within block i (i.e., ranks within a given row) (*Friedman Test*). The null hypothesis of the Friedman test is that the treatment effects have identical effects, and the alternative hypothesis is that at least one treatment is different from at least one other treatment (*Friedman Test*). The test statistic for this test is given by

$$T_1 = \frac{12}{bk(k+1)} \sum_{i=1}^{k} \left(R_i - \frac{b(k+1)}{2} \right)^2 \tag{6.2}$$

where the critical region can be found by

$$T_1 > \chi^2_{(\alpha,\, k-1)} \tag{6.3}$$

where χ^2 is the percent point function of the chi-square distribution. We reject the null hypothesis if the test statistic is in the critical region (*Friedman Test*).

Note that Conover recommends the test statistic

$$T_2 = \frac{(b-1)T_1}{b(k-1) - T_1} \tag{6.4}$$

since it has a more accurate approximate distribution. In this case, the critical region can be found by

$$T_2 > F_{(\alpha,\, k-1,\, (b-1)(k-1))} \tag{6.5}$$

where F is the percent point function of the F distribution. We reject the null hypothesis if the test statistic is in the critical region (*Friedman Test*).

If the test delivers a significant result, the Nemenyi post hoc test will be used to detect which treatment means significantly differ from one another. The Nemenyi test makes pairwise tests of performance.

6.1.2 Scheirer-Ray-Hare Test

The Scheirer-Ray-Hare test is an extension of the Kruskal-Wallis test to accommodate factorial designs. Appropriate data for this test are two-way data arranged in a factorial design where the dependent variable is ordinal, interval, or ratio (Mangiafico). Additionally, there must be two treatment or group independent variables, where each is a factor with two or more levels (these are the Treatment and Block variables); lastly, the observations in the data set must be independent (Mangiafico). Unfortunately, there is no appropriate post hoc pairwise comparison test.

6.2 Parametric Methods – Generalized Linear Mixed Regression Models

When data closely fits a parametric model, nonparametric tests may provide less statistical power and inferential detail than tests performed on parametric models. We will therefore examine counts of live scale insects/*Encarsia citrina* through Poisson, negative binomial 1 (also known as Quasi-Poisson), and negative binomial 2 models, as well as their zero-inflated variants.

Additionally, the presence/absence of parasitism and entomopathogenic fungus is represented by binary data, which is naturally suited to binomial modeling. We will thus also fit the presence/absence of parasitism and entomopathogenic fungus to binomial GLMs.

The data is blocked on sections of each field, based on the researcher's intuition of soil quality. For live/dead scale count and the presence/absence of parasitism and entomopathogenic fungus, data is taken per-twig.

While we expect different baseline values for scale count, fungus, and parasitism across different blocks and trees, we do not anticipate the *effect of the pesticides* to vary across the same block or tree. We can therefore fit mixed effects models with random intercepts, rather than random slopes, for the block and tree, with the tree nested within the block.

Additionally, because *Encarsia* counts are per-tree, for *Encarsia* we will only use a random intercept for the block.

6.2.1 Binomial

We will characterize the presence of parasitism and fungus per pesticide treatment with the binomial distribution. The parameters in a binomial distribution are the sample size and the probability (*Binary Logistic Regression*).

$$Y_{\text{trt}} \sim Binomial(n_{\text{trt}}, p_{\text{trt}}) \tag{6.6}$$

where n_{trt} is the number of observations (twigs) of parasitism/fungus per pesticide treatment and p_{trt} represents the probability of parasitism/fungus for that treatment. We will fit the data to a mixed effects logistic regression model with random intercepts for the block and tree:

$$\text{logit}(Pr(Y_{ijk} = 1) = p_{ijk}) = \beta_0 + \beta_1 \cdot \text{Treatment}_{ijk} + \beta_2 \cdot \text{Treatment}_{ijk} + \cdots + b_i + t_{ij} \tag{6.7}$$

where

$$\text{logit}(p_{ijk}) = \log\left(\frac{p_{ijk}}{1 - p_{ijk}}\right) \tag{6.8}$$

$$b_i \sim N(0, \sigma_b^2),\ t_{ij} \sim N(0, \sigma_t^2)$$

Y_{ijk} is the presence of parasitism/fungus per twig and $\left(\frac{p_{ijk}}{1-p_{ijk}}\right)$ represents the odds (the proportion of observed parasitism/fungus over the proportion of unobserved parasitism/fungus). $Treatment$ is a dummy variable indicating the usage of each treatment (1 per observation). β_0 corresponds to no treatment and β_i represents the log-odds change in the presence of parasitism or entomopathogenic fungus for each treatment compared to the control. Additionally, b_i represents the random effect of the block, t_{ij} represents the random effect of the tree within block i, and k symbolizes the twig within the tree.

We will then take estimated marginal means and perform post-hoc pairwise multiple comparisons tests with the Benjamini-Hochberg adjustment. The Benjamini-Hochberg procedure reduces the probability of false positives by adjusting the significance level for multiple comparisons (Obermaier, 2024). If the adjusted p-value for a comparison is low (less than 0.05), we can conclude that the groups/treatments tested are significantly different.

6.2.2 Poisson, Negative Binomial 1 (Quasi-Poisson), and Negative Binomial 2

The Poisson is the typical count model, but real data frequently violates its assumption of equal mean and variance (*Poisson Regression*).

$$Pr(Y = y_{ijk}|\mu) = \frac{e^{-\mu_{ijk}}\mu_{ijk}^{y_{ijk}}}{y_{ijk}!} \tag{6.9}$$

where i is the block, j is the tree within the block, and k is the twig within the tree. Y_{ijk} is the count of scale insects for that block, tree, and twig. μ_{ijk} is the expected Poisson insect count.

The negative binomial distributions offer greater flexibility, permitting the variance to exceed the mean (overdispersion) (*Negative Binomial Regression*). The negative binomial 2 distribution is the default negative binomial distribution included in most software packages. Its variance has a quadratic ($Var(Y) = \mu + 2$)

relationship with the mean. The negative binomial 1 distribution, also known as the Quasi-Poisson, only differs in that its variance is directly proportional to the mean ($Var(Y) = \mu(1+\alpha)$) (Bolker et al., 2012).

$$g(y_{ijk}) = Pr(Y = y_{ijk}|\mu_{ijk}, \alpha) = \frac{\Gamma(y_{ijk} + \alpha^{-1})}{\Gamma(\alpha^{-1})\Gamma(y_{ijk}+1)} \left(\frac{1}{1+\alpha\mu_{ijk}}\right)^{\alpha^{-1}} \left(\frac{\alpha\mu_{ijk}}{1+\alpha\mu_{ijk}}\right)^{y_{ijk}} \tag{6.10}$$

