# Evaluation of Organically Acceptable Methods to Control Periodical Cicada (Hemiptera: Cicadidae) Oviposition Injury on Nonbearing Apple Trees[1]

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**Abstract** Broad-spectrum insecticides are the standard control method used in tree fruit orchards to control periodical cicadas (*Magicicada* spp.) and to reduce associated oviposition injury to woody host plant tissue. The purpose of this study was to evaluate the effectiveness of two organically approved methods; foliar applications of Organic Materials Review Institute (OMRI)-registered insecticides; and physical exclusion to manage periodical cicada oviposition injury in a commercial apple orchard. Insecticides evaluated included kaolin clay and neem + karanja oil (mixed in a 1:1 ratio). The physical exclusion method involved covering trees with polypropylene fabric. Oviposition injury assessed during the study included the number of periodical cicada eggnests, eggnests per scar, and flagged branches. Neither kaolin clay nor neem + karanja oil significantly reduced periodical cicada oviposition injury compared with the untreated control. Trees covered with exclusion fabric sustained no injury from periodical cicadas. Despite the injury sustained by insecticide-treated and control trees, the extent of periodical cicada oviposition with several tree growth characteristics (tree height, tree canopy width, and trunk circumference) was not significantly correlated.

**Key Words** *Magicicada*, mechanical control, kaolin, neem, karanja

Periodical cicadas, *Magicicada* spp., are an important economic pest of young agricultural and ornamental trees in the eastern United States. Adult periodical cicadas synchronously emerge from the soil in enormous numbers within a given area every 13 or 17 years to mate and oviposit in woody tissue. Females create a series of slits, or eggnests, along the length of twigs and branches that have diameters ranging between 3 and 14 mm (Miller 1997; Miller and Crowley 1998; White 1973, 1980). The ovipositional wounds often appear as a linear scar approx. 4–8 cm in length (Miller 1997; Miller and Crowley 1998). Oviposition injury can kill affected woody tissue, resulting in growth loss of host plants (Hogmire et al. 1990; Koenig and Liebhold 2003; Miller and Crowley 1998; Smith and Linderman 1974), altered tree architecture (Asquith 1954; Hogmire et al. 1990; Smith and Linderman 1974), and fruit crop loss (Graham and Cocran 1954; Hogmire et al. 1990). In addition, oviposition scars may increase susceptibility to pathogenic infections

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(Ostry and Anderson 1983; Smith and Linderman 1974; Van der Zwet et al. 1997). In some cases, injury from periodical cicadas can persist and still be recognizable on woody tissue after over a decade (Craig 1941).

In nonbearing orchards, managing periodical cicada oviposition injury typically involves the application of broad-spectrum insecticides. Although application of several classes of insecticides, including carbamates, organophosphates, and pyrethroids, have successfully been used to control emerging periodical cicada populations, there have been variable reports on the efficacy of these compounds to limit oviposition injury on host trees (Forsythe 1966; Hogmire et al. 1990; Weires and Straub 1980). When periodical cicada emergence occurs, they are the single, most-abundant animal in biomass per unit area (Dybas and Davis 1962). Because of their sheer numbers, and the constant influx of immigrating females from outside treatment areas over an extended period of time, it is difficult for many insecticides to provide the required level of protection within labeled application intervals (Weires and Straub 1980). Insecticides that have provided some level of protection from periodical cicada oviposition injury have generally had long residual activity or repellent properties (Hogmire et al. 1990; Weires and Straub 1980).

