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USE OF LANDSCAPE FABRIC TO MANAGE DIAPREPES ROOT WEEVIL IN CITRUS GROVES

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ABSTRACT

Experiments were conducted at 3 sites in Florida to determine whether landscape fabric, used as soil mulch, can reduce damage to citrus trees by *Diaprepes abbreviatus*. The mulches were intended to prevent newly hatched weevil larvae from entering the soil to feed on roots and to prevent teneral adult weevils from exiting the soil to initiate egg-laying. The weight of aboveground parts of trees at a site heavily infested by *D. abbreviatus* on the east coast was 70% larger ($P \leq 0.05$) for trees grown for 3 years on mulched compared to unmulched soil. Mulching did not affect the amount of feeding damage to roots at the east coast site, suggesting that mulched trees tolerated the damage better than trees in bare soil. Small plot size and relatively narrow fabric dimensions at the east coast site may have facilitated the entry of neonate larvae into soil. At a site on the Central Ridge with low weevil population density, average trunk cross-sectional area of 5-year-old mulched trees was 31% greater ($P < 0.02$) than trees in bare soil. At both this site and a central flatwoods site, the number of adult weevils captured in ground traps that catch weevils emerging from soil was reduced by up to 99% when traps were installed next to trees on mulch compared to bare soil. Adult weevils did not appear to migrate beneath fabric to emerge at the edges because mean numbers of weevils trapped at the edges of the fabric (2.75 ± 1.01) did not differ ($P > 0.05$) from those trapped at the same position on unmulched trees (4.38 ± 1.95). Additional work is needed to demonstrate the effect of fabric mulches on weevil population density. Nevertheless, fabric mulches were shown to consistently increase tree growth in weevil-infested orchards. Fabric mulches also eliminate the need for herbicides and potentially insecticides or other IPM tactics to manage root weevil pests.

Key Words: *Diaprepes abbreviatus, Artipus floridanus*, mulch, cultural control, physical barrier, landscape fabric

RESUMEN

Se realizaron experimentos en 3 sitios de la Florida para determinar si la tela sintética para el jardín, usada como un mantillo del suelo, puede reducir el daño a los árboles de cítricos por *Diaprepes abbreviatus*. La intención de poner el mantillo fue para prevenir que las larvas recién nacidas del picudo entraran el suelo para alimentarse sobre las raíces y para prevenir que los picudos adultos tenerales salgan del suelo para iniciar la ovisposición. El peso de las partes de los árboles que están arriba de la tierra en sitios muy infestados por *D. abbreviatus* en la costa este fue 70% mas alto ($P \leq 0.05$) para los árboles sembrados en mantillo por 3 años en comparación con los sembrados en suelo sin mantillo. El puesto del mantillo no afecto la cantidad del daño causado por la alimentación de las raíces en el sitio el la costa este, sugiriendo que los árboles sembrados en mantillo toleraron el daño mejor que los árboles sembrados solamente en suelo desnudo. El tamaño pequeño de las parécelas y la dimensión relativamente estrecha de la tela usada en el sitio de la costa este puede haber facilitado la entrada de las larvas recién nacidas al suelo. En el sitio de la Cresta Central con una densidad de población mas baja del picudo, el promedio de la área cruce seccional de los árboles sembrados en mantillo por 5 años fue 31% mayor ($P < 0.02$) que la en suelo desnudo. En este sitio y en el sitio con el drenaje del suelo impedido, el número de los adultos de picudos capturados emergiendo del suelo en las trampas del suelo fue reducido hasta 99% cuando las trampas fueron instaladas a la par de los árboles sembrados en mantillo en comparación con los árboles en suelos desnudos. Los picudos adultos no aparentan emigrar debajo de la tela para emerger por los bordes porque el numero promedio de los picudos capturados en los bordes de la tela (2.75 ± 1.01) no fue diferente ($P > 0.05$) que el numero capturado en la misma posición en los árboles no sembrados en mantillo (4.38 ± 1.95). Se necesita trabajo adicional para mostrar el efecto de los mantillos hechos de tela sobre la densidad de la población de picudo. Sin embargo, se mostró que el uso de los mantillos de tela aumento consistemente el crecimiento de árboles en huertos infestados con picudo. Los mantillos de tela también eliminaron la necesidad para usar herbicidas e insecticidas u otras tácticas de MIP para el manejo de los picudos de las raíces como plaga.