Both the Poisson and negative binomial use a log link equation of the form:

$$\log(\mu_{ijk}) = \beta_0 + \beta_1 \cdot \text{Treatment}_{ijk} + \beta_2 \cdot \text{Treatment}_{ijk} \ldots + b_i + t_{ij} \tag{6.11}$$
$$b_i \sim \mathcal{N}(0, \sigma_b^2),\ t_{ij} \sim \mathcal{N}(0, \sigma_t^2)$$

$$\log(\mu_{ijkl}) = \beta_0 + \beta_1 \cdot \text{Treatment}_{ijkl} + \beta_2 \cdot \text{Treatment}_{ijkl} \ldots + b_i + t_{ij} + s_{ijk} \tag{6.12}$$
$$b_i \sim \mathcal{N}(0, \sigma_b^2),\ t_{ij} \sim \mathcal{N}(0, \sigma_t^2),\ s_{ijk} \sim \mathcal{N}(0, \sigma_s^2)$$

where α is the shape (dispersion) parameter. i is the block, and j is the tree within the block; k is the twig within the tree. Y_{ijk} is the count of scale insects. μ_{ijk} symbolizes the expected insect count for the kth sample twig for the jth tree within the ith block, and $Treatment$ is a dummy variable indicating the usage of each treatment (1 per observation). β_0 represents the effect of no treatment, while the regression coefficients $\beta_1, \ldots, \beta_k$ signal the change in the log of the expected scale insect or Encarsia count for the treatment compared to the no-treatment control.

The *Encarsia* and scale count models are mostly identical, but the *Encarsia* model eschews the tree effect k, as *Encarsia* observations exist at the tree level, rather than the twig.

6.2.3 Zero-Inflated Models (Poisson and Negative Binomial 1 & 2)

The experiments produced many zero insect counts. Our client theorized that the zero counts may exceed those permitted by standard count models, based on her previous modeling attempts.

Multiple conditions influenced counts of zero insects. In some cases, unsuitable conditions prevented insects from moving to specific trees. In others, the pesticides worked perfectly. Zero-inflated count models fit two different processes: the first strictly generating zeros and the second producing the full count range (0, 1, 2...). We can model unsuitable conditions for insect habitation with the fixed-zero process, and the effectiveness of the pesticide using the count process.

We will examine the zero-inflated equivalents of the models in the previous section: zero-inflated Poisson, and zero-inflated negative binomial 1 and 2.

The form for the **zero-inflated Poisson** is:

$$Pr(y_{ijk} = l) = \begin{cases} \pi_{ijk} + (1-\pi_{ijk})e^{-\mu_{ijk}}, & \text{if } l = 0 \\ (1-\pi_{ijk})\frac{\mu_{ijk}^{y_{ijk}} e^{-\mu_{ijk}}}{y_{ijk}!}, & \text{if } l > 0 \end{cases} \tag{6.13}$$

The logistic link function for π_{ijk} is defined below.

The first equation represents the fixed-zero process, and the second represents the Poisson distribution as described in the previous section. μ_{ijk} is the probability of extra zeros (the fixed-zero process).

The form for the **zero-inflated negative binomial (both 1 and 2)** is:

$$Pr(y_{ijk} = l) = \begin{cases} \pi_{ijk} + (1 - \pi_{ijk})g(y_{ijk} = 0), & \text{if } l = 0 \\ (1 - \pi_{ijk})g(y_{ijk}), & \text{if } l > 0 \end{cases} \tag{6.14}$$

The first equation represents the fixed-zero process, and $g(y_{ijk})$ in the second signals the negative binomial distribution given by Equation (6.10) in the previous section. Both the negative binomials 1 and 2 use this distributional form; they differ only by their α (dispersion parameter) and μ_{ijk} relationships. π_{ijk} signifies the probability of extra zeros (the fixed-zero process).

The negative binomial and Poisson components include the same k regressor variables from the previous section, shown in equation (6.12).

For the fixed zero process, the zero-inflated negative binomial and Poisson also use a logistic link function of the form:

$$\pi_{ijk} = \frac{\lambda_{ijk}}{1 + \lambda_{ijk}} \tag{6.15}$$

where

$$\lambda_{ijk} = e^{\ln(t_{ijk}) + \gamma_1 z_{1ijk} + \gamma_2 z_{2ijk} + \cdots + \gamma_m z_{mijk}} \tag{6.16}$$

The logistic component includes an exposure time t and a set of m regressor variables z_m. The regression coefficients for the fixed-zero process, denoted by γ_m, indicate the change in the log-odds of an excess zero count from the fixed-zero process when the habitat is unsuitable for scale insects/*Encarsia*.

We will use the estimated marginal means to perform post-hoc multiple comparison tests, with the Benjamini-Hochberg adjustment described previously.

7 Results

For Studies 1 and 2, analyses were performed separately for the months of July and November. This is not the case for Study 3 as the corresponding data was only collected in November. Figures/tables beginning with the letter "A" are located in the appendix. All confidence intervals presented are constructed with 95% confidence.

7.1 Nonparametric Methods – Friedman Test, Scheirer-Ray-Hare Test

All nonparametric analyses tested whether MeanLiveScale differed by treatment. *Encarsia* counts were not examined with such methods due to small sample sizes after filtering the data appropriately.

7.1.1 Study 1

For July, the Friedman test proved significant with a p-value of 0.012. The Nemenyi test was then conducted to find pairwise differences (see Table A1). The only treatments that differ significantly are the May 2-3 and May 28 treatments, with a p-value of 0.013. The Scheirer-Ray-Hare test was also conducted, the corresponding results can be seen in Table A2. The effect of Treatment was not significant with a p-value of 0.062.

For November, the Friedman test could not be conducted because the data could not be condensed to an unreplicated complete block design due to uncollected data. However, we were able to perform the Scheirer-Ray-Hare test. This test found that the effect of Treatment was significant with a p-value of approximately 0, as seen in Table A3.

7.1.2 Study 2

For July, the Friedman test was not significant, with a p-value of 0.5779. As seen in Table A20, the Scheirer-Ray-Hare test also yielded an insignificant p-value of approximately 0.15 for the effect of Treatment.

For November, the Friedman test was not significant, with a p-value of 0.1562. As seen in Table A21, the Scheirer-Ray-Hare test yielded a significant p-value of 0.017 for the effect of Treatment.

7.1.3 Study 3

The Friedman test proved significant with a p-value of 0.01147. The Nemenyi test was then conducted to find pairwise differences, as seen in Table A32. There were two sets of treatments that differed from one another: Acetamiprid and Flupyradifurone as well as Dinotefuran and Flupyradifurone, with p-values of 0.041 and 0.023, respectively. No treatments differed significantly from the control. The Scheirer-Ray-Hare test was also conducted, which yielded a significant p-value of approximately 0 for the effect of Treatment, as seen in Table A33.

