INFLUENCE OF ORCHARD WEED MANAGEMENT PRACTICES ON SOIL DWELLING STAGES OF PLUM CURCULIO, *CONOTRACHELUS NENUPHAR* (COLEOPTERA: CURCULIONIDAE)

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Abstract

Plum curculio, *Conotrachelus nenuphar* Herbst (Coleoptera: Curculionidae), is a key pest of peaches in the southeastern United States. Part of its life cycle, specifically, the pre-pupal, pupal and pre-adult stages are spent in the soil. Experiments were conducted in 2 peach orchards to evaluate the effects of some common orchard weed management practices on the development of the soil dwelling life stages of plum curculio. Four common orchard weed management practices (treatments) were evaluated in plots (3 m × 3 m) located under peach tree canopies: centipede grass, *Eremochloa ophiuroides* (Munro) understory (soil covered with centipede grass); weed free understory (bare soil, weeds removed with herbicide sprays); weedy (natural weeds) understory; and pine bark understory (soil covered with pine bark). Fewer numbers of adult plum curculio emerged from the centipede grass understory plots compared with weed free, weedy or pine bark treated understories. Similar results were obtained in the greenhouse: fewer adults emerged from centipede grass than bare soil in spring 2009. Possible reasons for the lower emergence of plum curculio in centipede grass plots are proposed.

Key Words: centipede grass, orchard understory, pine bark

Resumen

El picudo de la ciruela, *Conotrachelus nenuphar* Herbst (Coleoptera: Curculionidae), es una plaga clave del durazno (= melocotón) en el sureste de los Estados Unidos. Parte de su ciclo de vida, especificamente, las etapas de pre-pupa, pupa y pre-adulto se desarrolla en el suelo. Se realizaron experimentos en dos huertos de durazno para evaluar los efectos de algunas prácticas comunes de manejo de malezas sobre el desarrollo de las etapas de la vida del picudo de la ciruela que se encuentran en el suelo. Cuatro prácticas comunes de manejo de malezas (tratamientos) en huertas fueron evaluados en parcelas (3 m × 3 m), ubicado bajo las copas de los árboles de durazno: el sotobosque (suelo cubierto del pasto cienpiés, *Eremochloa ophiuroides* (Munro)); el sotobosque libre de malezas (suelo desnudo, las malezas eliminadas con aplicaciones de herbicidas); el sotobosque con malezas (naturales) y el sotobosque de corteza de pino (suelo cubierto con corteza de pino). Un menor número de adultos del picudo de la ciruela emergieron de las parcelas del sotobosque cubierto de pasto ciempiés en comparación con los sotobosques de tratamientos sin malezas, con malezas naturales o de corteza de pino. Resultados similares fueron obtenidos también en el invernadero: un menor número de adultos emergieron del pasto ciempiés que el suelo desnudo en la primavera del 2009. Se proponen las posibles razones para la menor emergencia del picudo de la ciruela en las parcelas del pasto ciempiés.

Palabras Clave: pasto ciempiés, césped ciempiés, huerto sotobosque, picudo de la ciruela, corteza de pino

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Weed management practices of most peach growers in the southeastern U.S. are diverse (Horton & Ellis 1989; Horton & Johnson 2005). The majority of peach growers maintain grasses or sod between the rows and herbicide strips around the trees as the main weed management practice (Mitchem & Parker 2005; Mitchem 2005), while some allow their orchards to become weedy with very minimal weed management, particularly during the off-season. Some fruit growers also use mulching as another way of managing weeds in their orchards (Niggli et al. 1990). Also pine bark is used in orchards as mulch to conserve soil moisture, increase soil organic matter, prevent erosion, and provide plant nutrient sources in peach and apple orchards (Foshee et al. 1999). Other mulch types such as straw, hay, sawdust, chipped pruning have been used for similar purposes (Roper 2004). In other orchards, growers maintain bare soil surfaces by spraying a recommended herbicide or use shallow cultivation because of concerns about competition from weeds (Elmore et al. 1997; Roper 2004). Bare soils absorb more heat during the day and therefore reduce crop losses associated with spring frosts experienced in many parts of the region (Roper 2004; Horton & Johnson 2005).There is currently no consensus on the best weed management practice to be used by southern tree fruit growers. Any practice must balance the growth of the tree and fruit yield, maintain good soil structure, reduce erosion, and not compete with the trees for water and nutrients, nor harbor insect pests (Roper 2004).

