Nursery Management of Two Major Below-Ground Feeding Plant Pests: Root Mealybug, *Rhizoecus sp.* and Rice Root Aphid, *Rhopalosiphum rufiabdominalis* (Sasaki) (Hemiptera: Pseudococcidae and Aphididae)[1]

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Abstract

Root mealybug (*Rhizoecus* sp.) and rice root aphid (*Rhopalosiphum rufibdominalis*) are below-ground feeding insects that are difficult to control and have become major pests as production of their host plants has grown. Field trials were designed to investigate the impact new insecticides and biopesticides have on root mealybugs and rice root aphids. In our first three trials, we investigated the effects of biopesticides, entomopathogenic nematodes or fungi on reflexed stonecrop (*Sedum rupestre*) and stonecrop (*S. montanum*) against root mealybug. We found that flupyradifurone (Altus), flonicamid (Aria), chlorantraniliprole (Acelepryn), pymetrozine (Endeavor), *Beauveria bassiana* (Mycotrol), *Chromobacterium subtsugae* (Grandevo), *Burkholderia* spp. strain A396 (Venerate), cyantraniliprole (Mainspring) and *Steinernema carpocapsae* (Millenium) significantly reduced root mealybug populations compared to nontreated controls when applied as drenches in a curative manner. In our fourth trial, we evaluated biopesticides and *Beauveria bassiana*, on rice root aphid feeding on common rush (*Juncus effusus*) roots. Results showed pymetrozine significantly reduced populations as early as 14 days after treatment and continued to reduce their population throughout the remainder of the trial. However, chlorantraniliprole, cyantraniliprole, *Beauveria bassiana*, M-306 and MBI-203 did not significantly reduce rice root aphid populations until 28 days after initial application. Predator activity on root balls of *Juncus effusus* plants was also noted during the trials and may provide an integrated pest management (IPM) approach in controlling populations.

Index words: reflexed stonecrop, *Sedum rupestre* L, stonecrop, *Sedum montanum* Song. & Perr, common rush, *Juncus* effuses L, *Beauveria bassiana*, Mycotrol, *Steinernema carpocapsae*, Millenium, reduced-risk pesticides, *Chromobacterium subtsugae* (Grandevo), flupyradifurone, Altus, flonicamid, Aria, chlorantraniliprole, Acelepryn, pymetrozine, Endeavor, *Burkholderia* spp. strain A396, Venerate, cyantraniliprole, Mainspring, M-306, MBI-203.

Chemicals used in this study: flupyradifurone (Altus); flonicamid (Aria); chlorantraniliprole (Acelepryn); cyantraniliprole (Mainspring); pyrometrozine (Endeavor); *Burkholderia* spp. strain 396 (Venerate); *Chromobacterium subtsugae* (Grandevo); *Beauveria bassiana* (Mycotrol); AMBI-203 WDG – 30% *Chromobacterium subtsugae* strain PRAA4-1^T cells and spent fermentation media. EPA registration number 84059-27; MBI-206 EP – 94.46% Heat-killed *Burkholderia* spp. strain A396 cells and spent fermentation media. EPA registration number 84059-14; MBI-203 SC2 – 98% *Chromobacterium subtsugae* strain PRAA4-1^T cells and spent fermentation media. Experimental; MBI-306 SC1 - 94.46% non-viable *Burkholderia* spp. strain A396 cells and spent fermentation media. Experimental.

Species used in this study: Root mealybug, *Rhizoecus* sp; Rice root aphid, *Rhopalosiphum rufiabdominalis* (Sasaki); reflexed stonecrop, *Sedum rupestre*; stonecrop, *Sedum montanum*; common rush, *Juncus effusus.*

Significance to Horticulture Industry

Root mealybug (*Rhizoecus* sp.) and rice root aphids (*Rhopalosiphum rufibdominalis*) are below-ground feeding insects that are difficult to control and have become major pests of horticulture trade plants, including green-roof plants, ornamental plants and cannabis crops. Our research identified several newer, reduced risk conventional and bio-insecticides that were effective preventatively and curatively. Preventative applications of flonicamid and flupyradifurone can effectively protect plants from root mealybug infestations. Additionally, our results showed chlorantraniliprole (Acelepryn), cyantraniliprole (Mainspring), pymetrozine (Endeavor), *Beauveria bassiana* (Mycotrol), flonicamid (Aria), and flupyradifurone (Altus) all provided curative control of root mealybugs found infesting *Sedum*. Our rice root aphid trial showed that chlorantraniliprole and cyantriliprole, M-306, *Beauveria bassiana*, MBI-203 and pymetrozine all significantly reduced rice root aphid populations at 28 days after initial application. We also found that rice root aphid had several predators active, including the mealybug destroyer, [*Cryptolaemus montrouzieri (Coleoptera: Coccinellidae)]*, rove beetle species (Coleoptera: Staphylinidae), and *Stratiolaelaps scimitus*, in the Acari: Mesostigmata: Laelapidae family. These root zone predators may contribute to an IPM (Integrated Pest Management) approach in suppressing populations. Insecticide efficacy against rice root

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aphids and potential impact on natural enemies should be investigated in future studies.

