Journal of Horticulture

Maier and Williamson, J Hortic 2016, 3:3
DOI: 10.4172/2376-0354.1000184

Research Article

Open Access

Evaluation of Kaolin Clay as an Alternative Management Tactic for Japanese Beetle Feeding Damage in Grape Vineyards

Reid M Maier* **and R Chris Williamson**

University of Wisconsin Madison, Madison, WI, USA

***Corresponding author:** Reid M Maier, University of Wisconsin Madison, Madison, WI, USA, Tel: 608-577-0549; E-mail: reidmaier@gmail.com

Received date: August 06, 2016; **Accepted date:** August 31, 2016; **Published date:** September 9, 2016

Abstract

The Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabaeidae), is an exotic, introduced Scarab that has become one of the most widespread and destructive insect pest of turf, landscapes and nursery crops in the eastern United States. It also damages various fruit, garden and field crops. Evaluation of certain conventional and non-conventional control agents in a Wisconsin vineyard revealed that bifenthrin, a fourth generation synthetic pyrethroid, provided the greatest Japanese beetle adult control in choice and no-choice feeding bioassays. *Bacillus thuringiensis gallariae* (Btg) was also effective in both bioassays. However, Btg residual activity was relatively limited; its performance decreased five days after treatment. Kaolin clay provided effective Japanese beetle adult management via consistent adult feeding damage mitigation in both study years. Field tests showed that various application Kaolin clay rates were effective in minimizing feeding damage by Japanese beetle adults, and no adverse effects were observed on several important fruit quality characteristics such as sugar content (Brix), acidity, number of fruit produced per plant and fruit weight. Kaolin clay is an alternative, non-insecticide management tactic that can be employed by grape growers to minimize feeding damage by Japanese beetle adults and reduce the amount of conventional insecticide input needed to maintain grape quality.

Keywords: Japanese beetle; *Bacillus thuringiensis gallariae*; Kaolin clay; Grapes

Introduction

The Japanese beetle, *Popillia japonica* (Newman), is an exotic, invasive Scarab species that is one of the most widespread and destructive pests in turf, landscapes and nursery crops in the eastern United States. It is a major pest of many cultivated crops with a host range of over 350 species of plants [1]. Damage to fruit crops by Japanese beetle adults can be both direct and indirect. Direct effect includes feeding on the fruit and indirect damage includes the skeletonizing or feeding damage to plant leaves that reduces the surface area needed for plant photosynthesis [2]. Grapes are considered one of the most highly preferred hosts of Japanese beetle [3]; in the south-eastern United States where viticulture is a growing industry, it is considered a severe pest [4]. Langford et al. [5], reported that grape varieties including Concord, Worden, Niagara and others that are typically cultured and cultivated in the North-eastern states are highly susceptible to severe feeding damage by Japanese beetle adults. Gu and Pomper [6] showed that the most preferred and attractive grape varieties were *Vitis vinifera*, French hybrids, and *Vitis aestivalis*, likely because they have thin, glossy and tender foliage. Feeding damage by Japanese beetle adults that result in leaf area loss as low as 9-11% can be detrimental to the quality of the current season's fruit [7]. Leaf feeding damage can also reduce the shoot length of first-year vines, and may be associated with earlier termination of late-season vine growth that can set back establishment and productivity of young grapevines [4]. Consequently, increased economic crop and revenue losses are quite commonly associated with Japanese beetle adult feeding damage.

Japanese beetle adults are susceptible to various conventional insecticides including bifenthrin, thiamethoxam and indoxacarb, and are particularly vulnerable to phosmet and carbaryl [8]. This latest approach includes the evaluation and use of alternative, non-conventional products that are commercially available as well as newly introduced products. The goal of this work is to help accelerate and facilitate the transition for Wisconsin vineyards from the reliance on conventional insecticides to alternative, non-conventional approaches. Conventional insecticides have been the first line of defence for managing Japanese beetle adults in vineyards. This is likely due to the limited amount of published information related to effective alternative, non-conventional management strategies.