Organic tree fruit producers and producers interested in limiting the use of broad-spectrum insecticides have few tools available to effectively manage periodical cicadas during emergence years. Nonchemical options such as netting, or other physical exclusion methods, have been used effectively to protect young trees from periodical cicada oviposition injury (Ahern et al. 2005; Graham and Cochran 1954; Hamilton 1953; Hogmire et al. 1990). However, this pest management technique can be labor intensive and cost prohibitive in some orchards (Graham and Krestensen 1957; Hogmire et al. 1990). Kaolin clay (Surround WP Crop Protectant, NovaSource, Phoenix, AZ, USA) is an Organic Materials Review Institute (OMRI)-registered (organic) insecticide labeled for periodical cicada suppression. Application of kaolin clay results in a film over plant material, which serves as a physical barrier to repel various insect pests or suppress infestations by altering necessary visual or tactile host stimuli. Kaolin clay is reported as being an oviposition deterrent to a variety of key insect pests in fruit orchards in the United States (Glenn et al. 1999; Knight et al. 2000; Unruh et al. 2000) and has been shown to significantly reduce vine cicada, *Psalmocharias alhageos* (Kolenati), oviposition injury in vineyards in Iran (Valizadeh et al. 2013). Although there are no published accounts of the efficacy of kaolin clay particle film applications to deter oviposition by periodical cicadas, it has been recommended as a reduced-risk alternative for cicada control in nonbearing orchards (Pfeiffer et al. 2019).

Two additional organic insecticides that may have potential for limiting periodical cicada oviposition injury are botanical extracts of the neem tree, *Azadirachta indica* A. Juss. (Meliaceae), and the pongam oiltree, *Millettia pinnata* (L.) Panigrahi (Fabaceae) (formerly *Pongamia pinnata* [L.] Pierre). Oil extracted from the seeds of neem and pongam (also known as karanja) contain many bioactive compounds that are responsible for a wide range of effects against insect pests including repellency, oviposition inhibition, and toxicity (Pavela 2007; Schmutterer 1990; Van der Nat et. al. 1991). Karanja oil has shown synergistic effects when mixed with other insecticides (Kumar and Singh 2002) and has been recommended in combination with neem oil to enhance efficacy (Pavela 2007).

Field trials investigating the efficacy of reduced-risk insecticide compounds are necessary to potentially expand the range of chemical options available for management of periodical cicadas in nonbearing fruit orchards. The purpose of this study was to compare the use of two botanical insecticides (neem and karanja oil used in combination) and kaolin clay alone with a nonchemical physical barrier and to determine their effectiveness at reducing periodical cicada oviposition injury in relation to unprotected and untreated trees. The effect of periodical cicada oviposition injury on tree growth was also examined.

## Materials and Methods

**Study site.** In 2016, periodical cicadas in brood V emerged throughout much of West Virginia. This study was conducted in a commercial apple orchard block located in Marion County, WV, during 2016 and spring 2017. Apple cultivars used in the study were 'Golden Russett' and 'Gravenstein' trees on G.11 rootstock and 'Grimes Golden', 'King David', and 'Roxbury Russett' trees on G.16 rootstock. All trees in the block were planted in 2014 at a spacing of 4.6 m between trees and 7.6 m between rows. Trees measured approximately 1.6 m in height and 0.6 m in width.

Emergence of periodical cicadas in the orchard block was first observed 16 May, and the onset of male calling occurred 22 May. Two species, *Magicicada cassini* (Fisher) and *Magicicada septendecim* (L.), were observed and heard calling during the study. Sweep net samples collected 14 June showed *M. cassini* as the dominant species present. The cessation of oviposition and male calling at the study site occurred on 29 June.

**Experimental design and treatments.** Four treatments were arranged in a randomized complete block design and replicated 10 times in single tree plots. Two replicate blocks were assigned to each apple cultivar row. Treatments included trees covered with polypropylene fabric to exclude cicadas (Agribon AG-15, Johnny's Selected Seeds, Fairfield, ME, USA), trees treated with organically approved insecticides, and untreated/unprotected (control) trees. Organic insecticide treatments included kaolin clay particle film (56 kg [AI]/ha; Surround WP), and cold pressed neem + karanja seed oil at a 1:1 ratio (1.5% solution; Ahimsa Alternative Inc., Bloomington, MN, USA). Oil sprays were applied as an emulsion in water using 0.2% (v/v) liquid soap (Dr. Bronner's, Vista, CA, USA) as the emulsifier.