Introduction

Root mealybug (*Rhizoecus* sp.) and rice root aphids (*Rhopalosiphum rufibdominalis*) are major pests of plants in the horticulture trade. They are below-ground feeding insects that have become more difficult to control as production of their host plants increases. This group of aphids are frequently overlooked because they feed below-ground. Their host plants include green-roof plants, ornamental plants and cannabis crops, and they can even be found infesting plants grown hydroponically (Blackman and Eastop 2000, Cranshaw et. al. 2019, Gilrein 2015, Gilrein 2017, Lagos-Kutz 2018, Stoetzel et. al. 1996, Technazio 2021, Yano et. al. 1983). Soil-dwelling insects and insect pests associated with aquatic situations are difficult to manage with insecticides due to environmental concerns. The objective of our study is to reduce the populations of rice root aphids and mealybugs in order to help curb destruction of plants used in the green-roof trade, ornamental production, and cannabis crops. Our four field trials were designed to investigate the impact new insecticides and biopesticides have on root mealybugs and rice root aphids.

The North American green-roof industry continues to be a driving force in sustainability and resilience planning, with municipalities like San Francisco, Portland and Denver recently adopting mandatory green roof policies for new buildings. There is an opportunity to install billions of square feet of rooftops across North America. Policy support in cities like Washington, D.C. and Toronto is also driving market growth (Owen and Behe 2020).

In nursery ornamental production, the number of plant species being damaged by these pests is increasing. The root mealybug feeds on the roots of anemone, chrysanthemum, gladiolus, iris and numerous other flowers, shrubs, and ornamental grasses. We have seen an increase of root mealybug and rice root aphid in greenhouse plant nurseries in Maryland and Delaware, mainly in sedum, rush, and aster species. In Maryland, we found root mealybug thriving on various stonecrop species.

We have also found these two pests showing up in greater frequency in cannabis crops with the proliferation of greenhouses producing plant plugs of field hemp and in medical marijuana plant operations. Field hemp (*Cannabis sativa* L.) production of plug plants and production of greenhouse grown medical marijuana have increased dramatically over the last decade. Since the recent legalization of industrial hemp (IH; *Cannabis sativa* L.) in the United States, cultivation and research of IH-fiber, grain, biomass, and to a greater extent, the non-intoxicating cannabidiol (CBD) compound has gained much attention.

Root mealybug (Rhizoecus sp.). Root mealybugs are 2.4 to 3.9 mm (.094 to 0.15 in) long and are covered lightly with a white wax coating. The white mycelium-like masses usually form on the outside and bottom of the rootball**.** This white wax produced by the root mealybug is the first thing most growers notice. Female mealybugs lay eggs which tend to hatch in about 24 hours. They can also give live birth to crawlers, which are quite mobile. The crawlers use sucking mouthparts to feed on roots once they find a suitable site. Their full life cycle is between two and four months, with adults living from 27 to 57 days, depending on the species (Gill et al. 2019).

Root mealybug moves slowly and purposefully between pots and flats of plants grown on weed barrier cloth, exiting and entering through drainage holes. Certain production methods are contributing to this rising problem. For example, grouping plants close together in growing areas with infested plants and growing plants on the ground on weed barrier mats allows for easy movement of root mealybugs from infested plants to non-infested plants.

Rice root aphid (Rhopalosiphum rufiabdominalis). Several aphid species, including rice root aphid, live in colonies on plant roots. Rice root aphids can feed on plants grown in both soil and hydroponic systems. These aphids produce a white protective wax that helps block excess moisture (Gilrein 2021). Like the root mealybug, the white wax is what most growers notice on the root systems of susceptible plants. Nymphs and adults do not move unless dislodged or disturbed. Females live birth nymphs and rapidly build up colonies on the root system (Cranshaw et. al 2018 and Cranshaw et. al. 2019). Reproduction is asexual as with many species of above ground aphids. Rice root aphids feed by sucking fluids from the phloem of the plant. Wingless stages are generally observed belowground, feeding on roots, and winged stages are also produced which emerge from soil to fly to new plants (Cranshaw et. al 2018).

On cannabis crops and the aquatic plant involved in our trial, *Juncus effusus*, the rice root aphid has an anholocyclic life cycle and is found almost entirely in association with plant roots. In anholocyclic life cycles, species only produce asexual females; they do not produce sexual females and males. Colonization of new plants is largely by alate forms (winged) that may emerge from soil in large numbers as plants near maturity (Cranshaw and Wainwright 2020).

Rice root aphid is a widespread species (Blackman and Eastop 2000, Hesler and Kindler 2007) with North American collections dating to 1900 (Doncaster 1956). The first published observation of the insect in the United States was on roots of cotton in South Carolina (Mason 1937), but this species is primarily associated with roots of grasses (Poaceae) and sedges (Cyperaceae) (Blackman and Eastop 2000). Kindler et al. 2004, provide a review of the numerous published records of this species on small grain crops in North America.