Kaolin clay has been commonly used in the green industry for several years as an effective alternative pest management tactic for a variety of insect pests. It's a white, non-porous, non-swelling, non-abrasive fine-grained aluminosilicate mineral that easily disperses in water and is chemically inert over a relatively wide pH range [9]. Kaolin clay is a management option for insect control for tree nurseries and various crops such as cotton, blueberry, and roses. Kaolin clay has been shown to reduce populations of grape phylloxera, *Daktulasphaira vitifoliae* (Fitch) in grape vineyards [10]. The mechanisms of action of Kaolin clay against insect pests include repellency, tactile or visual cue interference and impairment or disruption of oviposition and feeding activity [11]. The abrasive mineral particles promote insect desiccation due to cuticle disruption and digestive system obstruction and also change the host plants' colour, affecting the recognition and attractiveness of the plant [12].

In addition to the aforementioned benefits of Kaolin clay regarding insect pests, it is also proclaimed to have characteristics or properties that are beneficial to the plants. Thomas [13] reported that Kaolin clay can reduce the canopy temperature of apple trees, which in turn

Citation: Maier RM, Williamson RC (2016) Evaluation of Kaolin Clay as an Alternative Management Tactic for Japanese Beetle Feeding Damage in Grape Vineyards. J Hortic 3: 184. doi:10.4172/2376-0354.1000184

increased productivity. Because kaolin clay is reported to produce desirable attributes in fruit, it is also equally important to understand any potential negative characteristics or effects. This is especially important when working with high-value crops including fruit; potential negative attributes or side effects could have an adverse economic impact due to poor fruit quality.

The primary goal of this study was to evaluate alternative control agents for Japanese beetle adults in grapes. The specific objectives were to 1) compare the effectiveness of three control products to reduce feeding damage by Japanese beetles using a choice and non-choice test. Choice test is defined by simply applying the various products to the plants and allow the beetles to naturally visit and feed. The non-choice test was performed by purposefully subjecting beetles to the various treated plants without the option of visiting and feeding other plants. 2) compare the effectiveness of different application rates of Kaolin clay; and, 3) to assess potential adverse effects of Kaolin clay on fruit characteristics that are critical to grape growers including sugar content, acidity, fruit production and fruit weight.

Materials and Methods

Study site

The research was conducted at a vineyard with a history of Japanese beetle damage (Wollersheim Winery, Prairie du sac, WI). The study site consisted of 10.9 hectares of managed grapes that included four winter-hardy grape hybrids, they include: two French-American red hybrids; 1) Marechal Foch and 2) Leon Millot and two Wisconsin-native American white hybrids; 1) St. Pepin and 2) LaCrosse. The oldest grape variety was a 40 year-old Marechal Foch variety and it was located in a field with a 12% slope in a Seaton silt loam soil. A sward (stand) of turfgrass was used as a ground cover between individual fields and between grape rows within fields to prevent soil erosion. The rows within each field are 3.48 m apart and are supported by 1.82 m tall wood posts positioned evenly, every 6.4 m. The area between each post is commonly referred to as a grape panel. Each grape panel contains three grape plants positioned 2.1 m apart. Metal wire spans the width of the entire panel as a support for the grape vines. This wire is attached to wooden posts at either end. Directly below the grape plants is an area of bare soil (no vegetation) 0.9 m wide. This area is typically managed with annual treatments of glyphosate, a non-selective herbicide to maintain the barren area. Grape plants are commonly pruned and limbs are retrained for structure during dormancy during the months of January and February. Grapes are typically irrigated on an as needed basis by a drip irrigation system. Chemical pesticide applications are made throughout the growing season on an as needed basis to manage Japanese beetle adults, grape phylloxera and downy mildew. Pesticide applications are made using a tractor mounted, PTO powered air blast sprayer (Cima Sprayer: Pavia, Italy). Respective control products evaluated were applied using a hand-held CO2 backpack sprayer equipped with a TeeJet 8004VS nozzle at 33 psi (2.27 bar) and 55 psi for the Btg product (3.79 bars).

Choice test insecticide trial

Four trials with 14 replications arranged in a complete randomized design were performed to evaluate the effectiveness of various control agents on Japanese beetle adults in 2013 and 2014. Each grape panel was considered a replication. Each trial consisted of the following products and rates: Bifenthrin: 0.016 kg/ha (Lesco Brand), Btg: 29.3 g/L applied at 52.8 liter/ha (Phyllom LLC), Kaolin Clay: 4.52 kg/liter/ha (Novasource) and an untreated control. Treatments were applied when Japanese beetle adult emergence was first observed. Application dates in 2013 were July 12, July 22, August 1 and August 12, feeding damage was evaluated on August 22. In 2014, products were applied on July 15, July 20 and August 2, feeding damage was evaluated on August 14.