In most cases, the selection of the type of management practice by growers is based mainly on weed management, control of erosion and soil moisture improvement with very little consideration given to insect pest management (Brown & Tworkoski 2004; Gannon et al. 2006; Mathews et al. 2004). Some studies have shown, however, that the type of weed management practice adopted in any orchard understory could impact both the above and below-ground arthropod communities (Altieri & Whitcomb 1980; Brown & Gange 1990; Andow 1991; Mathews et al. 2004; Norris & Kogan 2000, 2005). For example, planting cover crops has been reported to affect pest dispersal, colonization, and reproduction of some insects (Risch et al. 1983).

Plum curculio is currently a serious pest of peaches in Alabama and much of the southeastern U.S. (Horton & Ellis 1989; Johnson et al. 2002; Akotsen-Mensah 2010; Akotsen-Mensah et al. 2011). Two strains, the northern and southern strains, occur in continental North America, east of the Rocky Mountains with few isolated populations in Box Elder County, Utah (Alston & Stark 2000). The northern strain extends from New Jersey (McClanan 2002) and into Canada (N 50°), while the southern strain ranges from the southern New Jersey to Florida (McClanan 2002; Zhang 2007). In Alabama, the southern strain has 2 or more generations per year (Akotsen-Mensah 2010). The northern strain, on the other hand, is univoltine (Chapman 1938; McClanan 2002; Zhang 2007).

Several stages of its life cycle, specifically, the pre-pupal, pupal and pre-adult (or teneral) stages are spent in the soil. The adults, after emerging in spring from their overwintering sites, mate and migrate to find feeding and oviposition sites within nearby orchards. The female lays its eggs in developing fruit. The eggs hatch and the larvae eat their way into the developing fruit. Some infested fruits prematurely abort either before or during the time the fully grown fourth instar larva is about to pupate. The larvae exit fruits on the tree and aborted fruits on the ground, and enter the soil to pupate. The larvae spend varying amounts of time in the pre-pupal stage before final pupation. The time spent in the soil before adult emergence depends greatly on soil conditions. Given these variables, we hypothesized that the type of weed management practices used by peach growers would impact the development of the soil dwelling immature stages of plum curculio and ultimately adult emergence from the soil.

The objective of this study was to evaluate the effects of some commonly used weed management practices on the development of the pre-pupae and pupae of plum curculio in the soil. Data were also collected on the abundance of other arthropods such as ground beetles (Carabidae), tiger beetles (Cicindelidae), ants (Formicidae) and spiders as these arthropods have been reported to prey on soil dwelling stages of plum curculio (Mampe & Neunzig 1967; Jenkins et al. 2006).Ultimately, we hope to identify and recommend to commercial peach growers weed management practices which will be unfavorable to the development of the plum curculio while having minimal impact on tree growth and fruit yield.

Materials and Methods

Rearing of Insects

The colony of plum curculio larvae used for the greenhouse study was maintained on pesticide-free green thinning apples in a growth chamber at 25 ± 1 °C, 65-70% RH, and 12:12h L:D. The adult weevils used to establish the laboratory colony had been collected from peach orchards in central Alabama and reared for more than 10 generations before the tests. The colony was periodically supplemented with weevils collected from the same field locations in Alabama. The rearing procedures followed those of Smith (1957) and Amis & Snow (1985).