The rice root aphid is dark green to mottled brown, and can be found on roots and on above-ground plant parts, including some grasses and solanaceous, e.g., tomato (*Solanum lycopersicum* L.), pepper (*Capsicum annuum* L.) crops and even in hydroponic culture. This aphid is often associated with the roots of various grasses, including wheat (*Tritichum* spp.) and barley (*Hordeum vulgare* L.*)*, and recently gained notoriety as a pest of hemp (*Cannabis sativa*). Gilrein (2021) has seen it on greenhouse foliage crops (e.g. *Dieffenbachia*) and other plants, often on stems

Table 1. **Treatments for the three root mealybug field trials, rates of use, and application method during the trials that were conducted in 2018 - 2019. Foliar applications were applied with two liters of water and drenched plants were dipped in a tray containing two liters of water.**

Product	Application Rate	Application Method
Field Trial I 2018 (curative)		
Water	Nontreated Control	Foliar spray
Flonicamid (Aria)	0.22 g/L (0.008 oz./0.26 gallons)	Foliar spray
Flupyradiflurone (Altus)	0.22 ml/L (0.0074 oz./0.26 gallons)	Soil drench
Flupyradiflurone (Altus)	0.30 ml/L (0.01 oz./0.26 gallons)	Soil drench
Chlorantraniliprole (Acelepryn)	0.62 ml/L (0.021 oz./0.26 gallons)	Soil drench
Cyantraniliprole (Mainspring)	0.62 ml/L (0.021 oz./0.26 gallons)	Soil drench
Pymetrozine (Endeavor)	0.37 g/L (0.013 oz./0.26 gallons)	Foliar spray
Field Trial II 2018 (preventative)		
Water	Nontreated Control	Foliar spray
Flonicamid (Aria)	0.22 g/L (0.008 oz./0.26 gallons)	Soil drench
Flupyradiflurone (Altus)	0.22 ml/L (0.0074 oz./0.26 gallons)	Soil drench
Flupyradiflurone (Altus)	0.30 ml/L (0.01 oz./0.26 gallons)	Soil drench
Field Trial III 2019 (curative)		
Water	Nontreated Control	Foliar spray
Burkholderia spp. strain A396 (Venerate)	8.0 ml/L (0.27 oz/0.26 gallons)	Soil drench
Burkholderia spp. strain A396 (Venerate)	16.0 ml/L (0.541 oz./0.26 gallons)	Soil drench
Beauveria bassiana (Mycotrol)	2.25 g/L (0.079 oz./0.26 gallons)	Soil drench
Chromobacterium subtsugae (Grandevo)	4.0 g/L (0.141 oz./0.26 gallons)	Soil drench
Chromobacterium subtsugae (Grandevo)	8.0 g/L (0.282 oz./0.26 gallons)	Soil drench
Cyantranilirpole (Mainspring)	0.62 ml/L (0.021 oz./0.26 gallons)	Soil drench
Cyantraniliprole (Mainspring) + *Steinernema carpocapsae* (Millenium)	0.62 ml/L + 2.0 billion/ha (0.021 oz./100 gallons + 2 billion/2.47 acres)	Soil drench
Steinernema carpocapsae (Millenium)	2.0 billion/ha (2 billion/2.47 acres)	Soil drench

around the soil line. It has also been noted on *Lysimachia* and on *Cannabis* and field hemp crops (Cranshaw, et al. 2018 and Cranshaw and Wainwright-Evans 2020).

In the green industry broad spectrum pesticides have been used with little efficacy. Traditional pesticides impact beneficial organisms that feed on root mealybug and root aphid. Consequently, newer pesticides that target the pest with lower impact on beneficials warrants our investigations. Entomopathogens are biological control agents that have been used for years in IPM programs to manage pest problems in greenhouses, and *Beauveria bassiana* has been used for greenhouse pests such as whiteflies, thrips, and aphids found on foliage. Applications of *Isaria fumosorosea* have the potential to control root aphids because sufficient soil moisture can be achieved with soil applications such as chemigation, drenches, or soil injection (Cranshaw and Wainwright-Evans 2020). Entomopathogenic nematodes have been used to manage soil dwelling pests in greenhouses such as thrips, fungus gnats and black vine weevils. We investigated several new low risk pesticides, entomopathogens and bio-pesticides for control of these two major groups of below-ground pests. In our trials we recorded activity of major predators active in the root zones.

Materials and Methods

Root mealybug (Rhizoecus sp.) trials. Our trials were conducted at a green roof plant nursery that had reflexed stonecrop (*Sedum rupestre*) and stonecrop (*Sedum montanum*) infested with root mealybugs. We concentrated on root mealybug in evaluating several new classes of systemic chemicals and entomopathogens applied as foliar sprays or soil drenches. Waxy filaments help us focus on the presence of root mealybugs. Plugs with waxy filaments and mealybugs on the outside of the root ball were placed in the center portion of the plug-trays where treatments were applied. Pretreatment counts were made by removing a plug from a tray and examining it under a dissecting scope. The number of root mealybugs found per plant prior to treatments was recorded.