In 2013, Japanese beetle adult feeding damage was visually evaluated on a scale of 1 to 10 where 1 was minimal damage and 10 severe damage. In 2014, feeding damage was assessed using a more quantitative method that could be readily replicated for future studies. The process for this improved assessment method consisted of using a defined sample area which was 0.5 m × 0.3 m and placed over the top portion of the grape plants. The percent feeding damage was calculated by dividing the number of damaged leaves by the total number of leaves within the sample area. This damage assessment was only performed on the top of the grape plants where the majority of the damage is known to occur (Rowe 1996). Raw data violated the assumptions of normality required for ANOVA and therefore were transformed. However, the transformed data did not fit a normal distribution. Consequently, a non-parametric Kruskal-Wallis test was used followed by a Steel-Dwass All Pairs Method (non-parametric equivalent of Tukey's HSD) using JMP version 11 (SAS 2013).

Insecticide treatment, no-choice test

This experiment consisted of four trials with 14 replications arranged in a complete randomized block design. Each trial evaluated the effects of various control agents on Japanese beetle adults in 2013 and 2014. In 2013, the study was performed in a field of LaCrosse and in 2014 the study was conducted on a field comprised of Marechal Foch grapes. Three control agents at respective application rates were evaluated: 1) Bifenthrin: 0.016 kg/ha (Lesco Brand), 2) *Bacillus thuringiensis gallariae*: 29.3 g/L at an application rate of 52.8 liter/ha (Phyllom LLC), 3) Kaolin Clay: 4.52 kg/liter/ha and 4) an untreated control. Treatments were applied when Japanese beetle adults were first observed.

After the first treatment application was performed and the leaves were dry, a mesh bag containing five live Japanese beetle adults was placed over a single leaf attached to the grape vine. Japanese beetle adults were captured approximately four hours prior to the commencement of the study using a commercially available trap (Spectrum, Middleton, WI) equipped with a floral lure. The traps were located at the O.J. Noer Turfgrass Research and Education Facility (Verona, WI). After 24 hours of exposure, the mesh bags were removed and the number of live beetles in each bag was counted. An additional cohort of beetles were challenged to the respective treated grape leaves 10 days after treatment in 2013 and five days after treatment in 2014. In addition to counting live beetles, an assessment of the leaf area damaged was recorded from the single leaf from each mesh bag at each sampling date. Each leaf was assessed by means of a visual observation and the proportion of leaf area (percent), that was eaten (feeding damage) was determined. Leaf assessment was performed at the same time as the live beetles were counted. For 2013 and 2014, comparisons of interaction effects were performed using a two-way ANOVA followed by a Tukey's HSD test for both average live beetles and percent leaf material eaten. Data for both live beetles and proportion of leaf material eaten for 2013 and 2014 had main effects which did not fit a normal distribution, requiring the performance of a Kruskal-Wallis test and a Steel-Dwass All Pairs Method. All statistical analysis was performed using JMP version 11 (SAS 2013).

Kaolin clay application Trial

Four trials with 12 replications arranged in a completely randomized design were performed to evaluate the effect of Kaolin clay on Japanese beetle adults in a field of Marechal Foch grapes. Three application rates were used: 1) 5.4 kg/ha; 2) 11.3 kg/ha (suggested manufacturer's application rate); 3) 17.0 kg/ha; and 4) 22.6 kg/ha. Kaolin clay was applied on the following dates in 2014: July 16, July 28, August 9, August 19 and in 2015: July 1, July 11, July 21, July 30, August 8 and August 19.