Field Study

The study was conducted at the Chilton Research and Extension Centre (CREC), Clanton, Alabama during the 2007-2009 peach growing seasons. The 2007 study was done in an unmanaged peach orchard that had not received any insecticide or fungicide application since its establishment in 1985, and high plum curculio populations had historically been recorded in the orchard. Three trees along the same row were randomly selected and 4 small plots (3 m × 3 m) were established on each side of the canopy of the selected trees. The following treatment plots were established: (1) centipede grass (*Eremochloa ophiuroides* (Munro) Hack; Poales: Poaceae) understory (soil covered with centipede grass); (2)

weed free understory (bare soil, weeds removed with herbicide sprays); (3) weedy (natural weeds) understory; and (4) pine bark understory (soil covered with pine bark). No single weed species dominated the weedy understory treatments. Some common broadleaf weeds found under the tree canopy and generally in the orchard were dandelion (*Taraxacum officinale* F. H. Wigg; Asterales: Asteraceae), blessed thistle (*Cnicus benedictus* L.; Asterales: Asteraceae), henbit (*Lamium amplexicaule* L. Asterales: Asteraceae), and wild blackberry *Rubus spp.*, Rosales: Rosaceae) and some grasses like bahiagrass (*Paspalum notatum* Flüggé; Poales: Poaceae), Bermudagrass (*Cynodon dactylon* L. Pers.; Poales: Poaceae), and crabgrass *Digitaria* spp.; Poales: Poaceae). Treatments 1 and 3 were established 3-4 wk before larvae were ready to be introduced. Twenty fourth-instar larvae collected from aborted peach fruits were placed in the soil in each plot, after which a large wire cone emergence trap (base diam 50.8 cm and height 61 cm) (Mulder et al. 1997) was set over the introduced larvae to monitor adult emergence. Because the plum curculio's behavior in the field involves frequent drops from the trees to the ground as a result of any disturbance, we sought to eliminate any adults which were present in the treatments before the installation of the emergence traps. All adults appearing in the cone emergence traps within 7 d of trap placement were considered already present and thus not used in the analyses. The traps were then observed for 21 d after emergence of the first plum curculio adult. The number of adults that emerged into each cone trap was counted and recorded.

Pitfall traps were deployed in the treatment plots, outside the cone traps as an additional sampling method to determine the presence and abundance of other ground-dwelling arthropods in the unmanaged orchard. Although several arthropods were found in the pitfall traps, the following were recorded based on previous reports on their importance in orchards: ground beetles (Carabidae), tiger beetles (Cicindelidae), ants (Formicidae), and spiders (all species).

Similar methods were used in 2008 and 2009, except that the study was replicated in both yr in a commercial orchard (located ~1.5 km from the unmanaged peach orchard at CREC) planted to 'Loring' peach variety with no insecticides applied. Because very few fourth instar larvae were collected from aborted fruits in 2008 and 2009, the number of larvae placed in each cone trap was reduced to 10 instead of 20.

In all years, plot maintenance was done by using a hand held mower to cut overgrown weeds in the weedy and centipede grass orchards to a height of ~10 cm. Hand-picking was also used to remove undesirable plants from the centipede grass and pine bark treated plots when necessary.

Greenhouse Study

To determine whether the various performances of the different weed management practices were due to the variable conditions inherent infield studies, the treatments were evaluated under greenhouse conditions [25 ± 2 °C, 50 ± 10% RH, and 12:12 h L: D] during summer and spring 2009. Before the main experiment in 2009, a series of experiments (preliminary tests) were first carried out to determine the ideal soil conditions required to produce optimum growth of centipede grass and natural weeds and to establish those without live plants (pine bark and weed free).

In spring 2009, the following treatments were established in 100 × 40 × 40 cm plastic Rubbermaid® containers: (1) centipedegrass; (2) weed free (weeds removed with atrazine at 1.5 quarts per ac [3.5L per ha); (3) weedy (weeds picked at random from unmanaged peach orchard); and (4) pine bark . Centipede grasses used for the experiments were obtained as sod grass from Beck's Turf, Tuskegee, Alabama. The weed free and weedy orchard treatments were established from the same unmanaged peach orchard used for the field study. Care was taken to remove all soil remnants on the roots of the weeds before they were planted. The weeds were planted densely enough to be representative of natural orchard weed growth. Two weedy orchard treatments were established. One of these treatments was used for the weed free treatments by spraying Atrazine at ¾th of the recommended field rate. The pine bark was obtained from Home Depot Stores, Opelika, Alabama. All treatments were established on autoclaved field soil in order to eliminate the effects of predators of plum curculio such as ground and tiger beetles, ants and spiders (Jenkins et al. 2006). A depth of ~15 cm was chosen for the autoclaved field soil on which the treatments were established. This ensured that both the larvae and plant roots had adequate soil for development.