Treatments were initiated on 24 May before oviposition was first observed. For the exclusion treatment, fabric was cut to size and draped over the canopy of the tree with the ends collected and fastened around the trunk. Fabric was removed from trees 30 June after cessation of oviposition. Insecticide treatments were applied six times at 7-d intervals using a backpack sprayer (Solo, Newport News, VA, USA). Insecticides were manually agitated before spraying each treatment tree to the point of runoff. To minimize off-target drift of insecticides, all spray applications were applied in the morning only when wind speeds and environmental conditions were optimal.

**Injury assessment.** Oviposition injury from periodical cicadas was assessed 30 June. Four primary scaffold branches (one in each quadrant), ranging between 9.5–16.0 mm in diameter near the site of attachment to the trunk, were selected from each tree for evaluation. A 40-cm section from the middle of each branch was examined for the number of periodical cicada eggnests and scars. An eggnest was defined as a single linear slit in woody tissue with tufts of wood fibers protruding from the wound (White 1980). A scar consisted of an uninterrupted, linear arrangement of eggnests that resulted from repeated injection of the ovipositor into woody tissue. Counts of eggnests and scars from each of the 40-cm branch sections were pooled to obtain tree-specific totals. The total number of eggnests was divided by the total number of scars to obtain the average number of eggnests per scar for each tree. Eggnests per scar was used to assess the duration of an oviposition session and as an indicator for whether preferences existed among treatments (Ahern et al. 2005; White 1980). In addition to eggnests and eggnests per scar, the number of branches exhibiting flagging injury was recorded on 2 Aug.

**Tree growth evaluation.** To quantify tree growth, the initial measurements of tree height, tree canopy width, and trunk circumference (20 cm above the soil line) were recorded 23 May. Measurements were again taken in spring 2017 after dormant pruning of trees, and the percentage change in growth was recorded.

**Data analysis.** Eggnest data did not conform to the assumptions of normality due to the presence of all zero values in the exclusion treatment. Therefore, data were analyzed using a Kruskal-Wallis nonparametric analysis of variance (ANOVA) with means of significant effects separated using the Mann–Whitney *U*-test. Eggnests per scar and flagging data were square root transformed to stabilize variances and analyzed using ANOVA, with means of significant effects separated using Tukey's honestly significant difference test. The exclusion treatment was omitted from this analysis because no eggnests were present on branches. Spearman nonparametric correlation analyses were used to quantify the relationship between tree growth characteristics (tree height, canopy width, and trunk circumference) and number of eggnests per tree. All statistical analyses were conducted using Statistical Analysis System (SAS) software (SAS Institute 2008). Results from all tests were considered statistically different at $P < 0.05$.

## Results

The mean number of eggnests per tree was significantly lower in the exclusion treatment ($H = 22.94$; df $= 3$; $P < 0.0001$) than in all other treatments, which did not differ significantly (Fig. 1). The mean ($\pm$ standard error [SE]) number of eggnests per scar did not differ significantly among the kaolin clay (6.4 $\pm$ 0.6), neem + karanja (7.1 $\pm$ 0.8), and control (6.6 $\pm$ 0.6) treatments ($F = 0.38$; df $= 2, 29$; $P = 0.6858$). Similarly, the mean ($\pm$SE) number of flagged branches per tree did not differ significantly among the kaolin clay (1.5 $\pm$ 0.5), neem + karanja (1.0 $\pm$ 0.5), and control (1.9 $\pm$ 0.7) treatments ($F = 0.69$; df $= 2, 29$; $P = 0.5115$). Overall, the percentage change in tree height, tree canopy width, and trunk circumference was not significantly correlated with the number of eggnests per tree (Table 1).