7.2 Parametric Methods – Generalized Linear Regression Models

Across all studies, we discovered that the negative binomial 1 (quasi-Poisson) distribution provided the best fit for both live scale count and *Encarsia* count. The zero-inflated negative binomial 2 distribution also fits the data well. Prioritizing simplicity, we selected the negative binomial 1 for our final analysis.

We will note that for Study 2, it did not make sense to continue with the analysis of entomopathogenic fungus because after filtering the data appropriately, the fungus variable was almost all zeroes. Therefore, we believe that there is not enough information within the data to result in a meaningful analysis and we have eschewed it.

7.2.1 Study 1 – Scale Count

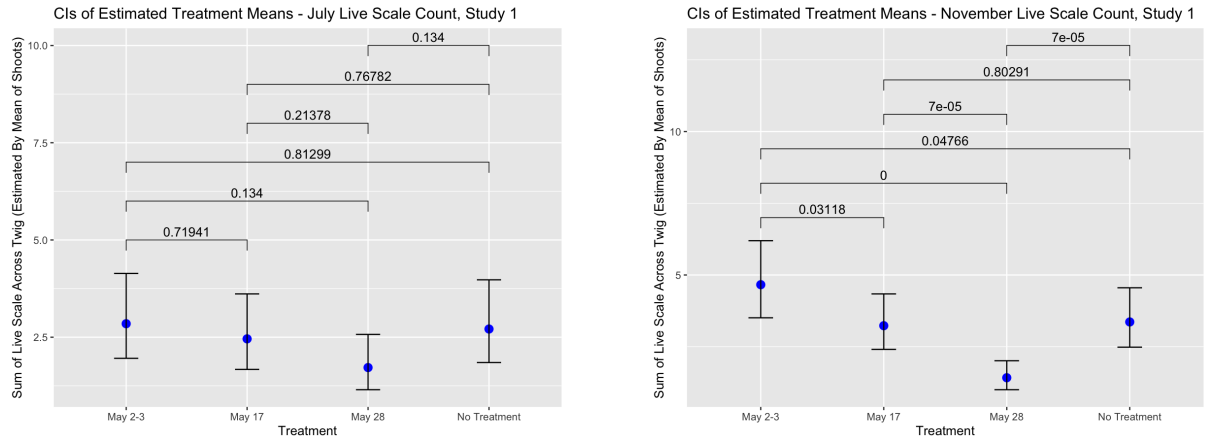

Figure 10: Graphs of confidence intervals for estimated treatment means with overlaid p-values for pairwise comparisons – Study 1 scale count, July (left) and November (right)

In July, we detected no difference between the treatment and control for any treatment application dates for live scale count, as seen in Figure 10. Tables A4 and A5 show the estimated marginal means with corresponding confidence intervals for each treatment as well as all pairwise comparisons, respectively.

In November, we observed strong evidence for the effectiveness of the May 28th application vs the control (no treatment). There is an estimated difference of -1.945 live scale per twig, with a p-value of approximately

0, as seen in Table A7, which illustrates all pairwise comparisons. The estimated marginal mean for the May 28th treatment is 1.42, with a confidence interval of [1.00, 2.01]. Table A6 shows the estimated marginal means and corresponding confidence intervals for all treatments.

7.2.2 Study 1 – *Encarsia citrina*

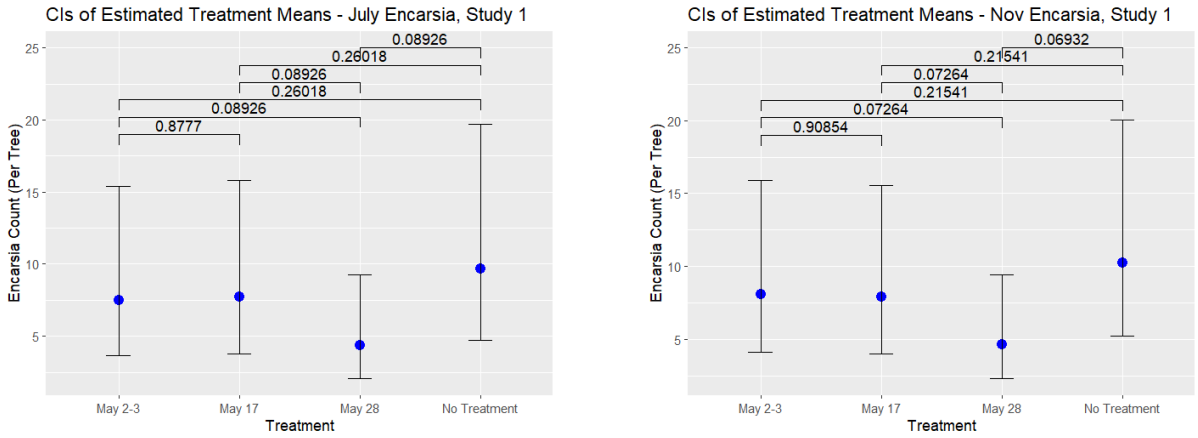

Figure 11: Graphs of confidence intervals for estimated treatment means with overlaid p-values for pairwise comparisons – Study 1 *Encarsia citrina*, July (left) and November (right)

There was a milder effect seen with the May 28th application on *Encarsia* counts in July and November. The effect between the May 28th application and the control had a borderline insignificant p-value of 0.069 for November, and an insignificant p-value of 0.089 for July. There were no pairwise treatment comparisons considered statistically significant for July or November, as illustrated in Figure 11. Tables A8 and A10 illustrate the treatment means more precisely.

7.2.3 Study 1 – Parasitism

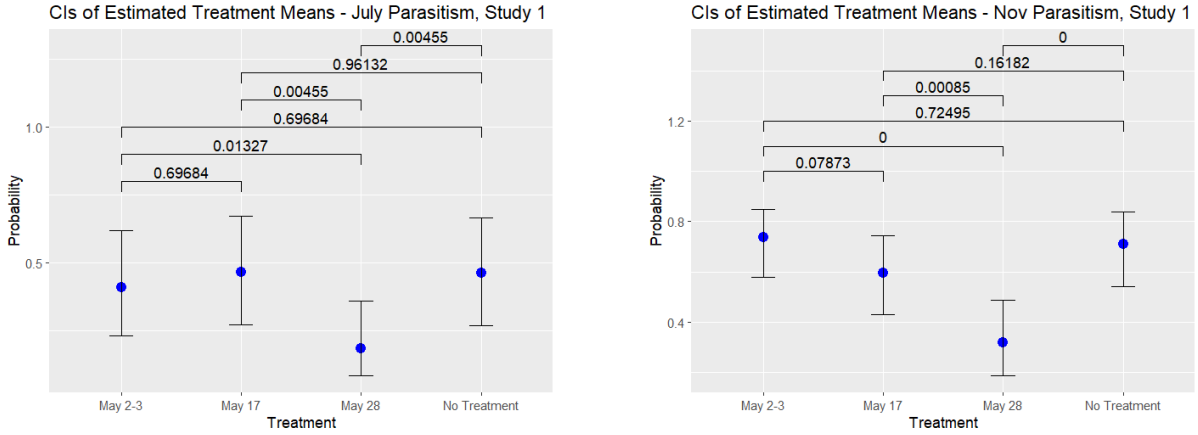

Figure 12: Graphs of confidence intervals for estimated treatment means with overlaid p-values for pairwise comparisons – Study 1 parasitism, July (left) and November (right)