Japanese beetle adult feeding damage was assessed on August 30, 2014 by using the same sampling unit (5.0 m by 3.0 m) for all trials. The feeding damage proportion was calculated by dividing the number of damaged leaves by the total number of leaves within the sample area to calculate a percent feeding damage to grape leaves by Japanese beetle adults. Feeding damage assessment was performed on the upper portion (crown) of the grape plants where the majority of the damage is known to occur (Rowe 1996). Data were analyzed using a two-way ANOVA on square root transformed data. Individual years were analyzed using a one-way ANOVA with root transformed data, with means separated by the Tukey's HSD using JMP version 11 (SAS 2013).

pH and brix assessment for the Kaolin clay study

In 2014 and 2015, two days prior to grape harvest, individual grapes were removed from random clumps located in a minimum of four different locations within a treated and control panel until full capacity of a 0.47 L plastic bag was reached. Each bag was maintained in a plastic travel cooler with ice. About 14 hours after collecting the grapes, the grapes were pressed by hand to release grape extract, then poured into a glass beaker for the assessment of pH and brix. A benchtop pH meter model Beckman 350 (Beckman-Coulter, Brea, CA) was used in the evaluation of pH and a digital refractometer Model Atago Pal-1 (Atago USA inc., Bellevue, WA) was used to determine brix. Raw data for pH did not violate the assumptions of an ANOVA and therefore was analyzed using a one-way ANOVA with means separated using Tukey's HSD. The interaction effect was significant and therefore rates were evaluated using a one-way ANOVA for each individual year. The raw data for evaluating brix violated the assumptions of an ANOVA. As a result, a non-parametric Kruskal-Wallis test was used and means were separated using the Steel-Dwass All Pairs Method which is the non-parametric equivalent of Tukey's HSD using JMP version 11 (SAS 2013).

Weight of grape clusters

Three random grape clusters from each grape panel for a total of 60 panels were weighed using a digital scale while still attached to the grape vine. The three measurements were combined to calculate an average weight per cluster for each panel. These data did not fit a normal distribution, violating the assumptions of ANOVA. As a result, a non-parametric Kruskal-Wallis test was used followed by a Steel-Dwass All Pairs Method (non-parametric equivalent of Tukey's HSD) using JMP version 11 (SAS 2013).

Quantity of grape clusters

The number of grape clusters were counted while still attached to the vine in each treatment panel for a total of 60 panels three days prior to grape harvest in 2014 and 2015. Raw data violated the assumptions of normality required for ANOVA. Due to the nature of these data, transformations were attempted. However, these data did not fit a normal distribution, violating the assumptions of ANOVA. As a result, a non-parametric Kruskal-Wallis test was used followed by a Steel-Dwass All Pairs Method (non-parametric equivalent of Tukey's HSD) using JMP version 11 (SAS 2013).

Results

Insecticide treatment: Choice test

Regardless of the evaluation technique, the results for each had similar trends (Figure 1 and 2). The untreated control and the Btg treatment treatments were statistically similar and had measurably higher feeding damage in both seasons.

The bifenthrin treatments exhibited the lowest amount of feeding damage in both years, 2013 and 2014, 12.60 ± 2.75% of the grape leaves showing damage in 2014 compared to the Kaolin clay treatment where 22.80 ± 3.77% of the grape leaves experienced feeding damage. The bifenthrin treatment performed considerably better than the Kaolin clay treatment, significantly less leaf feeding damage occurred in 2013 (X2=37.3, df=3, P<0.001, 2014 (X2=41.9, df=3, P<0.0001 Figure 1A and 1B respectively).

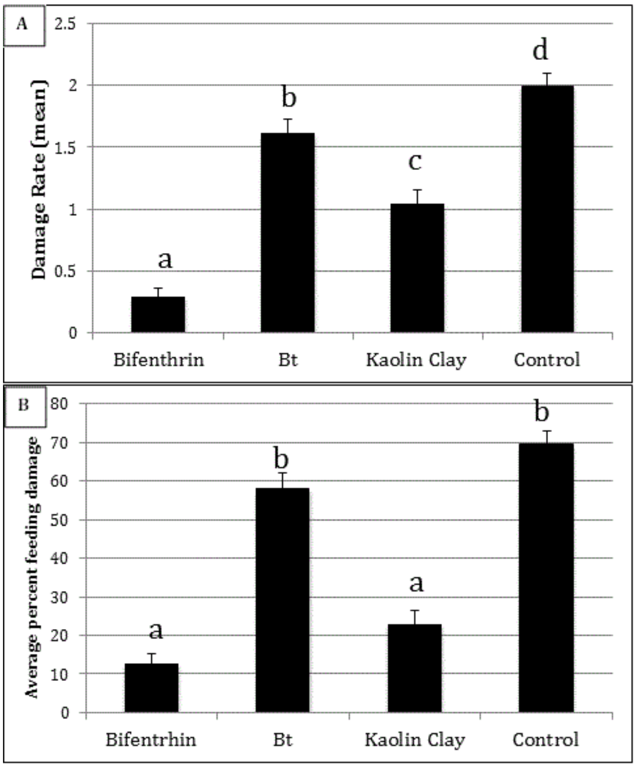

Figure 1: Mean ± SEM feeding damage rating of various control products in a choice test, for A. 2013, and B. 2014. Groups associated with different letters did differ significantly at an experiment wise error rate of 0.05.