The tropical root weevil, *Diaprepes abbreviatus* (L.), is a serious pest of citrus found throughout the Caribbean Basin and in all citrus producing regions of Florida. There are no current estimates of the economic importance of the weevil, but a decade ago it was thought to cause losses of $75-100 million to citrus industries in Florida and the Caribbean (McCoy 1999). Despite being present in the state since at least 1964, the aboveground stages of the insect have not come under significant natural control in citrus groves (Peña et al. 2006). However, predation of subterranean larval stages by endemic entomopathogenic nematodes may regulate *D. abbreviatus* populations on the deep sandy soils of the Central Ridge (Duncan et al. 2003, 2007; Futch et al. 2005).

At latitudes below 29°N in Florida, *D. abbreviatus* oviposits and develops through its life cycle during all but the coldest months (Duncan et al. 2007; Lapointe et al. 2007). Adult weevils lay eggs on foliage and neonate larvae fall to the soil where they develop for several months while feeding on progressively larger roots. Root feeding can facilitate infection by *Phytophthora nicotiana* or *P. palmivora* and the resulting pest-disease complex can kill trees (Graham et al. 2003). The weevil pupates in the rhizosphere and teneral adults emerge from soil to initiate egg-laying during most of the year. Management tactics currently available to growers (insecticides applied to foliage and entomopathogenic nematodes applied to soil) have short persistence and are only modestly successful due to the continual recruitment of neonate larvae into the soil and teneral adults into the canopy (McCoy et al. 2004). Because registration of pesticides with long residual activity is unlikely, improved management of *D. abbreviatus* will probably require advances in host plant resistance, or biological or cultural control tactics.

Physical barriers that prevent weevils from entering and/or exiting soil would break the weevil life cycle. Barriers in the form of mulches could reduce irrigation frequency and reliance on herbicides and insecticides. McKenzie et al. (2001) tested several types of landscape fabric as barriers to soil entry by neonate *D. abbreviatus*. The 2 most successful fabrics reduced soil entry by larvae between 95% and 100% during 48 h in laboratory trials. In this paper we report results of field experiments using one or both of these fabrics as mulches beneath citrus trees at different locations in Florida.

Materials and Methods

East Coast Flatwoods Site

Altogether, 270 budded citrus trees (*Citrus sinensis* 'Midsweet' on *C. volkameriana* 'Volkamer lemon') were planted in Feb 2001, at the University of Florida's Indian River Research and Education Center at Fort Pierce, FL. Budded trees (approximately 30 cm tall) were planted at 1.5 m intervals within single-bed rows, approximately triple the recommended density for commercial groves. The grove was located on a poorly drained hydric (Winder) soil, subject to seasonal flooding for short periods of time. All trees were fertilized monthly with 113 g/tree during 2001 and 150 g/tree during 2002 of 10-10-10 with minor nutrients. During 2003, trees received 680 g/tree of 6-6-6 NPK. Trees were watered by microjet irrigation as needed. A randomized block design with 3 replicates of 3 treatments was used. Replicates consisted of 30 trees in single rows. Treatments included a no-mulch control, and 2 mulch treatments consisting of Dalen Weed-X® commercial landscaping fabric (spun polyester/polyolefin bilayer, Dalen Products Inc., Knoxville, TN), and Lumite 994GC, a woven polyester landscaping fabric (Synthetic Industries, Gainesville, GA). For each of the 2 landscaping fabric treatments, 2 sheets of fabric (0.91 meters wide) were laid, one on each side of a row to be planted with trees and overlapped by 0.3 meters thereby covering a width of 1.5 m. Holes were cut in the fabrics to plant the trees and a circular piece of the respective fabric, cut from the periphery to the center point, was placed around the base of each tree to provide coverage of the soil where the fabric had been cut to plant the tree.