After the treatments involving live plants were well established in containers,4 polyvinyl chloride (PVC) pipes of 12 cm diam. were cut to a height of ~25 cm and inserted into each of the containers. Twenty newly emerged, laboratory-reared fourth-instar larvae of plum curculio (~15-18 mg each), were introduced into each PVC pipe (plot). Four replicates (i.e., 4 PVC pipes) were established in each treatment container. A boll weevil trap top was used to cover the top of each PVC pipe to ensure that emerging adults did not escape. Adults that emerged into the boll weevil trap top (Great Lakes IPM, Inc., Vestaburg, Michigan) were collected and recorded daily until no adult appeared in the trap top for a period of 14 d. This procedure was repeated in the summer 2009 experiment except that 10 instead of 20 fourth-instar larvae were used. Also, the number of replicates was increased to 8 in the summer.

Statistical Analysis

Adult emergence from the field experiments were converted to percentage emergence and tested for the linearity, normality and variance equality. Percentage data that did not meet these assumptions were arcsine transformed $\sqrt{(x + 0.1)}$ to stabilize heteroscedastic variances and ensure normality. The data were then analyzed using a one-way ANOVA for each year and multiple comparisons of the means were done using the Tukey-Kramer honestly significant difference (HSD) test ($P < 0.05$; JMP version 7.0, SAS Inc. Cary, North Carolina, 2007). Count data involving other arthropods were treated likewise after data transformation by using $\sqrt{(x + 0.5)}$. Due to generally low densities in the plots, the numbers of ground and tiger beetles, ants and spiders collected using pitfall traps were pooled across sampling dates (i.e., total arthropods) and analyzed with one-way ANOVA. The data from the greenhouse experiments were similarly analyzed using a one-way ANOVA. In all cases, transformed data was used for multiple comparisons made among treatments using the Tukey-Kramer HSD test ($P < 0.05$; JMP version 7.0, SAS Inc. Cary, North Carolina, 2007). However, actual means are reported.

Results

Field Study

Adult Emergence in Different Weed Management Treatments.

Significant differences were recorded in the emergence of adult plum curculio from the different weed management treatments in the unmanaged peach orchard in 2007 ($F_{3, 21} = 4.03, P = 0.0207$), but not in 2008 ($F_{3, 21} = 0.62, P = 0.6128$) and 2009 ($F_{3, 21} = 1.46, P = 0.2496$). Adult emergence was significantly lower in the centipede grass treated understory compared with the weed free understory in 2007 (Fig. 1A). Location of the plots within the unmanaged orchard was not significant in 2007 ($F_{3, 21} = 1.64, P = 0.2057$), 2008 ($F_{3, 21} = 0.88, P = 0.4668$), or 2009 ($F_{3, 21} = 2.51, P = 0.0815$).

In the 'Loring' orchard, no significant difference was observed among the treatments in 2008 ($F_{3, 18} = 0.70, P = 0.5615$), but the treatment effect was significant in 2009 ($F_{3, 18} = 3.13, P = 0.0514$). In general, fewer adults emerged from the centipede grass treatment than from the remaining treatments (Fig. 1B). The analysis also showed that location of the treatment plots within the 'Loring' orchard did not have any significant effect on the number of plum curculios that emerged from the treatments in 2008 ($F_{2, 18} = 0.88, P = 0.4319$) and 2009 ($F_{2, 18} = 2.37, P = 0.1216$).

Occurrence of Other Arthropods in Treatment Plots.