## Discussion

Limited data are available on the efficacy of reduced-risk and organically approved insecticides for control of periodical cicadas. In this study, kaolin clay and neem + karanja oil were not able to adequately reduce periodical cicada oviposition

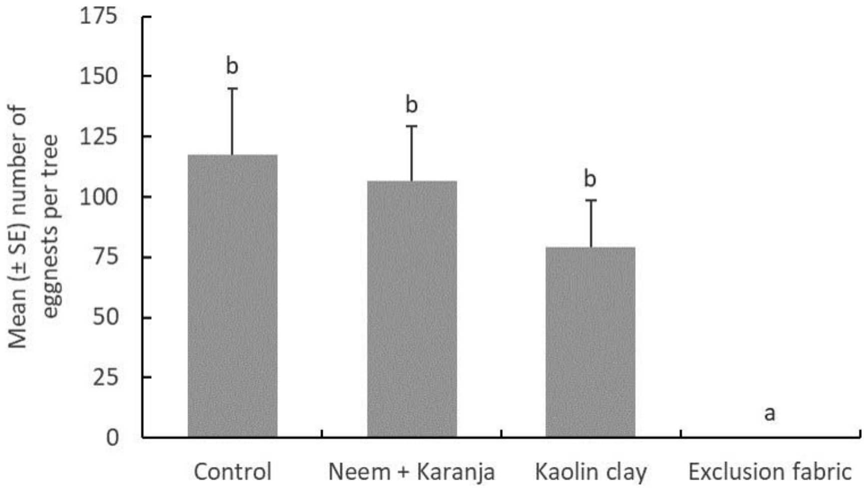


**Fig. 1. Mean (±standard error) number of eggnests per tree. Bars with different letters denote significant differences among treatments (Tukey's honestly significant difference test, $P < 0.05$).**

injury to young apple trees. Kaolin clay treated trees had numerically fewer periodical cicada eggnests than did trees in the neem + karanja and control treatments, but significant levels of injury still occurred when compared with trees covered with exclusion fabric. Although the effectiveness of kaolin clay can be diminished by inadequate coverage of the material and frequent rainfall events, thorough and consistent coverage of woody plant material was maintained in this study until cessation of periodical cicada oviposition activity. Regardless of these measures, periodical cicadas were observed readily feeding and ovipositing on kaolin clay–treated twigs and branches.

Despite the documented effectiveness of neem and karanja oil as a repellent or oviposition deterrent for several insect pest species (Pavela 2007; Schmutterer 1990; Van der Nat et. al. 1991), results from this study showed that these botanical extracts had minimal activity against periodical cicadas. While less is known about the action of compounds present in karanja oil, neem is generally recognized as

**Table 1. Spearman correlation coefficients ($n = 40$) of percentage change in tree growth characteristics correlated with number of eggnests per tree.**

| Treatment | Spearman's Correlation Coefficient | *P* Value |
|---|---|---|
| Tree height | −0.2161 | 0.1805 |
| Canopy width | −0.0141 | 0.9312 |
| Trunk circumference | 0.2762 | 0.0845 |

being less effective against adult insects, particularly at high population densities (Isman et al. 2004). In addition, neem has relatively low persistence in the environment because it is susceptible to photodegradation (Schmutterer 1988). Neem-based products typically have a residual effect of 5–7 d (Schmutterer 1990), which corresponds to the treatment intervals used in this study. However, various environmental factors (e.g., rainfall, temperature, solar radiation) are known to further affect persistence in the field (Pearsall and Hogue 2000; Schmutterer 1988). Although neem extracts have been shown to reduce fecundity of female insects and decrease survival of eggs (Schmutterer 1990), number of eggs present in eggnests and emergence of nymphs were not evaluated in this study.

Because periodical cicada eggnests are produced in series and not independently, the number of eggnests per scar has been used to assess the duration of an oviposition session and as an indicator for whether preferences exist among treatments or host plants (Ahern et al. 2005; White 1980). Results from this study showed that females constructed similar numbers of eggnests per oviposition session regardless of whether trees were treated with insecticides. This further suggests that neither kaolin clay or neem + karnaja effectively deterred females from ovipositing into woody tissue.