To determine the number of root weevil larvae (*D. abbreviatus* and *P. litus*) infesting roots and to assess root damage, every third tree (a total of 10 trees per replicate) was destructively sampled in Jan, 2002, 2003, and in Dec 2003. Sampled trees were manually uprooted with shovels. The stem was severed to separate scion from rootstock and the 2 portions were weighed separately. Roots and their associated soil were separated by hand. The roots, soil, and the soil remaining within the root zone (defined as a cylinder of soil with diameter equal to the diameter of the tree canopy and an average depth of 30 cm) were examined for the presence of root weevil larvae (*D. abbreviatus* and *P. litus*) for a minimum of 3 min by 2 field workers. Larvae were collected in vials and returned to the laboratory where they were weighed within 4 h of excavation.

Central Ridge and Central Flatwoods Sites

Lumite 994GC fabric mulch treatments were also evaluated in experiments at 2 sites in Central Florida. The Central Ridge site is at the UF-IFAS Citrus Research and Education Center at Lake Alfred. *Diaprepes abbreviatus* was detected at the site in 1990, but population densities have not grown to seriously damaging levels. *Artipus floridanus*, a weevil with a life history similar to *D. abbreviatus,* although less damaging to citrus, is also endemic at the site. Soil type is a deep, well-drained entisol (Astatula sand) typical of the Central Ridge. At the Central Flatwoods site near Poinciana, the soil is a poorly drained, loamy mollisol. The site has a long history of *D. abbreviatus* at population densities high enough to preclude profitable citrus production (McCoy et al. 2004).

The experimental design was a paired comparison of bare and mulched soil surfaces with 10 pairs of plots at the Central Ridge site and 8 pairs at the Central Flatwoods site. At the Central Ridge site, a single row of newly planted seedlings was used for the experiment. Each plant was genetically distinct and from a single family of hybrids of USDA 17-47 (*Citrus grandis* × *Poncirus trifoliata*) and Kinkoji (*C. obovoidea*) planted in Aug 2002 at a spacing of 1.3 × 6.4 m. Plots consisted of 5 adjacent seedlings and there were no border trees between plots. The first 5 pairs of treatments were on level soil and the remaining 5 pairs were on a fairly steep easterly downward slope. In Sep 2002, the soil surface of half of the plots was covered with Lumite fabric. Trenches 20 cm deep were dug the length of the plot (11.5 m) at a distance of 1.52 m from each side of the trees. One edge of a panel of the fabric was buried in the trench. A slit was cut in the fabric at each tree trunk to allow the panel to be stretched tightly across the soil to a distance of 15 cm beyond the midline of the plot where it was secured with metal pins. The same operation was performed on the opposite side of the plot, resulting in mulch panels 3.04 × 6.5 m with 0.3 m mulch overlap at the midline of the plot. The plots at the Central Flatwoods site consisted of pairs of adjacent mature, 20-year-old Hamlin orange trees (*C. sinensis*) on Swingle citrumelo roostocks (*Poncirus trifoliata* × *C. paradisi*) spaced at 4.6 × 8.2 m, with 2 rows on 18.2 m-wide beds. In Feb 2007, fabric mulch treatments were established as at the Central Ridge site, except that all edges were secured with metal pins. The mulch dimensions at this site were 3.3 × 9.2 m, centered on the 2 trees.

Tree trunk diameters at 30 cm above soil level were measured immediately after treatments were established and periodically, thereafter, for 60 months at the Central Ridge site. Conical wire mesh traps (Duncan et al. 2001) were installed beneath each tree (200 cages) in Apr 2006 and monitored weekly for teneral adult weevils that emerged from bare soil or mulched soil. The area at the base of traps was 0.65 m^2. When treatments were initiated at the Central Flatwoods site, 2 conical traps were established in-row on either side of each tree in a plot (4 traps per plot) and monitored weekly for four months for emergent adult weevils. On 7 Jul 2008, four conical traps were installed equidistiant from one another along the edge of each side of the landscape cloth (8 traps per plot) with half of the trap base area on the fabric and the remainder on bare soil. Traps were also installed at the same distance from the row center in control plots. These traps were monitored for 3 months to help establish whether teneral adults migrated beneath the cloth to emerge at the edges.