Although several insects were caught in the pitfall traps; we report those which have previously been shown to be important predators of plum curculio (Jenkins et al. 2006). In the unmanaged peach orchard, no significant differences were recorded among the treatments in the total number of arthropods in 2007 ($F_{3, 9} = 2.48, P = 0.1584$) and 2009 ($F_{3, 9} = 2.33, P = 0.1423$) (Fig. 1A). However, significant differences were recorded among the treatments in 2008 ($F_{3, 9} = 14.86, P = 0.0008$), with significantly fewer number of arthropods recorded in the weed free treatment than in the other treatments (Fig. 2A). In general, the highest number of arthropods was recorded in the weedy orchard treatment, while the lowest number was always recorded in the weed free treatment.

In the 'Loring' orchard, significantly higher numbers of arthropods were recorded in the weedy orchard treatment than in the other treatments in 2008 ($F_{3, 9} = 23.04, P = 0.0001$) (Fig. 2B). However, no significant differences were recorded in 2009 ($F_{3, 9} = 3.00, P = 0.0880$), although fewer arthropods were recorded in the weed free treatment (Fig. 2B).

Greenhouse Study

Emergence of adults was not significantly different among the different weed management treatments in the greenhouse in the spring of 2009 ($F_{3, 12} = 3.19, P = 0.0626$) and the summer of 2009 ($F_{3, 28} = 2.76, P < 0.0607$). However, numerically fewer adults emerged from the centipede grass treatment in spring 2009 (Fig. 3), which was consistent with the field results.

Discussion

This research provides data from 3 yr of field studies combined with 2 greenhouse experiments, which together suggest that plum curculio adult emergence can be influenced by the type of weed management practice adopted in peach orchards. Although not significant in many cases, the centipede grass treatment consistently recorded fewer plum curculio adults in the field suggesting that planting of centipede grass, a warm season grass, in peach orchards, can potentially reduce the development and adult emergence of the southern strain of plum curculio. Follow up experiments in the greenhouse, in which conditions were controlled, showed similar results.

The effects of orchard floor management practices on above and below ground arthropods, have been investigated in many agro-ecosystems (Altieri & Schmidt 1985; Russell 1989; Altieri & Letourneau 1982; Altieri 1992; Prokopy 1994; Hartwig & Ammon 2002; Tworkoski & Glenn 2008), however, very little is known about the response of the plum curculio and similar pests to orchard floor cultural practices.