In July, there were significant differences between: (1) the May 2-3rd and May 28th treatments, with a p-value of 0.013, (2) the May 17th and May 28th treatments, with a p-value of 0.004, and (3) the May 28th treatment and no-treatment control, with a p-value of 0.004 (see Figure 12). The May 28th application was

estimated to have a 27.8% lower proportion than the control, as illustrated in Table A13. Table A12 shows the estimated treatment means with corresponding confidence intervals.

In November, we saw similarly notable differences between the same treatments. The May 28th application had an estimated 39.3% lower proportion of parasitism than the control, with a corresponding pairwise p-value of approximately 0. Tables A14 and A15 show the estimated marginal means with corresponding confidence intervals for each treatment as well as all pairwise comparisons, respectively.

7.2.4 Study 1 – Entomopathogenic Fungus

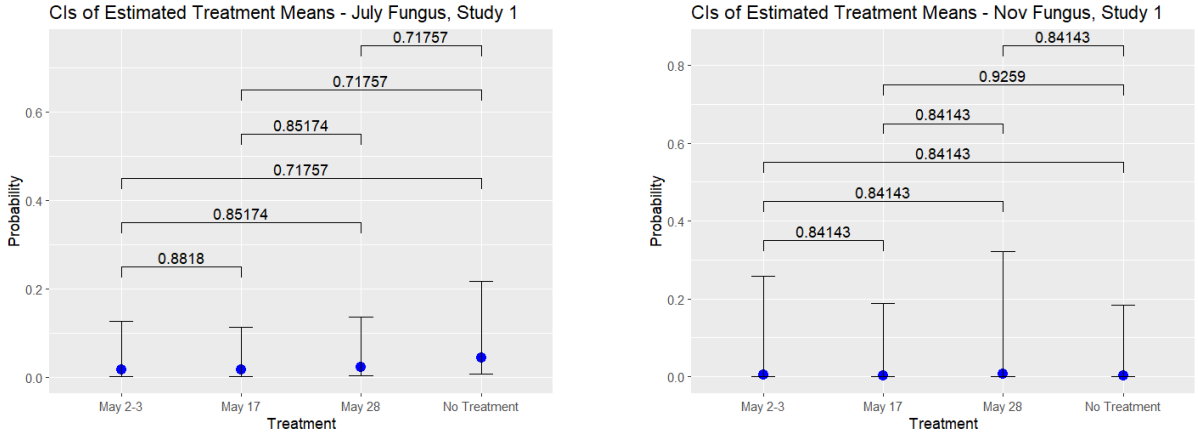

Figure 13: Graphs of confidence intervals for estimated treatment means with overlaid p-values for pairwise comparisons – Study 1 entomopathogenic fungus, July (left) and November (right)

No significant difference was observed for entomopathogenic fungus between any treatment combination across either July or November, as seen in Figure 13. The proportions of fungus across all treatments were very low (practically 0) as illustrated in Tables A16 and A18, lending to uncertainty.

7.2.5 Study 2 – Scale Count

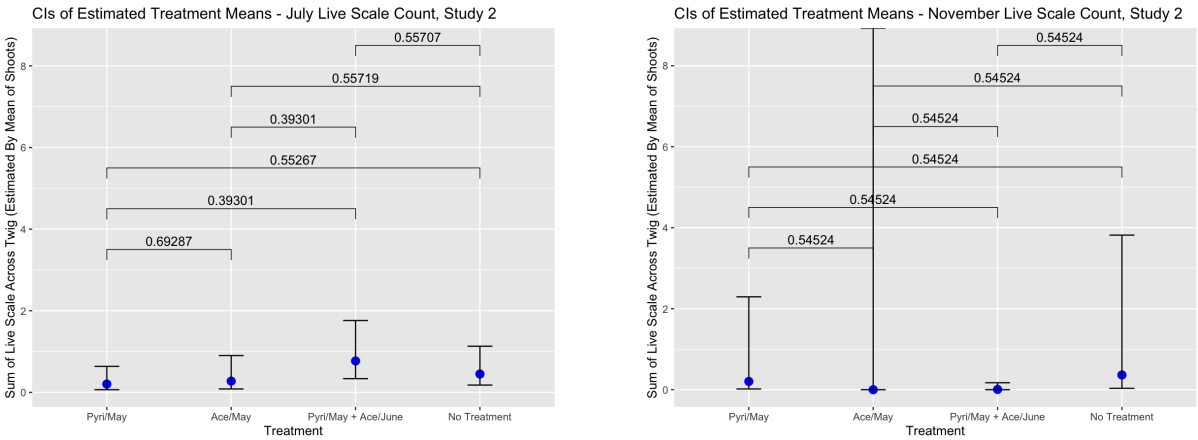

Figure 14: Graphs of confidence intervals for estimated treatment means with overlaid p-values for pairwise comparisons – Study 2 scale count, July (left) and November (right)

In July, we observed no significant differences between any of the treatments and the control. However, we visually observe that the scale count appears higher for the double-pesticide treatment (Pyri/May +

Ace/June) than the control, though the top end of the treatment mean confidence interval for the double pesticide treatment ([0.3364, 1.762]) is still under 2 scale insects per twig, which is very low. The confidence interval for the no-treatment control is also extremely narrow – [0.1789, 1.131] scale insects per twig. The data for July thus shows limited evidence for the effectiveness of any of the treatments studied. Tables A22 and A23 show the estimated marginal means with corresponding confidence intervals for each treatment as well as all pairwise comparisons, respectively.

In November, the results were also inconclusive. The Acetamiprid-only treatment resulted in an absolute 0 count across all blocks, resulting in an upper confidence limit of infinity (hence the strange looking bar on the graph in Figure 14). The average per-twig count of live scale insects across all treatments was also extremely low. Overall, we are unable to infer much about the effect of the pesticides for scale count in November. Tables A24 and A25 show the estimated marginal means with corresponding confidence intervals for each treatment as well as all pairwise comparisons, respectively.