Ant foraging activity on mulched and bare plots was assessed at the Central Ridge site with a hamburger bait assay. Raw hamburger was placed on filter paper in open plastic dishes (4 mm high × 48 mm dia., Millipore petrislide containers, Millipore Corporation, Bedford, MA). The outside and inside vertical surfaces of the dishes were roughened with sand paper to facilitate the entrance and exit of the ants (Stuart et al. 2003). A single dish was placed next to the trunk of each tree (n = 100) between 1400 h and 1500 h on 13 May 2004. Each dish was left open for 30 min, and was then covered with a plastic lid, which trapped all the ants currently at the bait inside the dish. The dishes were then returned to the lab and placed in a freezer for 48 h, and all the ants were counted and identified.

Data were analyzed by analysis of variance. To normalize counts and equalize variances before analysis, insect counts (number of adults per tree and number of egg masses per tree) were transformed by natural log (x + 1). Means were compared by Fisher's protected least significant difference (LSD) or Tukey's honestly significant difference test after a significant F-test at $\alpha = 0.05$ (StatView version 5.0, SAS Institute, Cary, NC, USA). Although tests of significance were based on transformed data, only untransformed data are presented. At the Central Ridge site, the differences in the 10 pairs of trunk area measurements were compared using a t-test of the null hypothesis that the mean difference is 0.0 (Minitab version 13.1, Minitab Inc., State College, PA, USA).

RESULTS

East Coast Flatwoods Site

The effect of treatment on tree growth was significant. At the end of the third year, the rootstock portion of trees with the Lumite and the Weed-X fabrics weighed 1.7 and 1.2 times, respectively, the weight of the rootstock portion of the control treatment (P = 0.10; Fig. 1A). Similarly, the scion portion of trees with the Lumite and the Weed-X fabrics weighed 2.4 and 1.4 times, respectively, the weight of the scion portion of the control treatment (P = 0.02; Fig. 1B)

No differences were observed throughout the 3-year study in the number of adult weevils on trees in the 3 treatments (ANOVA, α = 0.05). Lar-

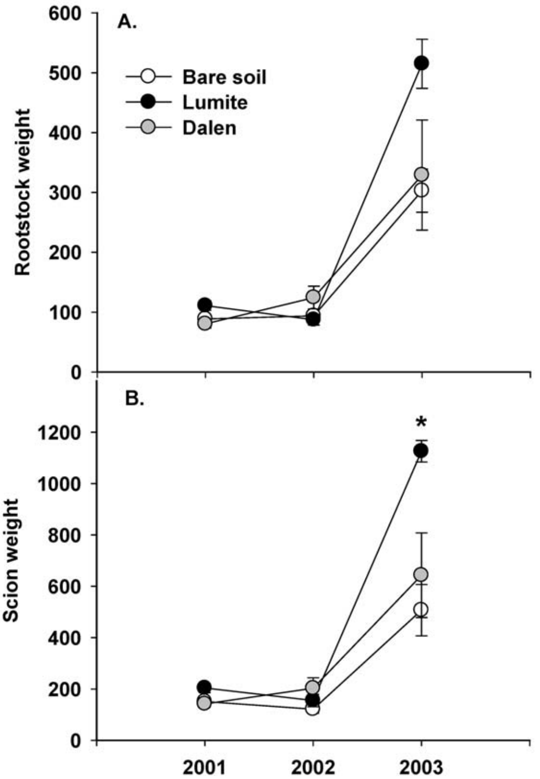

Fig. 1. The effects of Lumite 994GC, and Dalen Weed-X landscape fabrics on the growth of citrus tree rootstocks (A) and scions (B) during 3 yr at a infested by *Diaprepes abbreviatus* on Florida's east coast. Significant differences in means as determined by Tukey's Honestly Significant Difference Test are denoted by * ($P \leq 0.05$).

vae were difficult to recover from the Winder soil due to compaction and texture typical of this formation. On average, fewer than 1 larva was recovered per tree despite considerable scarring of roots. The mean number of larvae recovered per tree at the end of the third year did not differ between treatments (ANOVA, $\alpha = 0.05$) although there was a trend towards fewer larvae in the Lumite product (0.33 ± 0.11 larvae/tree) compared with the Weed-X (0.90 ± 0.55) and the control (0.61 ± 0.40).