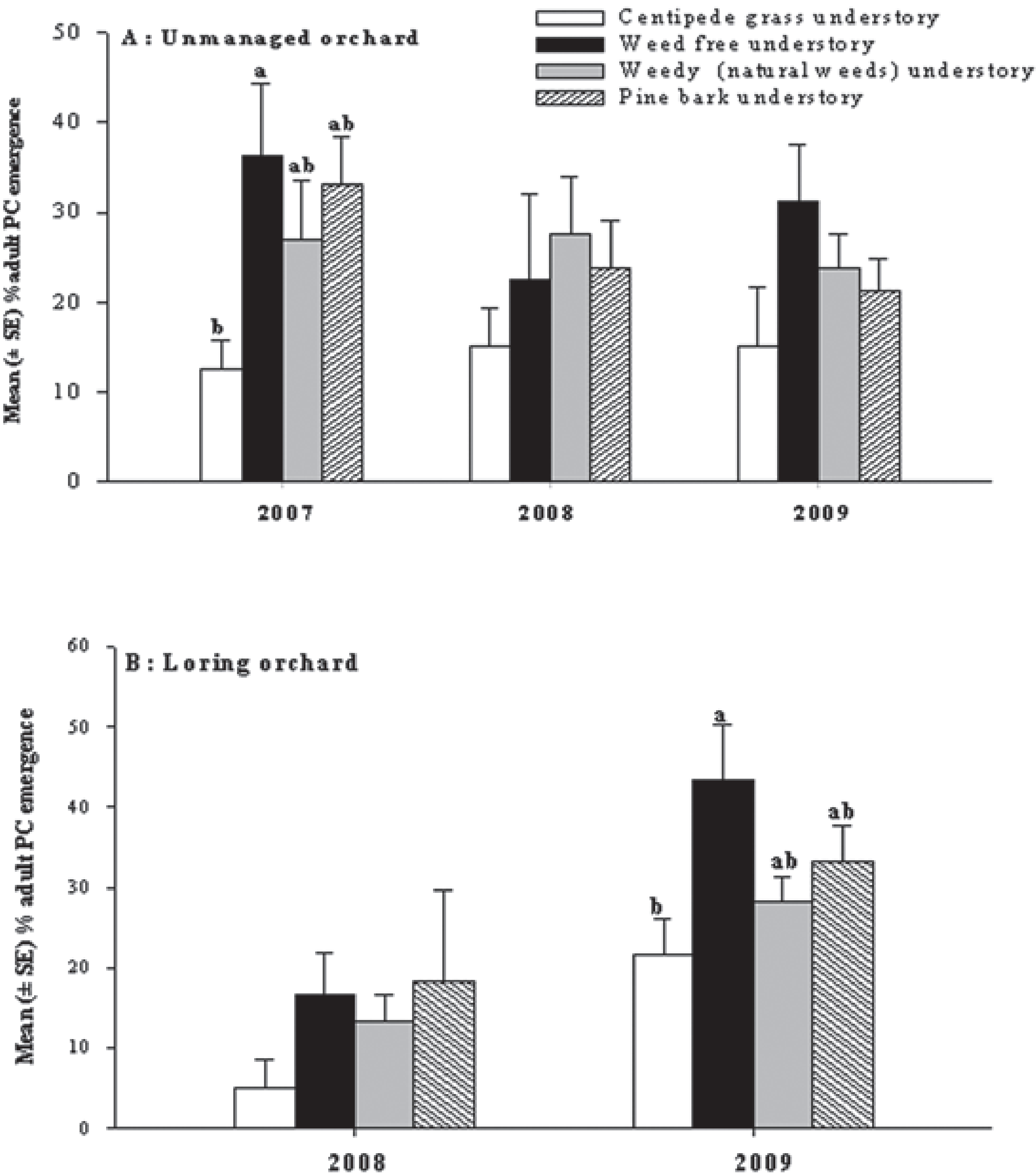

Fig. 1. Mean (± SE) percentage emergence of plum curculio from various weed management treatments in (A) an unmanaged mixed variety peach block and (B) unmanaged Loring peach block in Clanton, Alabama during 2007-2009. Means within each year having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.05$).

The identification of a mechanism mediating reduced emergence of plum curculio in centipede grass was beyond the scope of this study. However, one plausible hypothesis is that the dense rooting system of centipede grass physically obstructed either the initial entry of the larvae into the soil or the emergence of the teneral adults from the soil. Indeed, Bao & Hirata (2006) reported that centipede grass is superior to other species of grasses because it has a high ability to develop tillers and stolons (roots). Wood et al. (2009) also observed that the thicker and more tightly woven rooting system of a hybrid bermudagrass ('Tifway') served as physical barrier to oviposition of the Japanese beetle.

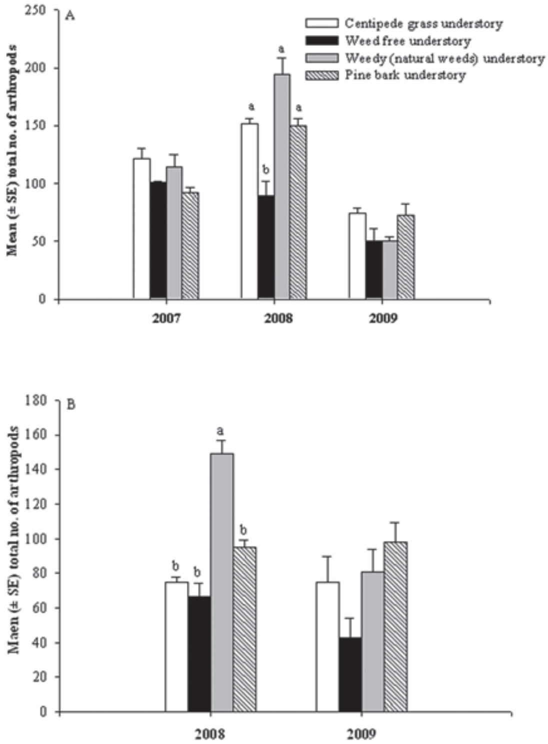

Fig. 2. Mean (± SE) number of total arthropods recorded in (A) an unmanaged and (B) Loring peach orchards at Clanton, AL. during 2007 and 2009 peach seasons. Means within each year having no letter in common are significantly different (ANOVA, Tukey–Kramer HSD, $P < 0.05$).