Insecticide treatment: No-choice test

The leaves in the bifenthrin treatment showed the fewest number of live beetles at one and 10 days post-treatment in 2013 (Table 1). Post treatment evaluations for live beetles showed significant differences among post-treatment dates in 2013 for bifenthrin (X2=5.37, df=1, P<0.02, and Btg; X2=2.8, df=1, P<0.09), but not for Kaolin clay (X2=0.129, df=1, P<0.72) or the control (X2=0.23, df=1, P<0.68).

			Bifenthrin	**Kaolin Clay**	**Btg**	**Control**
2013	**Beetles (mean)**	24 hrs	0.38 ± 0.31a	4.46 ± 0.18a	2.69 ± 0.36a	4.76 ± 0.12a
		10 d	1.69 ± 1.60b	4.53 ± 1.39a	3.46 ± 0.66a	4.84 ± 0.37a
		X2	5.37	0.12	2.81	0.23
		df	1	1	1	1
		P value	0.02	0.72	0.09	0.65
	Percent feeding damage	24 hrs	2.31 ± 0.84a	6.07 ± 5.39a	12.46 ± 3.61a	20.00 ± 3.96a
		10 d	7.53 ± 1.77b	18.07 ± 4.06b	22.30 ± 3.51b	31.92 ± 3.69b
		X2	7.31	8.9	4.9	4.54
		df	1	1	1	1
		P value	0.028	0.0031	0.026	0.035
2014	**Beetles (mean)**	24 hrs	1.75 ± 0.44a	4.91 ± 0.08a	4.25 ± 1.22a	4.75 ± 1.37a
		5 d	3.58 ± 0.31b	5.00 ± 0.06a	4.50 ± 0.19a	4.83 ± 0.16b
		10 d	1.75 ± 0.41c	4.41 ± 0.19b	4.00 ± 0.21a	4.02 ± 0.25a
		X2	10.91	10.7	2.69	13.37
		df	2	2	2	2
		P value	0.0049	0.0048	0.25	0.0012
	Percent damage	24 hrs	2.83 ± 1.25a	1.25 ± 0.53a	4.41 ± 1.33a	20.91 ± 4.96a
		5 d	6.25 ± 2.56a	4.33 ± 1.21b	9.91 ± 1.80b	16.25 ± 2.42a
		10 d	4.08 ± 2.21a	8.00 ± 1.15c	14.66 ± 2.26c	17.50 ± 1.75a
		X2	3.29	14.5	10.73	0.55
		df	2	2	2	2
		P value	0.192	0.0007	0.0043	0.73

Table 1: No-choice test, mean ± SEM 2013 and 2014, live beetles and percent leaf tissue damage per control product based on post treatment time. Groups associated with different letters did differ significantly at an experiment wise error rate of 0.05.

In 2013, feeding damage was least where bifenthrin was applied compared to all other treatments within their respective post-treatment dates. The leaves in the Kaolin clay treatment exhibited slightly higher feeding damage than the Bifenthrin treatment, however it had measurably less leaf feeding damage compared to the Btg and the untreated control at both post-treatment assessment times (Table 1).

The bifenthrin treatement had the fewest number of live beetles in post-treatment evaluations compared to the Kaolin clay, control, and Btg treatments at all post- treatment assessment times (Table 1).

Feeding damage 24 hours and 5 days post-treatment was least where Kaolin clay was applied compared to all other treatments in 2014 (Figure 1B). The bifenthrin treatment provided measurably less performance compared to the Kaolin Clay treatment 10 days post-treatment (Table 1).