7.2.6 Study 2 – *Encarsia citrina*

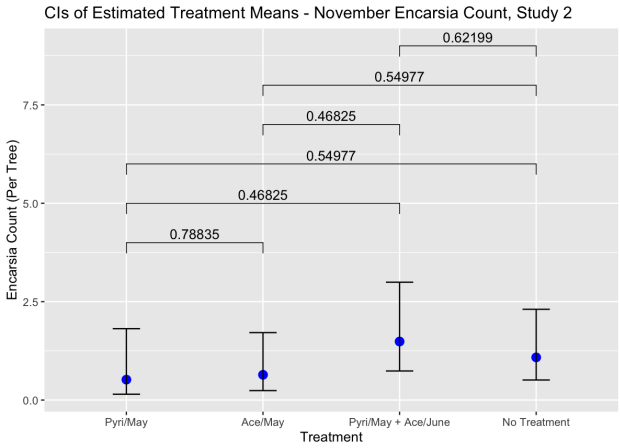

Figure 15: Graph of confidence intervals for estimated treatment means with overlaid p-values for pairwise comparisons – Study 2 *Encarsia citrina*, November only

The Study 2 *Encarsia* data was identical between July and November, so we have only included the graph for November. Similar to the scale count data, we see a higher absolute count for the double pesticide application (Pyri/May + Ace/June), though the count difference is insubstantial overall, as shown by the large p-values in Figure 15. In total, we did not observe a significant effect for any treatments studied on *Encarsia* counts, with per-tree counts ranging only between a few insects. The maximum estimated treatment mean, at 1.487, was for the Pyri/May + Ace/June treatment, with a corresponding confidence interval of [0.739, 2.99]. Table A26 more thoroughly illustrates the confidence intervals of the estimated treatment means.

7.2.7 Study 2 – Parasitism

In July, by looking at Figure 16, we see that the probability of parasitism within the Ace/May treatment appears slightly lower than that of the other treatments. The Ace/May treatment has a confidence interval of [0.0592, 0.464] vs [0.2386, 0.745] for the control, but the evidence for a significant difference is weak, yielding a p-value of 0.13. Table A28 shows the estimated marginal means with corresponding confidence intervals for each treatment, and A29 displays pairwise comparisons.

In November, all parasitism proportions were very similar. As illustrated in Figure 16, there is no significant effect between any treatment and the control. Tables A30 and A31 show the estimated marginal means with corresponding confidence intervals for each treatment as well as all pairwise comparisons, respectively. We conclude that evidence for notable effects on parasitism for either July or November is limited.

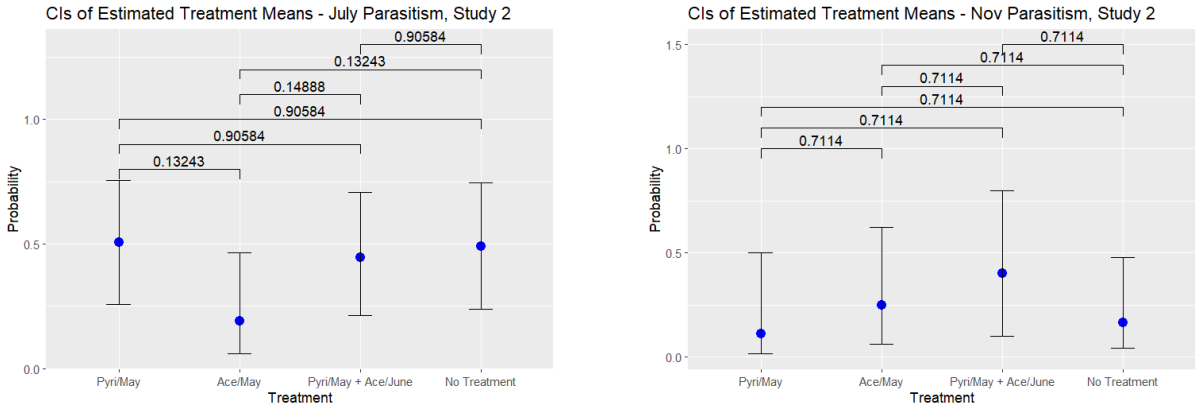

Figure 16: Graphs of confidence intervals for estimated treatment means with overlaid p-values for pairwise comparisons – Study 2 parasitism, July (left) and November (right)

7.2.8 Study 3 – Scale Count

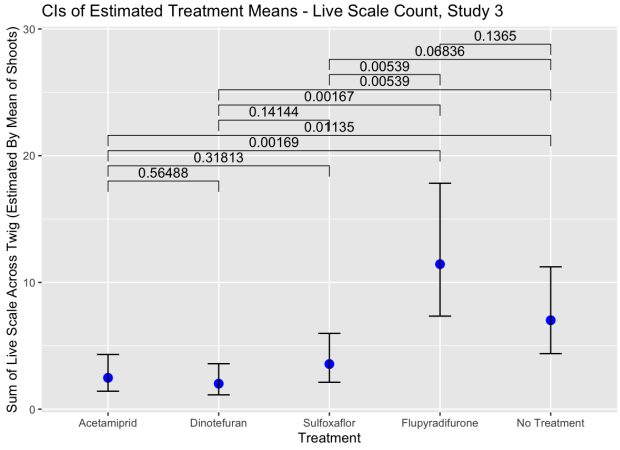

Figure 17: Graph of confidence intervals for estimated treatment means with overlaid p-values for pairwise comparisons – Study 3 scale count

As illustrated in Figure 17, we can see that the comparison between Acetamiprid and the control had a significant p-value of 0.0114. The estimated marginal mean of Acetamiprid is 2.47 with a confidence interval of [1.41, 4.31]. The comparison between Dinotefuran and the control also yielded a significant p-value of 0.0054. The estimated marginal mean of Dinotefuran is 2.01 with a confidence interval of [1.13, 3.59]. The comparison between Sulfoxaflor and the control was borderline insignificant with a p-value of 0.0684. The comparison between Flupyradifurone and the control yielded an insignificant p-value of 0.1365. By looking at Figure 17, we can see that Flupyradifurone appears to perform worse than all other treatments, including the control. Tables A34 and A35 show estimated marginal means with corresponding confidence intervals for each treatment as well as all pairwise comparisons, respectively.