Our expectation that weed free or bare soil (weed removed with herbicides) treatment, the most common orchard floor practice in the region, would be the most favorable to plum curculio emergence from the soil was supported by our data. Indeed we had expected that weed free orchard understory with the least plant cover for natural enemies would allow the highest survival of plum curculio larvae and pupae. Low survival of immature plum curculio in the soil was possibly due to exposure to inclement and unfavorable conditions such as sunlight, excessive soil moisture, as was the case in the greenhouse study in summer 2009. In fact, a comparison of soil temperatures within weed free versus weedy (normal orchard weeds) treatments under the canopy, and at locations outside the canopy drip line, showed that soil temperatures beneath the canopy were conducive for plum curculio development. Our results therefore suggest that the common practice of maintaining bare soil surfaces under peach trees with the goal of minimizing crop losses associated with spring frosts (Roper 2004; Horton & Johnson 2005), may also favor plum curculio development and adult emergence.

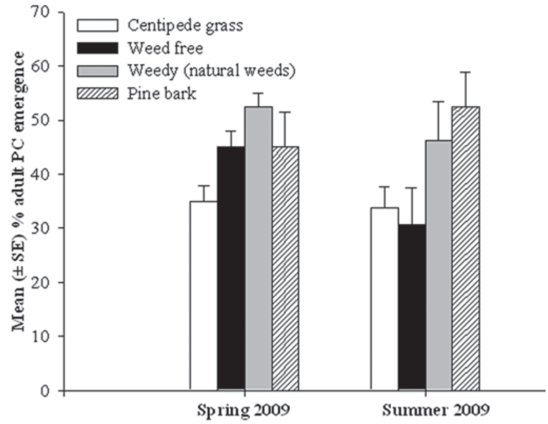

Fig. 3. Mean (± SE) percentage emergence of plum curculio adults in various weed management treatments in the greenhouse. No significant differences were recorded (ANOVA, Tukey–Kramer HSD, $P > 0.05$), however plum curculio emergence was numerically lower in the centipede grass treatment in spring 2009.

The other arthropods were present in the test plots made noteworthy contributions, which were not statistically significant in most cases. If, as expected, these arthropods should have a negative effect on plum curculio survival in the soil, then their numbers should be higher in treatments with reduced emergence of plum curculio and vice versa. This was supported by the data only in a few cases. For example, in the weed free treatments, fewer arthropods and higher emergence of plum curculio were recorded, suggesting some contribution of these arthropods as predators of immature plum curculio (Mampe & Neunzig 1967; Jenkins et al. 2006).

Analysis of historic weather records in the study area also showed that precipitation was very variable (unpublished data) during the time that the plum curculio was in the soil, which suggests a possible effect of environmental factors on plum curculio development and the performance of the treatments. The generally low level of emergence recorded in both the field and greenhouse studies suggests that immature plum curculios in the soil are highly prone to natural mortality factors.

In summary, given that losses of insecticides used to control plum curculio through FQPA (1996) restrictions will continue, and that pest management systems will continue to become less reliant on broad spectrum insecticides, research on cultural pest management practices, such as manipulation of the orchard habitat reported in this study, will become more important. Biologically-based practices such as planting of centipede grass and either the enhancement or the release of predatory natural enemies or entomopathogens could constitute an important component of an integrated pest management program against the plum curculio (Mampe & Neunzig 1967; Jenkins et al. 2006). A better understanding of the mechanisms mediating our results is necessary and worthy of further investigation.

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