Kaolin clay application trial

There was a significant difference in the interaction between year and trial therefore, (F=3.21, df=4, P=0.015) main effects for different rates had to be evaluated for each year separately. In 2014, all treatments were significantly different from control. The 5.44 kg/ha, 11.33 kg/ha were significantly different from each other and from the 17.0 kg/ha and 22.6 kg/ha rates. The 17.0 kg/ha and 22.6 kg/ha rates were not significantly different from each other (F=28.41, df=4, P<0.0001). In 2015, 5.4, 11.3, 17.0, 22.6 kg/ha) were not significantly different from each other, however the 17 and 22.6 kg/ha application rate were significantly different from the untreated control (F=3.11, df=4, P<0.221, Figure 2A and B).

Ph and brix assessment for the Kaolin clay study

In 2014, no differences in pH were observed among the various kaolin clay application rates (F=1.85, df=4, P=0.76). In 2015, the pH value obtained for the 17 kg/ha application of Kaolin clay was significantly lower from all other rates of Kaolin clay. The interaction effect between year and rates was significant therefore the main effect of rates was evaluated without combining the two years (Table 2).

The brix for the different application rates of Kaolin clay didn't differ from the untreated control (X2=2.78, df=4, P=0.59; Table 2).

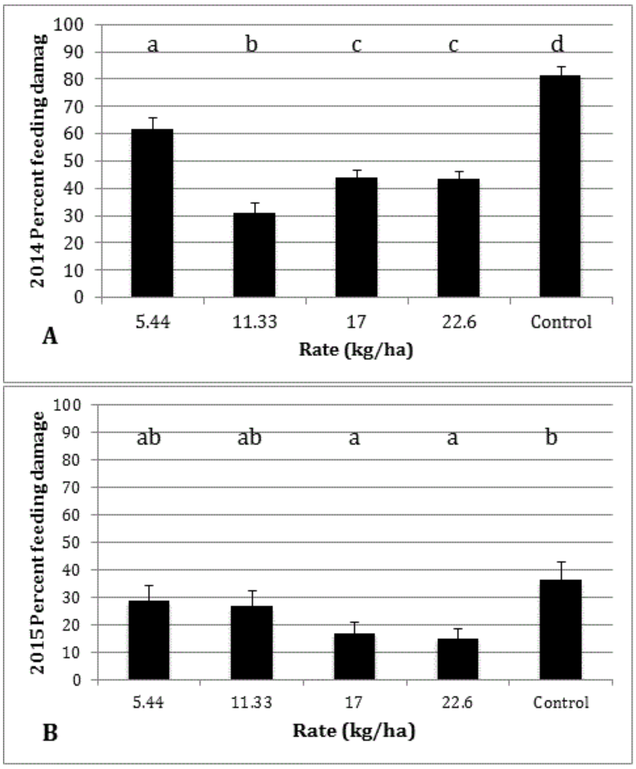

Figure 2: 2014, A and 2015, B Comparisons of mean ± SEM percent feeding damage by Japanese beetle adults using various rates of Kaolin clay on grapes. Groups associated with different letters did differ significantly at an experiment wise error rate of 0.05.

Weight and quantity of grape clusters for the Kaolin clay study

Cluster weight didn't differ among various Kaolin clay application rates (F=7.53, df=4, P<0.11) (Table 2). No significant difference occurred in the quantity of grape clusters between the application rates of Kaolin clay. Although, Kaolin clay applied at the 17 kg/ha application rate, panels exhibited the fewest number of grapes and transformational analysis of the data revealed a lack of normality. A Kruskal-Wallis test suggested no significant differences between treatments, X2=3.87, df=4, P<0.42 (Table 2).

Treatment/ Rate(lbs/a)	pH (year)	Brix	Weight (g)/ cluster	Clusters/ panel
12.5	3.13 ± 0.013 (2014) 3.18 ± 0.019 (2015)	19.85 ± 0.21	96.17 ± 8.45	23.1 ± 3.57
25	3.14 ± 0.013 (2014) 3.21 ± 0.024 (2015)	20.2 ± 0.28	95.27 ± 9.64	22.58 ± 2.98
37.5	3.14 ± 0.015 (2014) 3.11 ± 0.021 (2015)	19.46 ± 0.33	89.92 ± 5.59	17.16 ± 2.41
50	3.17 ± 0.021 (2014) 3.19 ± 0.014 (2015)	20.22 ± 0.21	100.68 ± 6.83	20.79 ± 2.94
Control	3.13 ± 0.019 (2014) 3.19 ± 0.014 (2015)	19.83 ± 0.31	101.00 ± 5.85	24.20 ± 2.64
F value	0.79 (2014) 4.32 (2015)		7.53	
X2		2.78		3.87
p Value	0.53 (2014) 0.004 (2015)	0.59	0.11	0.42
Df	4	4	4	4

Table 2: 2014 and 2015 Comparisons for mean ± SEM pH, Brix, Weight per cluster, and cluster number among various rates of Kaolin clay Groups.