In our first trial in 2018, we used *Sedum rupestre* and *S. montanum* plugs infested with the root mealybug and divided flats, 30 × 60 cm (11.8 × 23.6 in) into eight replicates for seven treatments (Table 1). Each plug, 2.5 cm diameter and 8 cm deep (0.98 and 2.1 in), in a tray was considered an experimental unit. Substrate was a peat moss and pine bark mix. Treatments were made on April 25. This field trial evaluated the efficacy of our treatments when applied curatively. The number of mealybugs found on the rootball was recorded on a numbered plant tag and a data sheet. Treatments were made to an entire plug-tray and plants in the center portion of the tray were used to evaluate efficacy. Plants were maintained using current production practices at the nursery. Some of the treatments were applied as a soil drench or as a foliar application. The foliar applications were made with 2 Liter Spray Docs at 276 kPa (40 PSI). Treatments were applied once in a randomized complete (8) block design, and efficacy data was obtained 33 days after the initial treatment. The amount applied to the treated plants was two liters (2.1 qt).

Table 2. Treatments applied to common rush (*J. affusus*) to manage the rice root aphid (*R. rufiabdominalis*) during the 2020 growing season. All applications were sprenched (spray plus drench) onto the plants with one liter of solution.

Material	Application Rate
Water	Nontreated Control
Cyantraniliprole (Mainspring)	0.62 ml/L (0.021 oz./0.26 gallons)
Chlorantraniliprole (Acelepryn)	0.62 ml/L (0.021 oz./0.26 gallons)
Pymetrozine (Endeavor)	0.37 g/L (0.013 oz./0.26 gallons)
Pymetrozine (Endeavor)	0.22 g/L (0.008 oz./0.26 gallons)
Chromobacterium subtsugae (Grandevo)	3.6 g/L (0.13 oz./0.26 gallons)
Burkholderia spp. strain A396 (Venerate)	10.0 ml/L (0.34 oz./100 0.26 gallons)
M-306 SE1	0.5 ml/L (0.017 oz./0.26 gallons)
MBI-203SC1	5.0 ml/L (0.17 oz./0.26 gallons)
Beauveria bassiana (Mycotrol)	2.4 g/L (0.085 oz./0.26 gallons)

Twelve plants were removed from the center portion of each plug-tray for each treatment and were examined for root mealybugs. Survival of root mealybugs was determined by probing the insect to see if it would move and it was examined for discoloration.

In the second trial in 2018, we examined the efficacy of insecticides applied as a preventative treatment. This above-ground container trial had four treatments and eight blocks. Sedum plugs (2.5 cm diameter and 8 cm deep (0.98 and 2.1 in) were examined for the presence of root mealybugs under the dissecting scope as described previously, but those without waxy filaments and no insects were used to create plug-trays free of root mealybugs. Plug-trays with noninfested plants were treated with the insecticides shown in Table 1 on April 25, and placed next to trays heavily infested with root mealybugs. The volume used during these treatments was two liters. Efficacy evaluation of this trial involved counting 12 plugs from the center of each tray similar to the first field trial.

Our third field trial was conducted in 2019 and focused on biologically-based pesticides and entomopathogenic nematodes (Table 1). We conducted pre- and post-treatment counts of root mealybugs as described for the other field trials. *Beauveria bassiana*, *Burkhoderia* (the company heat treats this organism as part of its process to make this insecticide), and *Chromobacterium* treatments were made every seven days on July 2, 9, and 16, whereas cyantraniliprole and *Steinernema carpocapsae* were applied once on July 2 after pretreatment counts were finished. Samples consisted of six plugs from the center of each plug-tray and there were five replicates with nine treatments. In this third trial we had to reduce to six plugs due to the limited number of infested plugs available. Root mealybug mortality was accessed 36 days after the initial treatments, similar to previous field trials.

Rice root aphid (Rhopalosiphum rufiabdominalis) trial. We obtained 740 *Juncus effusus* from a native plant nursery to use in our experiment. We examined the root system of the 740 and narrowed the numbers down to the 162 used in our trials. We selected plants with more than two to three rice root aphids (*R. rufiabdominalis*) in the root zones. Some had as high as 40 in their root zones.

Four plants of each treatment were placed in a plug tray and this represented one block of our trial. We had four replicates and 10 treatments (Table 2) in our randomized complete block designed experiment. We conducted our pre-treatment counts on 23 June 2020 using dissection scopes and portable light sources. Prior to treatment, plants were grouped by relative densities of rice root aphids on root masses. Plants were randomly assigned treatments after this grouping. *Beauveria bassiana* was the last treatment added to the trial and the remaining plugs available had fewer rice root aphids on root masses. The lower number was due to random selection of plants. Our M-306 SE1 and MBI-203SC1 (Marrone products) treatments were applied on 23 and 30 June, and 7 and 14 July 2020. The remainder of our treatments were only applied on 23 June 2020. All of the treatments were applied to the plants as a sprench application. Sprench applications consist of spraying the plant until there is run-off that saturates the potting media. The volume of water used for each application was one liter. Plants were moved into a greenhouse after treatment and irrigated as needed to maintain the moist root masses the *Juncus* required. The plants were maintained with natural lighting in a greenhouse environment.