The Lumite fabric remained largely intact through the 3 growing seasons at the flatwoods site. The Weed-X fabric became more susceptible to tears over time and many perforations of varying sizes were observed at the end of the 3-year trial. Most notably, these included shotgun-like patterns of holes produced by the red imported fire ant *Solenopsis invicta* Buren that constructed mounds below, through, and above the Weed-X fabric. We also observed in the Weed-X fabric, but not the Lumite fabric, what may have been exit holes produced by emerging adult *D. abbreviatus*, but we could not confirm the origin of the holes.

Central Ridge and Central Flatwoods Sites

Trees in mulched plots on the Central Ridge were larger ($P \leq 0.05$) than those in bare soil within 8 months of imposing the treatments (Fig. 2A). After 5 years of growth, the mean cross sectional trunk area of trees growing in mulched soil was 31% greater ($P < 0.02$) than that of trees growing in bare soil. There was a location effect on trunk size. Differences were small in the 5 treatment pairs at higher elevation, but increased with decreasing elevation in the remaining treatment pairs (data not shown). Average trunk size was not affected by elevation for trees in mulched plots, but trunk size of trees in bare plots was directly related to elevation.

Significantly fewer *D. abbreviatus* and *A. floridanus* weevils were recovered from ground traps adjacent to young trees growing in mulched soil compared to trees growing in bare soil (Fig. 2, inset). During 17 months, 219 adult *A. floridanus* were trapped at the experimental site, compared to just 12 adult *D. abbreviatus*. In contrast, 258 adult *D. abbreviatus* were trapped beneath the tree canopies during 4 months at the Central Flatwoods site. The mean (± SEM) number of weevils trapped per plot in bare soil (32.1 ± 12.4) was greater ($P < 0.001$) than that from mulched plots (0.125 ± 0.125; i.e., just 1 weevil). The average number of weevils trapped at the edges of the mulched

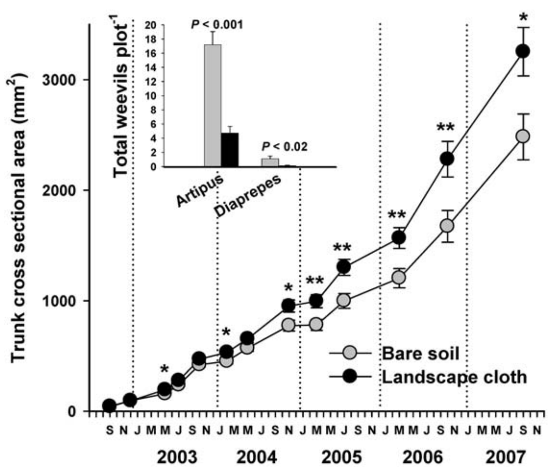

Fig. 2. Effects of Lumite 994GC landscape fabric mulch on the trunk diameter of citrus seedlings at Central Ridge site during 5 yr and on the numbers of adult *Artipus floridanus* and *Diaprepes abbreviatus* weevils captured in ground traps during 18 months (inset). Significant differences in means as determined by *t*-test for paired comparisons are denoted by * ($P \leq 0.05$) or ** ($P \leq 0.01$).

plots (2.75 ± 1.01) did not differ ($P > 0.05$) from that in bare plots (4.38 ± 1.95). In both treatments, the numbers of weevils recovered on the tops of beds (3.06 ± 1.05) were six-fold more numerous ($P = 0.02$) than on the lower, water furrow sides of the beds (0.5 ± 0.18).

The ant baiting assay captured 3,739 worker ants (0 to 281 per dish), which included 3,734 *S. invicta*, 4 *Dorymyrmex bureni* (Trager), and 1 *Brachymyrmex obscurior* Forel. Fabric mulch impaired foraging by ants. An average of 67 ± 9 *S. invicta* were recovered from stations on bare soil, compared to just 5 ± 2 ($P < 0.001$) on fabric mulch.