Discussion

Overall, the results of this work suggested conventional and non-conventional products are effective in mitigating feeding damage by Japanese beetle adults. The conventional insecticide bifenthrin was most efficacious and resulted in the least amount of Japanese beetle adult feeding damage compared to all other products. However, the Kaolin Clay treatment exhibited significant reduction in leaf feeding damage compared to the control. The results of this work suggest that Kaolin Clay is an effective alternative control tactic to conventional insecticides for managing Japanese beetle adults, especially for early and late treatment application timings where otherwise commercially available insecticides are needed to control Japanese beetle adults to mitigate feeding damage. The optimal treatment application timing to maximize the performance of Kaolin clay is when Japanese beetle adults first emerge (i.e., early season) and when populations are begin to subside (i.e., late season). During peak Japanese beetle adult activity, the use of conventional insecticides or the combination of Kaolin clay with other alternative, non-conventional products [14] are likely the best management option. It is unlikely that the use of conventional insecticides will be eliminated, however the results of this work provide an alternative management approach that can measurably reduce the reliance on conventional insecticides. A similar management strategy was discovered in other agricultural cropping systems where insect pest such as the cacao mired bug [15], cotton boll weevil [16] and eulophid wasps [17] were effectively managed using alternative, non-conventional products.

This work revealed that Kaolin clay had no measurable negative effect on important grape characteristics (i.e., pH, sugar content, grape cluster weight and the number of grape clusters per plant) that wine makers demand. While pH was found to be lower with an intermediate rate of Kaolin clay, however this result was not consistent and should be further investigated as pH is an important grape fruit quality characteristic. This outcome has been described in several other related studies involving the effects of Kaolin clay on fruit production, most studies had reported either no or positive effects of kaolin film on plant productivity and yield. Garcia et al. [18] showed significant increase in fruit weight, firmness, and fruit size of Kaolin clay on apples. Puterka et al. [11] reported an increase in fruit set and less fruit drop regarding the yield of pears with the use of Kaolin clay. Jifon and Syvertsen [19] showed an increase leaf carbon uptake in grapefruit during high temperature regimes. Creamer et al. [20] showed a reduction in water stress parameters during the hottest months in Chilean pepper production. Therefore, grape growers should not be concerned about potential negative or adverse effects of Kaolin clay when applied to grapes for management of Japanese beetle adults.

Although *Bacillus thuringiensis gallariae* is a biologically based (bacteria) insecticide, its performance (efficacy) was statistically similar to the Kaolin clay treatment, a non-efficacious treatment, and the untreated control. However, feeding damage by Japanese beetle adults on grape leaves treated with Btg has statistically significant less feeding damage than the untreated control. This occurrence may likely be attributable to Btg's known deterrent properties. Yendol et al. [21] reported that gypsy moth larvae preferred untreated leaves over Btg treated leaves. Additionally, similar Chen et al. [22] showed that the Asiatic rice borer preferred untreated stalk cuttings of rice over *Bacillus thuringiensis* treated stalk cuttings.

Kaolin clay and Btg are alternative, non-conventional products that provide effective and meaningful protection from feeding damage on grape leaves by Japanese beetle adults, particularly when population densities are not at peak level. This management approach will likely be an appealing option to grape growers and vineyard managers who desire to reduce the use of and be less reliant on conventional insecticides. Additionally, Kaolin clay does not have a pre-harvest interval, it can be applied with little concern for potential fruit contamination.

Acknowledgement

This research was funded through the Ruth Dickey Family Trust fellowship. We thank Philipe Coquard, Bruce Reeve, and Celine Coquard-Lenerz from the Wollershiem Winery for access to the study site. We also appreciate the help of P.J. Liesch, Glen Obear, Alder Lavin for their technical assistance.