Post-treatment counts used the same dissection scopes and portable light sources (7 and 21 July respectively, 14 and 28 DAT). Plant plugs were pulled from plug trays and the outside of the root mass was examined for various stages of *R. rufiabdominalis* feeding on roots at each sample event. We recorded the number of rice root aphids found during data collection on plant tags and kept those with the plant during the field trial. Rice root aphids were counted on all plants again at 14 DAT and were returned to the greenhouse in the same plug trays until the final count at 28 DAT. Collected data was recorded on the same plant tags used at the start of the experiment. Collection date was noted on the tags. Presence of natural enemies and other arthropods found on root masses were noted during the pre- and post-treatment counts. The average number of living rice root aphids found on the root mass were analyzed using ANOVA and Tukey HSD means separation procedures.

Analysis. Data were analyzed for normality and homogeneity of variance prior to ANOVA analysis with an α=0.05 using SAS JMP Pro 15. Data were transformed as needed to maintain assumptions for the analysis of variance. Tukey's honestly significant difference test (Tukey HSD) was used for means separation at α=0.05.

Results and Discussion

Root mealybug. In our first trial in 2018, all treatments resulted in significantly fewer living root mealybugs on plants (Fig. 1; F=325.2; df=6,611; $P<0.0001$) by the end of the field trial (33 DAT). The randomly selected plants that received flupyradiflurone treatments and the non-treated controls started the trial with significantly fewer root mealybugs due to random selection of plants (Fig. 1; F= 11.3; df=6,616; $P<0.0001$). These plants were grown further away from overhead irrigation valves, and the

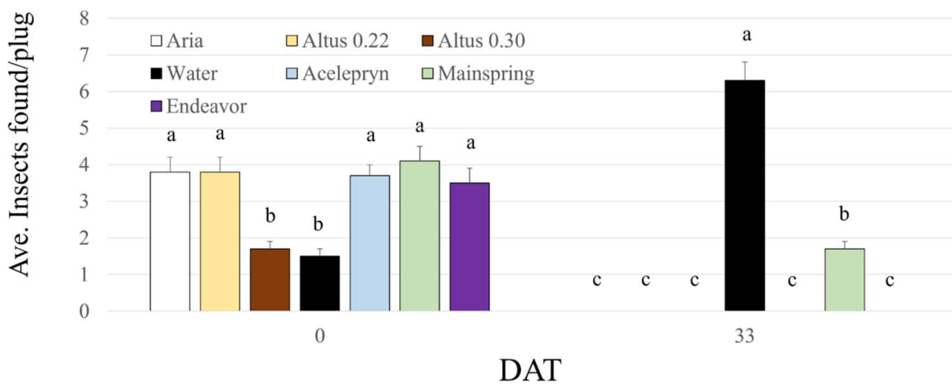

Fig. 1. Effects of insecticides applied curatively on root mealybug (*Rhizoecus* sp.) (± SEM) feeding on reflexed stonecrop (*Sedum rupestre*) or stonecrop (*S. montanum*) prior to application (0 days after treatment) and 33 days after application (DAT; ANOVA α=0.05) during the first field trial in 2018. Treatments with different letters are significantly different (Tukey HSD, α=0.05). Treatments were: Flonicamid (Aria); Pymetrozine (Endeavor); Flupyradifurone (Altus); Chlorantraniliprole (Acelepryn); Cyantraniliprole (Mainspring).

plants were consequently slightly drier than other plants selected during the set-up of the trial. Although cyantraniliprole-treated plants had fewer root mealybugs than nontreated controls, these plants had significantly more root mealybugs than other treatments in our final count. In the second field trial, all plants started as clean plants and without root mealybugs (Fig. 2). Nontreated plants had significantly more root mealybugs at the conclusion of this field trial compared to all other treatments (Fig. 2; $F = 46.4$; df=3,347; $P < 0.0001$). All treatments reduced root mealybug count compared to the nontreated control (Fig. 3).

Rice root aphid. Juncus effusus root masses were infested with strikingly high populations at the nursery and prior to insecticide treatments (Table 2; Fig. 4). Cyantraniliprole- and chlorantraniliprole-treated plants had significantly greater populations of rice root aphids per root mass at the beginning of the experiment due to random selection of plants than other treatments, whereas *Beauveria*-treated plants had significantly fewer. (NOTE: We found an ant associated with the rice root aphids in our field trial. These ants were more abundant during our pre-treatment data collection than later in the experiment. We did not observe the ants moving the rice root aphids but did observe them defending and engaging spiders and rove beetles.)

We found several soil predators active, including the mealybug destroyer (*Cryptolaemus montrouzieri*), rove beetle species, and a predacious mite, *Stratiolaelaps scimitus*, in the Laelapidae family. This mite is a small, light brown mite that is usually found in the upper layers of soil and is a generalist predator. In our field trials, we found mealybug destroyer larvae actively feeding on rice root aphids and we photographed it for documentation. They were active but did not destroy the insect populations. After the trial, the grower reported heavy activity from mealybug destroyers in the root zone of the aquatic grasses. The impact of individual chemicals on beneficial organisms is still unknown.