As predicted, covering trees with polypropylene fabric was the most effective method for protecting young apple trees from periodical cicada oviposition injury. These results concur with findings from previous studies that have evaluated similar physical exclusion methods (Ahern et al. 2005; Graham and Cochran 1954; Hamilton 1953; Hogmire et al. 1990). Although Hogmire et al. (1990) and Ahern et al. (2005) showed that netting provided greater protection from periodical cicadas than did insecticide treatments, they noted that oviposition injury and flagging could still occur on branches that pressed against the netting. In this study, no injury was recorded on trees protected with polypropylene fabric even though periodical cicadas were frequently observed landing and spending time on covered trees. Ahern et al. (2005) documented that the cost of netting (1-cm mesh size) to enclose a single 3-m-tall tree for exclusion of periodical cicadas was $2.82, which was similar to the cost of exclusion fabric for a single tree in this study. Hogmire et al. (1990) concluded that netting young trees to exclude cicadas in nonbearing apple orchards was approximately 15% more expensive than conventional insecticides applied with a handgun sprayer and that netting was more economical than insecticides applied with an airblast sprayer at tree densities $\leq$250/ha.

Early production of a newly planted orchard is essential to offset the cost of its establishment. Any factor that causes reductions in tree growth can potentially delay the ability of trees to support a full crop of fruit which, thus, affects the orchard's overall profitability. Results from this study showed that periodical cicada oviposition injury was not correlated with a reduction in multiple apple tree growth characteristics. These results are consistent with Cook and Holt (2002), who showed little evidence that cicada oviposition injury affected overall height and basal diameter of trees in an early successional prairie-forest in Kansas. Similarly, Flory and Mattingly (2008) noted that cicada oviposition did not generally reduce growth or reproduction of plants in a newly established plantation comprising six common and exotic host plant species found in deciduous forests in the eastern United States.

In contrast to these results, Hogmire et al. (1990) documented a significant negative correlation between cicada oviposition scarring and apple tree growth characteristics despite comparable levels of injury. In their study, they did not report any negative growth effects of using netting to exclude periodical cicadas. Although trees protected with polypropylene fabric in this study were not injured by periodical cicada, upward and downward twisting of shoots and stems occurred because growth was confined within the exclusion fabric. After completion of dormant pruning the following season, many of these deformed branches and terminals were removed or correctively pruned before the collection of final growth measurements. It is possible that the pruning of deformed branches and terminals in the exclusion treatment counteracted any growth benefits that may have been gained when compared with the other treatments. In addition, the apple trees used in this study had a mean ($\pm$SE) trunk diameter of 18.1 $\pm$ 0.6 mm, which is larger than what is normally preferred for oviposition by periodical cicadas (Miller 1997; Miller and Crowley 1998; White 1973, 1980). Personal observations from visits to other affected orchards in 2017 showed that trees with trunk diameters less than approx. 15 mm received substantial branch and trunk injury from periodical cicadas, which ultimately resulted in conspicuous growth loss from destruction of woody tissue. It is unclear from the Hogmire et al. (1990) study if the trunk diameters of trees used in their study were similarly more predisposed to damage by periodical cicada.

In conclusion, physical exclusion methods remain the most effective method for reducing periodical cicada oviposition injury in nonbearing fruit orchards. The organically approved insecticides evaluated in this study did not provide an effective measure of control when applied as weekly sprays during the cicada oviposition period. Although the injury caused by periodical cicada oviposition can cause branch flagging and breakage, no significant short-term reductions in tree growth were observed. Because previous studies have associated periodical cicada oviposition injury with reductions in fruit tree growth and productivity (Asquith 1954; Graham and Cochran 1954; Hogmire et al. 1990; Van der Zwet et al. 1997), further investigations of this phenomenon are needed.

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