Discussion

Mulching soil with landscape fabric caused citrus trees to grow larger at sites infested by *D. abbreviatus* on Florida's east coast and interior Central Ridge. Although, we were unable to demonstrate reduced larval prevalence or feeding damage to roots of mulched trees at the east coast site, fewer adult weevils emerged from mulched trees versus those on bare soil at the Central Ridge site and at a Central Flatwoods site, which indicates that reduced weevil activity on the roots of mulched trees could have contributed to these results. Alternatively, tree growth rates might have responded positively to elevated soil temperature and/or moisture in mulched plots, particularly in the cooler and drier winter-spring months, and the healthier trees might have been better able to tolerate root herbivory by weevil larvae. Fabric mulches have been reported to increase growth and/or yield of orchard crops such as nectarine (Szewczuk & Gudarowska 2006), cherry (Yin et al. 2007), apple (Merwin et al. 1995; Nielsen et al. 2003) and acid lime and mandarin (Shirgure, et al. 2003, 2005).

The reduced emergence of adult *D. abbreviatus* at the Central Ridge and Central Flatwoods sites could have occurred because fewer neonate larvae entered the soil and developed to adults under mulched trees and/or if adult weevils are unable to chew through the fabric. During 5 years at the Central Ridge site we found just 1 hole in the Lumite fabric that was likely caused by an emerging adult weevil, either *D. abbreviatus* or *A. floridanus*. No evidence was detected of adult emergence from Lumite fabric at the east coast site. We cannot discount the possibility that adults move laterally beneath the fabric until reaching an edge. However, lateral migration of adults beneath large areas of fabric to the edges should cause larger numbers to be trapped from mulched compared to unmulched plots (in which adults would trapped only if emerging from the small areas of soil directly beneath a trap) and this did not occur. Recovery of adults at fabric edges is unsurprising because *D. abbreviatus* oviposit on many of the weed species in row middles and some neonate larvae that fall from the tree canopy must succeed in migrating to the edge. Indeed, the relatively narrow width of the mulch at the east coast site may have allowed neonate larvae to enter soil by falling near or crawling to the fabric edge. We observed neonate larval behavior on the fabric mulch at the Central Ridge site in May. Larvae that were placed on the fabric in full sun at 1:00 PM ceased moving in less than 1 min. However, when placed on the fabric at 8:00 AM, larvae continued to migrate randomly on the fabric for a 30-min observation period. Because *D. abbreviatus* larvae eclose and fall from the canopy throughout the 24-h d (Stuart et al. 2003), those falling during the cooler hours of evening through early morning have a better chance of entering soil by encountering openings of adequate size on older fabric or by reaching the fabric edge. Our limited study of ant behavior on fabric mulch was conducted during mid-day. It would be interesting to see if the behavior differs during the cooler hours.

Diaprepes population pressure was fundamentally different at the Central Ridge site compared to the 2 flatwoods sites. Individual ground traps in bare plots at the Central Flatwoods site caught adult weevils at a rate more than 300-fold that of comparable traps at the Central Ridge site. Similarly high adult capture rates have been reported for the east coast flatwoods site (Bullock et al. 1999). Visible symptoms of damage to citrus trees at the three sites corresponded to the large differences in *D. abbreviatus* population levels, with much less damage apparent at the Central Ridge site. Regional variation in predation of weevils by endemic entomopathogenic nematodes has been proposed as one factor that modulates regional variability in *D. abbreviatus* population size (Duncan et al. 2003). Despite having fewer weevils and less evident tree decline at the Central Ridge site, a surprising amount of feeding damage to roots in the crown area and beyond occurred commonly on trees growing adjacent to the experiment that were removed to initiate new research. Thus, if the fabric mulch reduced recruitment of neonates into soil, lower root herbivory may have contributed to the increased growth of trees in the mulched plots.

Research is ongoing at the Central Flatwoods site to determine whether fabric mulches of sufficient width (≥1.5 m on each side of the trunk) can reduce weevil damage to the root system. However, even if confirmed, the high initial cost is a potential detriment to implementing fabric mulch as a control tactic. The cost of the Lumite fabric to mulch trees at the rate of 284 trees ha^{-1} is \$2,262.00. At the Central Ridge site, the physical integrity of the mulch remained excellent for 4 years, but signs of deterioration became evident mid-way through the 5th year. Annual herbicide savings in mulched orchards would be approximately \$370.00 ha^{-1} and would equal the fabric cost only after 6 years. Nevertheless, additional savings in pesticide and irrigation costs combined with faster tree growth and higher fruit yields could make the use of mulch a profitable management tactic.

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