7.2.9 Study 3 – Parasitism

The only two treatments that differed significantly from the control in regard to parasitism were Dinotefuran and Flupyradifurone, with both p-values being borderline significant with a value of 0.0453. However, as can be seen in Figure 18, the difference in the probability of observing parasitism between Dinotefuran and the control was a negative difference, estimated to be -37.3%. On the other hand, the difference in

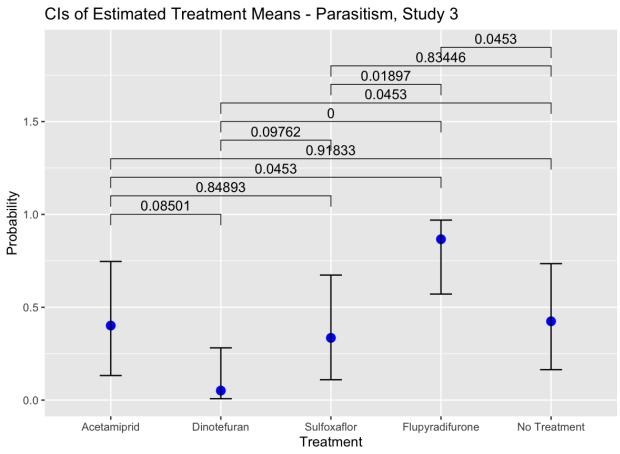

Figure 18: Graph of confidence intervals for estimated treatment means with overlaid p-values for pairwise comparisons – Study 3 parasitism

the probability of observing parasitism between Flupyradifurone and the control was a positive difference, estimated to be 44.2%. As can be seen in Table A37, which illustrates all pairwise comparisons, every treatment, including the control, differs significantly from Flupyradifurone, with Flupyradifurone consistently having a higher probability of observing parasitism. Table A36 shows estimated marginal means (in terms of the proportion/probability) with corresponding confidence intervals for all treatments.

7.2.10 Study 3 – Entomopathogenic Fungus

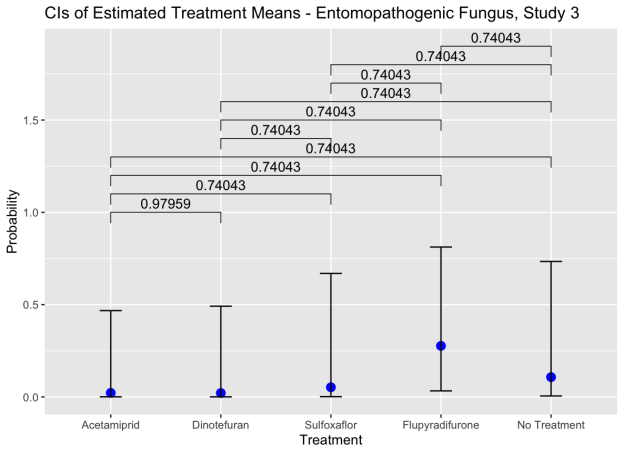

Figure 19: Graph of confidence intervals for estimated treatment means with overlaid p-values for pairwise comparisons – Study 3 entomopathogenic fungus

No significant effect was observed for entomopathogenic fungus for any treatment comparison, as illustrated in Figure 19. Table A38 shows estimated marginal means with corresponding confidence intervals for each treatment, while A39 displays pairwise comparisons.

8 Further Work

A follow-up could look at effects at the county level. Study 1 examined effects across four different counties. Although we incorporated block effects, defined by county and field subsection, we did not examine treatment

effects by-county. Given the substantial variation in growing conditions across counties, a per-county analysis warrants further investigation.

Effects could also be examined over time. Studies 1 and 2 collected data for the same treatments and twigs in both July and November - a potential next step could be to analyze changes between counts in July and November.

There is also room to scrutinize the impact of blocking. The spatial blocks were assigned informally through researcher intuition of soil quality. An additional study could quantify the block delineation and investigate the block-treatment interaction effects to better understand how each pesticide affects scale insects on trees under the block conditions.

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A Appendix

Table A1: Nemenyi test for Study 1, July scale count

Treatment	May 2–3	May 17	May 28
May 17	0.297	–	–
May 28	0.013	0.573	–
No Treatment	0.937	0.647	0.068

Table A2: Scheirer-Ray-Hare test for Study 1, July scale count

Factor	Df	Sum Sq	H	p-value
Treatment	3	68,303	7.325	0.062228
Block	21	572,151	61.359	0.000008
Treatment:Block	63	733,350	78.647	0.088327
Residuals	251	1,780,332		

Table A3: Scheirer-Ray-Hare test for Study 1, November scale count

Factor	Df	Sum Sq	H	p-value
Treatment	3	399,540	39.233	0.00000
Block	22	622,408	61.117	0.00002
Treatment:Block	63	661,074	64.914	0.40978
Residuals	263	1,898,773		

Table A4: Treatment means for Study 1, July scale count

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
May 2–3	2.85	0.544	1.96	4.14
May 17	2.46	0.483	1.67	3.61
May 28	1.72	0.353	1.15	2.57
No Treatment	2.71	0.530	1.85	3.98

Table A5: Pairwise comparisons for Study 1, July scale count

Contrast	Estimate	SE	p-value
May 2–3 – May 17	0.389	0.550	0.7194
May 2–3 – May 28	1.127	0.506	0.1340
May 2–3 – No Treatment	0.136	0.574	0.8130
May 17 – May 28	0.738	0.458	0.2138
May 17 – No Treatment	-0.253	0.541	0.7678
May 28 – No Treatment	-0.991	0.494	0.1340

Table A6: Treatment means for Study 1, November scale count

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
May 2–3	4.66	0.677	3.51	6.20
May 17	3.23	0.486	2.41	4.34
May 28	1.42	0.252	1.00	2.01
No Treatment	3.36	0.520	2.48	4.55

Table A7: Pairwise comparisons for Study 1, November scale count

Contrast	Estimate	SE	p-value
May 2–3 – May 17	1.430	0.618	0.0312
May 2–3 – May 28	3.243	0.609	<.0001
May 2–3 – No Treatment	1.299	0.631	0.0477
May 17 – May 28	1.814	0.437	0.0001
May 17 – No Treatment	-0.131	0.525	0.8029
May 28 – No Treatment	-1.945	0.469	0.0001

Table A8: Treatment means for Study 1, July *Encarsia*

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
May 2–3	7.49	2.76	3.64	15.41
May 17	7.70	2.83	3.75	15.82
May 28	4.36	1.67	2.05	9.24
No Treatment	9.67	3.52	4.74	19.73

Table A9: Pairwise comparisons for Study 1, July *Encarsia*

Contrast	Estimate	SE	p-value
May 2–3 - May 17	-0.208	1.35	0.8777
May 2–3 - May 28	3.133	1.56	0.0893
May 2–3 - No Treatment	-2.183	1.61	0.2602
May 17 - May 28	3.342	1.62	0.0893
May 17 - No Treatment	-1.974	1.60	0.2602
May 28 - No Treatment	-5.316	2.20	0.0893

Table A10: Treatment means for Study 1, November *Encarsia*

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
May 2–3	8.06	2.79	4.09	15.88
May 17	7.90	2.73	4.01	15.56
May 28	4.65	1.68	2.29	9.42
No Treatment	10.23	3.51	5.22	20.04