In our four field trials designed to investigate the impact new insecticides and biopesticides have on root mealybugs and rice root aphids, we found that preventative applications of flonicamid and flupyradifurone effectively protected plants from root mealybug infestations. Additionally, our results showed chlorantraniliprole, cyantraniliprole, pymetrozine, *Beauveria bassiana*, flonicamid, and flupyradifurone all provide curative control of root mealybugs found infesting *Sedum*. We also found that *R. rufiabdominalis* populations declined throughout our experiment regardless of treatment. This was likely attributed to increasing temperatures in mid-summer.

Some insecticides used in our experiments significantly reduced rice root aphid populations compared to nontreated

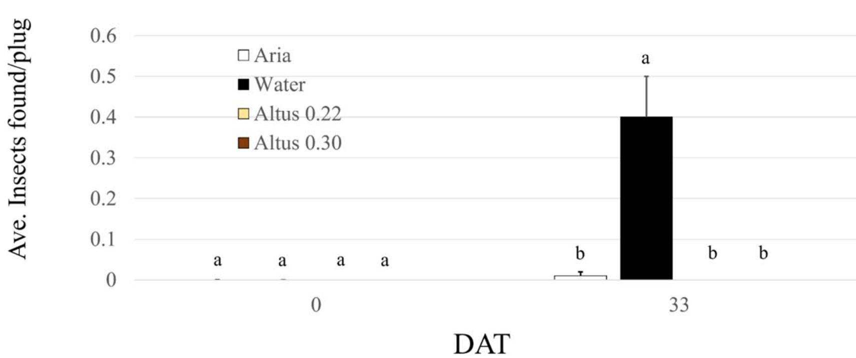

Fig. 2. Effects of insecticides applied preventatively on root mealybug (*Rhizoecus* sp.) (± SEM) feeding on reflexed stonecrop (*Sedum rupustre*) or stonecrop (*S. montanum*) 33 days after application (DAT; ANOVA α=0.05) during the second field trial in 2018. Treatments with different letters are significantly different (Tukey HSD, α=0.05). Treatments were: Flonicamid (Aria); Flupyradifurone (Altus).

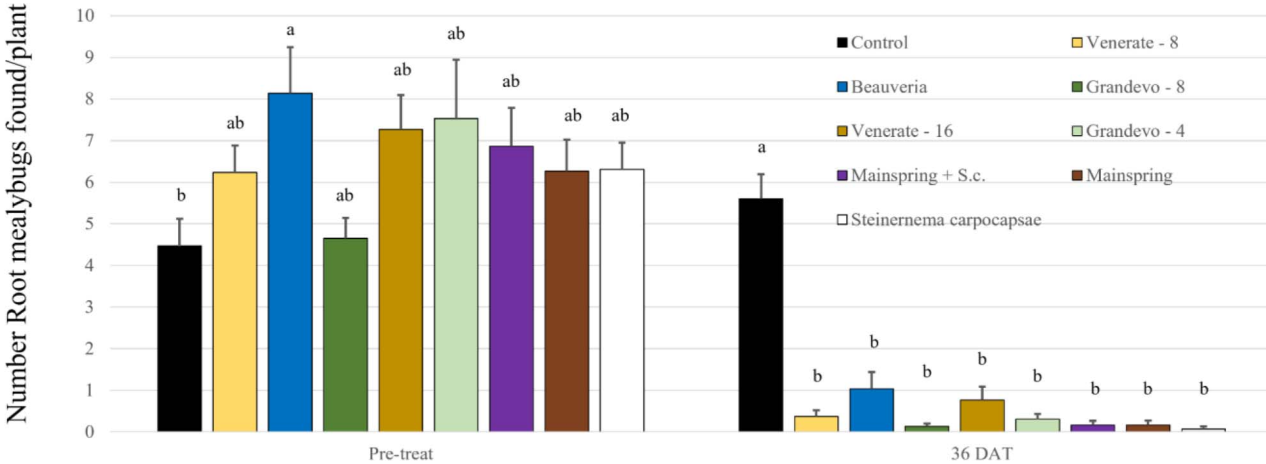

Fig. 3. Average number of root mealybug (*Rhizoecus* sp.) (± SEM) found feeding on reflexed stonecrop (*Sedum rupustre*) or stonecrop (*S. montanum*) prior to treatment or 36 days after application (DAT; ANOVA α=0.05). Treatments with different letters are significantly different (Tukey HSD, α=0.05). Treatments were: *Beauveria bassiana* (Mycotrol); *Burkholderia* spp. strain A396 (Venerate); Cyantraniliprole (Mainspring); *Steinernema carpocapsae* (Millenium); *Chromobacterium subtsugae* (Grandevo).

controls. Chlorantraniliprole-, cyantraniliprole-, and the higher rate of pymetrozine-treated plants had as many or a greater average number of rice root aphids per plant at the beginning of the experiment than nontreated control plants; however, by the end of the experiment very few rice root aphids were found on plants treated with those products (Fig. 1). *Chromobacterium subtsugae* and the heat-killed *Burkholderia* did not provide significant reduction of rice root aphid throughout the field trial. The heat-killed Burkholderia is part of the process used by the company to make this insecticide. The M-306 SE1, and MBI 203 SC1 treatments did not significantly reduce rice root aphid populations until 28 days after the initial application.