References

1. Potter DA, Held DW (2002) Biology and management of the Japanese beetle. Ann Rev Entomol 47: 175-205.
2. Johnson D, Rom C, Mcafee J, Mckern J, Stafne E, et al. (2010) Differences in defoliation of fruit genotypes by adult Japanese beetle feeding. J Am Pom Soc 64: 184-198.
3. Fleming WE (1972) Biology of Japanese beetles. US Dept of Agriculture Tech Bulletin 1449.
4. Hammons DL, Kurtural K, Potter DA (2010) Impact of insecticide-manipulated defoliation by Japanese beetle (*Popillia japonica*) on grapevines from vineyard establishment through production. Pest Management Science 66: 565-571.
5. Langford GS, Cory EN (1948) Host preference in Japanese beetles with special reference to grape and apple. J Econ Entomol 41: 823-824.
6. Gu S, Pomper QW (2008) Grape cultivar feeding preference of adult japanese beetles. Hortic Sci 43: 1996-199.
7. Boucher JT, Pfeiffer DG (1989) Influence of Japanese beetles (Coleoptera: Scarabaeidae) foliar feeding in Seyval Blanc grapevines in Virginia. J Econ Entomol 82: 220-225.
8. Hulbert D, Isaacs R, Vandervoort C, Wise JC (2011) Rainfastness and residual activity of insecticides to control Japanese beetle (Coleoptera: Scarabaeidae) in grapes. J Econ Entomol 104: 1656-1664.
9. Harben PW (1995) The Industrial minerals handy book (2nd eds), Ind Miner Div, Metals Bull, PLC London.
10. Sleezer S, Johnson DT, Lewis B, Googin F, Rothrock F, et al. (2011) Foliar grape Phylloxera, *Daktulosphaira vitifoliae* (Fitch), seasonal biology, predictive model and management in the Ozarks region of the United States. Acta Hortic 904: 151-156.
11. Puterka GJ, Glenn DM, Sekutowski DG (2000) Progress toward liquid formulations of particle films for insect and disease control in pear. Environ Entomol 29: 329-339.
12. Showler AT (2002) Effects of Kaolin-based particle film application on boll weevil (Coleoptera: Curculionidae) injury to cotton. J Econ Entomol 95: 754-762.
13. Thomas A, Muller M, Dodson B, Ellersieck M, Kaps, M (2004) A Kaolin-based particle film suppresses certain insect and fungal pests while reducing heat stress in apples. J Am Pom Soc 58: 42-52.
14. Alavo TBC, Yarou BB, Atachi P (2010) Field effects of kaolin particle film formulation against major cotton lepidopteran pests in North Benin, West Africa. Int J Pest Mang 56: 287-290.
15. Amalin DM, Averion L, Bihis D, Legaspi JC, David EF (2015) Effectiveness of kaolin clay particle film in managing *Helopeltis collaris* (Hemiptera: Miridae, a major pest of cacao in the Philippines. Flo Ento Soc 98: 354-355.
16. Silva CAD, Ramalho FS (2013) Kaolin spraying protects cotton plants against damages by boll weevil *Anthonmus grandis* Boheman (Coleopera: Curculionidae). J Pest Sci 86: 563-569.
17. Verde GL, Rizzo R, Baraco G, Lombardo A (2011) Effects of kaolin on *Ophelimus maskelli* (Hymenoptera: Eulophidae) in laboratory and nursery experiments. J Econ Entomol. 104: 180-187.
18. Garcia ME, Berkett LP, Bradshaw T (2004) First year results of the impact of a novel pest management technology on apple fruit quality. Acta Hortic 638: 85-88.
19. Jifon JL, Syvertsen JP (2003) Kaolin particle film applications can increase photosynthesis and water use efficiency of "Ruby red" grapefruit leaves. J Am Soc Horti Sci 128: 107-112.
20. Creamer R, Sanogo S, El-Sebai OA (2005) Kaolin-based foliar reflectant affects physiology and incidence of beet curly top virus but not yield of Chile pepper. Hort Sci 40: 574-576.
21. Yendol WG, Hamlen RA, Rosario S (1975) Feeding behavior of gypsy moth larvae on *Bacillus thuringensis*-treated foliage. J Econ Entomol 68: 25-27.
22. Chen H, Mang G, Zhang Q, Lin Y (2008) Effect of transgenic *Bacillus thuringiensis* rice lines on mortality and feeding behavior of rice stem borers (Lepidoptera : Crambidae). J Econ Entomol 101: 182-89.