Table A11: Pairwise comparisons for Study 1, November *Encarsia*

Contrast	Estimate	SE	p-value
May 2–3 - May 17	0.157	1.36	0.9085
May 2–3 - May 28	3.410	1.59	0.0726
May 2–3 - No Treatment	-2.171	1.62	0.2154
May 17 - May 28	3.254	1.55	0.0726
May 17 - No Treatment	-2.328	1.66	0.2154
May 28 - No Treatment	-5.581	2.21	0.0693

Table A12: Treatment means for Study 1, July parasitism

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
May 2–3	0.410	0.1040	0.2302	0.618
May 17	0.466	0.1080	0.2717	0.671
May 28	0.183	0.0693	0.0829	0.357
No Treatment	0.461	0.1070	0.2691	0.666

Table A13: Pairwise comparisons for Study 1, July parasitism

Contrast	Estimate	SE	p-value
May 2–3 - May 17	-0.0559	0.0927	0.6968
May 2–3 - May 28	0.2268	0.0835	0.0133
May 2–3 - No Treatment	-0.0513	0.0928	0.6968
May 17 - May 28	0.2826	0.0874	0.0045
May 17 - No Treatment	0.0046	0.0948	0.9613
May 28 - No Treatment	-0.2780	0.0877	0.0045

Table A14: Treatment means for Study 1, November parasitism

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
May 2–3	0.736	0.0699	0.579	0.849
May 17	0.595	0.0830	0.428	0.742
May 28	0.318	0.0788	0.186	0.487
No Treatment	0.711	0.0770	0.541	0.837

Table A15: Pairwise comparisons for Study 1, November parasitism

Contrast	Estimate	SE	p-value
May 2–3 - May 17	0.1409	0.0727	0.0787
May 2–3 - May 28	0.4182	0.0770	<.0001
May 2–3 - No Treatment	0.0249	0.0707	0.7249
May 17 - May 28	0.2774	0.0787	0.0008
May 17 - No Treatment	-0.1160	0.0776	0.1618
May 28 - No Treatment	-0.3934	0.0799	<.0001

Table A16: Treatment means for Study 1, July fungus

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
May 2–3	0.0186	0.0191	0.00245	0.128
May 17	0.0170	0.0171	0.00233	0.114
May 28	0.0233	0.0220	0.00357	0.137
No Treatment	0.0455	0.0391	0.00810	0.218

Table A17: Pairwise comparisons for Study 1, July fungus

Contrast	Estimate	SE	p-value
May 2–3 - May 17	0.00163	0.0110	0.8818
May 2–3 - May 28	-0.00464	0.0125	0.8517
May 2–3 - No Treatment	-0.02686	0.0255	0.7176
May 17 - May 28	-0.00627	0.0127	0.8517
May 17 - No Treatment	-0.02850	0.0268	0.7176
May 28 - No Treatment	-0.02223	0.0242	0.7176

Table A18: Treatment means for Study 1, November fungus

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
May 2–3	0.00423	0.00948	0.0000518	0.259
May 17	0.00265	0.00604	0.0000305	0.189
May 28	0.00593	0.01320	0.0000750	0.321
No Treatment	0.00253	0.00577	0.0000286	0.183

Table A19: Pairwise comparisons for Study 1, November fungus

Contrast	Estimate	SE	p-value
May 2–3 - May 17	0.001580	0.00381	0.8414
May 2–3 - May 28	-0.001693	0.00441	0.8414
May 2–3 - No Treatment	0.001706	0.00408	0.8414
May 17 - May 28	-0.003273	0.00739	0.8414
May 17 - No Treatment	0.000127	0.00136	0.9259
May 28 - No Treatment	0.003399	0.00766	0.8414

Table A20: Scheirer-Ray-Hare test for Study 2, July scale count

Factor	Df	Sum Sq	H	p-value
Treatment	3	1444.9	5.3198	0.14982
Block	3	653.3	2.4055	0.49260
Treatment:Block	9	6785.9	24.9851	0.00299
Residuals	47	7921.8		

Table A21: Scheirer-Ray-Hare test for Study 2, November scale count

Factor	Df	Sum Sq	H	p-value
Treatment	3	1524.0	10.174	0.0171452
Block	3	2685.2	17.926	0.0004556
Treatment:Block	9	3398.8	22.690	0.0069309
Residuals	48	1829.0		

Table A22: Treatment means for Study 2, July scale count

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
Pyri/May	0.203	0.119	0.0650	0.637
Ace/May	0.275	0.167	0.0839	0.902
Pyri/May + Ace/June	0.770	0.325	0.3364	1.762
No Treatment	0.450	0.212	0.1789	1.131

Table A23: Pairwise comparisons for Study 2, July scale count

Contrast	Estimate	SE	p-value
Pyri/May - Ace/May	-0.0716	0.181	0.6929
Pyri/May - Pyri/May + Ace/June	-0.5663	0.327	0.3930
Pyri/May - No Treatment	-0.2463	0.226	0.5527
Ace/May - Pyri/May + Ace/June	-0.4946	0.328	0.3930
Ace/May - No Treatment	-0.1747	0.239	0.5572
Pyri/May + Ace/June - No Treatment	0.3200	0.358	0.5571

Table A24: Treatment means for Study 2, November scale count

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
Pyri/May	0.20489	0.253	0.018299	2
Ace/May	0.00000	0.0000005	0.000000	Inf
Pyri/May + Ace/June	0.00674	0.0111	0.000264	0
No Treatment	0.36424	0.437	0.034748	4

Table A25: Pairwise comparisons for Study 2, November scale count

Contrast	Estimate	SE	p-value
Pyri/May - Ace/May	0.20489	0.2525	0.5452
Pyri/May - Pyri/May + Ace/June	0.19815	0.2447	0.5452
Pyri/May - No Treatment	-0.15935	0.2337	0.5452
Ace/May - Pyri/May + Ace/June	-0.00674	0.0111	0.5452
Ace/May - No Treatment	-0.36424	0.4367	0.5452
Pyri/May + Ace/June - No Treatment	-0.35750	0.4288	0.5452

Table A26: Treatment means for Study 2, *Encarsia*

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
Pyri/May	0.518	0.331	0.148	1.81
Ace/May	0.642	0.322	0.240	1.71
Pyri/May + Ace/June	1.487	0.531	0.739	2.99
No Treatment	1.084	0.418	0.510	2.31

Table A27: Pairwise comparisons for Study 2, *Encarsia*

Contrast	Estimate	SE	p-value
Pyri/May - Ace/May	-0.123	0.459	0.7883
Pyri/May - Pyri/May + Ace/June	-0.969	0.612	0.4682
Pyri/May - No Treatment	-0.566	0.524	0.5498
Ace/May - Pyri/May + Ace/June	-0.846	0.596	0.4682
Ace/May - No Treatment	-0.442	0.490	0.5498
Pyri/May + Ace/June - No Treatment	0.403	0.624	0.6220