Rice root aphid populations decreased significantly during the experiment regardless of treatment. Initially, the experiment was going to be conducted in April and May of 2020 when temperatures are typically between 15 - 25 C (59 - 77 F); however, the lock-down associated with the COVID-19 pandemic pushed the dates of the experiment into June 2020 and later. Ambient temperatures during the experiment were above 25 C (77 F) and often exceeded 30 C (86 F). The nursery supplying our infested plants informed us that they also had experienced population declines during the same timeframe in their hoop houses. Tsai and Lui (1998) found the optimal range for rice root aphid immature stages was between 10 and 20 C (50 - 69 F) and those reared at temperatures at 25 or 30 C

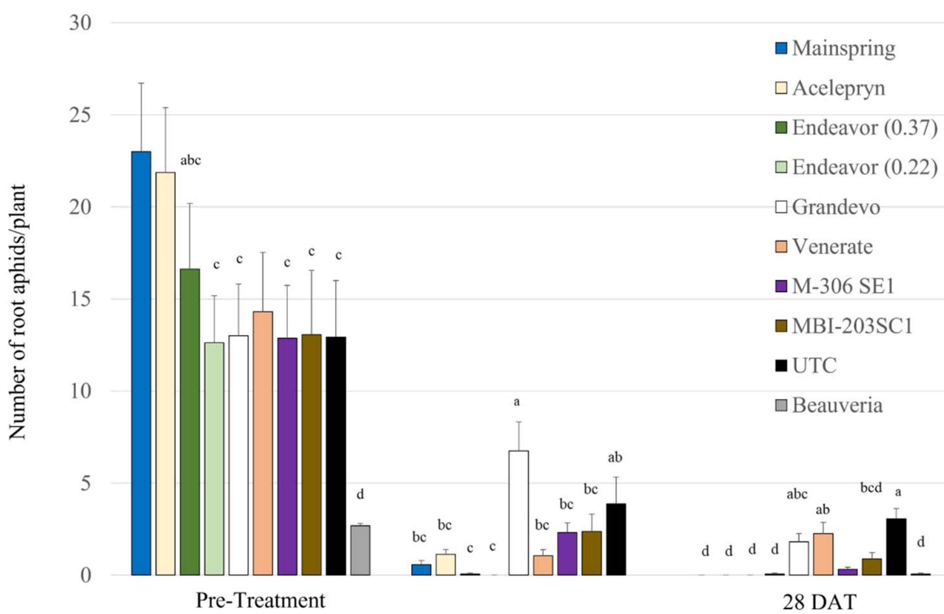

Fig. 4. Average number of rice root aphid (*Rhopalosiphum rufiabdominalis*) (Sasaki) (± S.E.) found on common rush (*Juncus effusus*) grown in nursery plug trays in a greenhouse prior to treatment and 14 or 28 days after (DAT) initial treatment. Bars with different letters are significantly different within an evaluation period (i.e., 14 DAT) at α=0.05 (Tukey HSD). Treatments were: Cyantraniliprole (Mainspring); Chlorantraniliprole (Acelepryn); Pyrometrozine (Endeavor); *Chromobacterium subtsugae* (Grandevo); *Burkholderia* spp. strain 396 (Venerate); M-306; MBI-203; UTC; *Beauveria bassiana* (Mycotrol).

(77 - 86 F) had significantly lower survivorship. We suspect the high temperatures during our experiment help explain the drastic reduction of rice root aphid populations infesting our control plants.

Ants and aphids demonstrate a mutualistic system where ants protect aphids from natural enemies and the ants benefit from the honeydew produced by the aphids. Our pre-treatment count of rice root aphids found ants crawling on root masses infested with higher rice root aphid populations compared to root masses without ants. Additionally, we observed rove beetles, predatory mites, and mealybug destroyers on root masses with few ants and fewer rice root aphids. Woin et al. (2006) found positive correlations between aphid populations and the numeric response of some lady beetle species during the latter part of their growing season. One of the common aphids found in the late growing season in their experiments was the rice root aphid (*R. rufiabdominalis*). We feel natural enemies may have also contributed to the decline of rice root aphid populations in our study since we encountered few ants during data collection after treatments.

Greenhouse operators and nursery growers continue to struggle to manage soil-dwelling insect pests because they are difficult to detect, may have subtle impacts on the crops, and insecticides can be less effective against soil pests compared to pests feeding on above-ground tissues. Additionally, neonicotinoids have been used in the past for managing pests with piercing-sucking mouthparts, but they are heavily scrutinized due to possible impacts on pollinators. Rice root aphids are a relatively new pest for perennial herbaceous plant nurseries or greenhouses, green roof environments, or hemp-oriented businesses. Our experiment showed efficacy of a few new insecticides as management options for the rice root aphid. We feel that applications of pymetrozine will reduce populations within two weeks of application.