Table A28: Treatment means for Study 2, July parasitism

Treatment	Est.	SE	Lower Confidence Limits	Upper Confidence Limits
Pyri/May	0.508	0.140	0.2562	0.755
Ace/May	0.189	0.103	0.0592	0.464
Pyri/May + Ace/June	0.447	0.137	0.2137	0.706
No Treatment	0.489	0.142	0.2386	0.745

Table A29: Pairwise comparisons for Study 2, July parasitism

Contrast	Estimate	SE	p-value
Pyri/May - Ace/May	0.3183	0.146	0.1324
Pyri/May - Pyri/May + Ace/June	0.0608	0.154	0.9058
Pyri/May - No Treatment	0.0186	0.157	0.9058
Ace/May - Pyri/May + Ace/June	-0.2575	0.144	0.1489
Ace/May - No Treatment	-0.2997	0.149	0.1324
Pyri/May + Ace/June - No Treatment	-0.0423	0.156	0.9058

Table A30: Treatment means for Study 2, November parasitism

Treatment	Est.	SE	Lower Confidence Limits	Upper Confidence Limits
Pyri/May	0.111	0.105	0.0154	0.500
Ace/May	0.250	0.153	0.0630	0.623
Pyri/May + Ace/June	0.400	0.219	0.1002	0.800
No Treatment	0.167	0.108	0.0420	0.477

Table A31: Pairwise comparisons for Study 2, November parasitism

Contrast	Estimate	SE	p-value
Pyri/May - Ace/May	-0.1389	0.186	0.7114
Pyri/May - Pyri/May + Ace/June	-0.2889	0.243	0.7114
Pyri/May - No Treatment	-0.0556	0.150	0.7114
Ace/May - Pyri/May + Ace/June	-0.1500	0.267	0.7114
Ace/May - No Treatment	0.0833	0.187	0.7114
Pyri/May + Ace/June - No Treatment	0.2333	0.244	0.7114

Table A32: Nemenyi test for Study 3, scale count

Treatment	Acetamiprid	Dinotefuran	Sulfoxaflor	Flupyradifurone
Dinotefuran	1.000	-	-	-
Sulfoxaflor	0.975	0.931	-	-
Flupyradifurone	0.041	0.023	0.180	-
No Treatment	0.373	0.266	0.751	0.855

Table A33: Scheirer-Ray-Hare test for Study 3, scale count

Factor	Df	Sum Sq	H	p-value
Treatment	4	25073	30.0074	0.00000
Block	4	7365	8.8142	0.06591
Treatment:Block	16	12755	15.2650	0.50532
Residuals	75	37528		

Table A34: Treatment means for Study 3, scale count

Treatment	Response	SE	Lower Confidence Limits	Upper Confidence Limits
Acetamiprid	2.47	0.702	1.41	4.31
Dinotefuran	2.01	0.593	1.13	3.59
Sulfoxaflor	3.56	0.941	2.12	5.98
Flupyradifurone	11.44	2.588	7.34	17.82
No Treatment	7.01	1.684	4.38	11.23

Table A35: Pairwise comparisons for Study 3, scale count

Contrast	Estimate	SE	p-value
Acetamiprid - Dinotefuran	0.459	0.797	0.5649
Acetamiprid - Sulfoxaflor	-1.089	1.022	0.3181
Acetamiprid - Flupyradifurone	-8.970	2.502	0.0017
Acetamiprid - No Treatment	-4.545	1.643	0.0114
Dinotefuran - Sulfoxaflor	-1.548	0.977	0.1414
Dinotefuran - Flupyradifurone	-9.429	2.505	0.0017
Dinotefuran - No Treatment	-5.004	1.631	0.0054
Sulfoxaflor - Flupyradifurone	-7.881	2.508	0.0054
Sulfoxaflor - No Treatment	-3.456	1.691	0.0684
Flupyradifurone - No Treatment	4.425	2.655	0.1365

Table A36: Treatment means for Study 3, parasitism

Treatment	Est.	SE	Lower Confidence Limits	Upper Confidence Limits
Acetamiprid	0.4013	0.1816	0.13224	0.747
Dinotefuran	0.0512	0.0491	0.00738	0.281
Sulfoxaflor	0.3350	0.1601	0.10964	0.673
Flupyradifurone	0.8664	0.0935	0.57096	0.969
No Treatment	0.4243	0.1651	0.16386	0.735

Table A37: Pairwise comparisons for Study 3, parasitism

Contrast	Estimate	SE	p-value
Acetamiprid - Dinotefuran	0.3500980	0.1794	0.0850
Acetamiprid - Sulfoxaflor	0.0663073	0.2209	0.8489
Acetamiprid - Flupyradifurone	-0.4650561	0.1987	0.0453
Acetamiprid - No Treatment	-0.0230314	0.2246	0.9183
Dinotefuran - Sulfoxaflor	-0.2837907	0.1557	0.0976
Dinotefuran - Flupyradifurone	-0.8151541	0.1134	¡.0001
Dinotefuran - No Treatment	-0.3731294	0.1637	0.0453
Sulfoxaflor - Flupyradifurone	-0.5313634	0.1836	0.0190
Sulfoxaflor - No Treatment	-0.0893387	0.2080	0.8345
Flupyradifurone - No Treatment	0.4420248	0.1824	0.0453

Table A38: Treatment means for Study 3, fungus

Treatment	Est.	SE	Lower Confidence Limits	Upper Confidence Limits
Acetamiprid	0.0219	0.0401	0.000572	0.468
Dinotefuran	0.0211	0.0401	0.000481	0.492
Sulfoxaflor	0.0523	0.0911	0.001504	0.669
Flupyradifurone	0.2766	0.2475	0.032752	0.812
No Treatment	0.1072	0.1530	0.005203	0.734

Table A39: Pairwise comparisons for Study 3, fungus

Contrast	Estimate	SE	p-value
Acetamiprid - Dinotefuran	0.0008	0.0313	0.9796
Acetamiprid - Sulfoxaflor	-0.0304	0.0705	0.7404
Acetamiprid - Flupyradifurone	-0.2547	0.2349	0.7404
Acetamiprid - No Treatment	-0.0853	0.1321	0.7404
Dinotefuran - Sulfoxaflor	-0.0312	0.0697	0.7404
Dinotefuran - Flupyradifurone	-0.2555	0.2345	0.7404
Dinotefuran - No Treatment	-0.0861	0.1315	0.7404
Sulfoxaflor - Flupyradifurone	-0.2243	0.2285	0.7404
Sulfoxaflor - No Treatment	-0.0549	0.1211	0.7404
Flupyradifurone - No Treatment	0.1694	0.2410	0.7404