Chlorantraniliprole, cyantraniliprole, M-306 and MBI-203 all significantly reduced populations by 28 days after treatment. These products are newer insecticides available or soon to be available to growers. Compatibility of these products with natural enemies, such as the mealybug destroyer, should be further evaluated in future studies. Our experiment found that pymetrozine significantly reduced rice root aphid populations at 14 days after treatment. *Chromobacterium subtsugae* and the heat-killed *Burkholderia* spp. strain A396 cells did not significantly reduce rice root aphid populations in our experiment. Both diamide insecticides, chlorantraniliprole and cyantriliprole, M-306, *Beauveria bassiana*, MBI-203 and pymetrozine all significantly reduced rice root aphid populations at 28 days after initial application.

Significant reduction of rice root aphid populations by the numbered products and diamides in this study suggest these products are insecticides that could be incorporated into a nursery management strategy targeting rice root aphids. These insecticides provide alternate modes of management for growers to use in pest management efforts. Ant management may be necessary for growers that wish to include biological control in a successful management plan. Insecticide efficacy against rice root aphids and potential impact on natural enemies should be investigated in future studies.

Literature Cited

Blackman, R. L. and V. F. Eastop. 2000. Aphids on the World's crops: an identification and information guide, 2nd ed. John Wiley & Sons Ltd., Chichester, UK. p. 476.

Cranshaw, W. S., S. E. Halbert, C. Favret, K. E. Britt, and G. L. Miller. 2018. *Phorodon cannabis* Passerini (Hemiptera: Aphididae), a newly recognized pest in North America found on industrial hemp. Insecta Mundi. 0662:1–12.

Cranshaw, W., M. Schreiner, K. Britt, T. P. Kuhar, J. McPartland, and J. Grant. 2019. Developing insect pest management systems for hemp in the United States: A work in progress. J. Integr. Pest Manag. 10:1–10.

Cranshaw, W. and S. Wainwright-Evans. 2020. *Cannabis sativa* as a host of rice root aphid (Hemiptera: Aphididae) in North America. J. Integr. Pest Manag. 11:1–4.

Dara, S. K. 2015. Reporting on the occurrence of rice root aphid and honeysuckle aphid and their management on organic celery. E-Journal of Entomology and Biologicals. https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=18740. Accessed August 21, 2015.

Doncaster, J. P. 1956. The rice root aphid. Bull. Ent. Res. 47:741–747.

Etzel, R. W. and F. L. Petitt. 1992. Association of *Verticillium lecanii* with population reduction of red rice root aphid (*Rhopalosiphum rufiabdominalis*) on aeroponically grown squash. Fla. Entomol. 75:605–606.

Gill, S., B. Kunkel, C. Schuster, S. Klick, and R. Ross. 2019. Root mealybug: What you don't see is hurting your plants. Growertalks. https://www.growertalks.com/Article/?articleid=24086. Accessed May 6, 2021.

Gilrein, D. 2021. Aphids in unexpected places. e-GRO Alert. 10:1–4.

Gilrein, D. 2015. Time to think about aphids – again. e-GRO Alert. 4:1–5.

Hesler, L. S. and S. D. Kindler. 2007. Abundance of rice root aphid among selected plant species and on plants grown with different soil-surface media. Great Lakes Entomol. 40:84–91.

Kindler, D., L. Hesler, N. Elliott, K. Shufran, and T. Springer. 2004. Cereal and grass hosts of the rice root aphid, *Rhopalosiphum rufiabdominalis* (Sasaki), and a description of an efficient greenhouse rearing technique. J. Agric. Urban Entomol. 21:51–59.

Lagos-Kutz, D., B. Potter, C. DiFonzo, H. Russell, and G. L. Hartman. 2018. Two aphid species, *Phorodon cannabis* and *Rhopalosiphum rufiabdominalis*, identified as potential pests of industrial hemp, *Cannabis sativa* L, in the US Midwest. Crop. Forage Turfgrass Manag. 4:180032.

Mason, P. W. 1937. A new root aphid (Homoptera: Aphididae). Proc. Entomol. Soc. 39:166–167.

Owen, W. and B. Behe. 2020. A national survey to characterize industrial hemp (*Cannabis sativa* L.) production challenges under protected cultivation. J. Agricultural Hemp Research. 1:1–22.

Stoetzel, M. B., G. L. Miller, P. J. O'Brien, and J. B. Graves. 1996. Aphids (Homoptera: Aphididae) colonizing cotton in the United States. Fla. Entomol. 79:193–205.

Technavio. 2021. Geen-roofs market by product, geography, and application – forecast and analysis 2020-2024. ttps://www.technavio.com/report/green-roofs-market-industry-analysis. Accessed July 1, 2020.

Tsai, J. H. and Y. H. Liu. 1998. Effect of temperature on development, survivorship, and reproduction of rice root aphid (Homoptera: Aphididae). Environ. Entomol. 27:662–666.

Woin, N., C. Volkmar, and T. Ghogomu. 2006. Numerical response of predatory ladybirds (Coccinellidae) to aphid outbreaks and their diversity in major rice ecosystems of Cameroon. Arch. Phytopathol. Pflanzenschutz. 39:189–196.

Yano, K., T. Miyake, and V. F. Eastop. 1983. The biology and economic importance of rice aphids (Hemiptera: Aphididae): A review. Bull. Entomol. Res. 73:539–566.