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Short Communication

Effect of papaya trunk angle on infestation by white peach scale, *Pseudaulacaspis pentagona* (Hemiptera: Diaspididae)

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ABSTRACT

Two papaya (*Carica papaya* L.) seedlings growing in one planting hole often results in angular or non-vertical growth of the trees. Data on trunk angularity, or leaning, (deviation from the vertical line of reference) and white peach scale, *Pseudaulacaspis pentagona* Targioni-Tozzetti (Hemiptera: Diaspididae), densities on paired papaya trees were collected approximately 1 year after infestation of a papaya field was discovered. Paired trees showed a significantly higher degree of leaning than single trees. White peach scale densities were significantly higher on tree trunks with a greater departure from vertical in paired comparisons. Therefore, paired tree planting practices may facilitate the development of economic infestations of white peach scale populations in papaya orchards.

Introduction

White peach scale, *Pseudaulacaspis pentagona* Targioni-Tozzetti (Hemiptera: Diaspididae) was first recorded in Hawaii in 1997 and since has become a widespread and serious pest on papaya, *Carica papaya* L. (Follett, 2000). Infestation can rapidly increase to levels where large areas of the trunks of papaya trees are completely covered by white peach scale. Overcrowding causes spread up the trunk, and in heavily infested trees scales move up onto fruit, preferring to settle in the calyx and peduncle regions. White peach scale on the fruit is a quarantine problem. Infested fruit shipments may be rejected in California, and Japan, an important market for Hawaii papayas, has zero tolerance for white peach scale. Scales can be removed from infested fruits by brushing, but at considerable cost. With papayas grown for the Japanese market, heavily infested fields may be abandoned. Control with available chemical insecticides is not effective, and currently no effective biological control program is established in Hawaii (Neumann et al., in press).

Female white peach scales deposit all their eggs (≈100–150 total eggs/female) in about a week. Eggs hatch in 3–4 days and the young scales (crawlers) settle on the host plants within two days after hatching (Miller and Davidson, 2005). Crawlers are active up to 24 h and disperse primarily within plants (Hanks and Denno, 1993a), but aerial dispersal among plants does occur and is important in colonization of new hosts (Hanks and Denno, 1993b). Dispersal of white peach scale crawlers in papaya orchards has not been studied, and the factors that may affect the establishment and spread of the white peach scale infestations in papaya orchards are unknown.

When planting papaya trees, farmers in Hawaii plant more than one seed in each hole, following Hawaii papaya growing recommendations (Nishina et al., 2000). This helps ensure that at least one healthy hermaphroditic plant will grow per planting hole. Later, trees should be thinned to one hermaphrodite per planting hole; however, growers frequently leave two seedlings growing from the same hole, apparently because they believe their overall fruit production will be higher if they follow this practice (Maureen Fitch, USDA, Hawaii Agricultural Research Center, personal communication). When two trees are left growing in the same planting hole the trees often grow at an angle, and we observed that leaning trees seemed to be more infested with white peach scale than vertical trees. Here we report observed differences in infestation rates of papaya trees with different trunk angles, and discuss how growing practices may contribute to the leaning of trees and, in turn, higher white peach scale infestation rates.

Materials and methods

Study site

In May 2008, a white peach scale infestation was found in a papaya field approximately 3 years old, already in production, between Kapoho and Kalapana in the lower Puna district, Big Island, Hawaii. The new infestation was limited to the border row which ran in a north–south direction along the eastern edge of the field. The infestation gradually spread westward toward the center of the

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field. Trunk angle and scale density data were collected from the field in June 2009.

Tree leaning

Papaya planting holes were spaced ≈ 1.5 meters apart in the row, and rows were spaced ≈ 3.5 meters apart. The degree of leaning of papaya trunks (i.e. deviation from the vertical reference line) was measured using a plumb-bob on 50 randomly selected single trees and 50 randomly selected paired trees (two trees growing per planting hole). The greatest angle between the plumb line and the trunk at 130 cm height from the ground was measured using a Swanson Speed Square angle measuring tool (Frankfort, IL). In paired trees, the tree with the smaller angle was designated "tree 1" (TR1) and the tree with the greater angle was designated "tree 2" (TR2). Differences in declination from the vertical in single trees versus paired trees designated as TR1 and TR2 were analyzed using 2-sample *t*-tests. Differences in declination between paired TR1 and TR2 trees were analyzed using paired *t*-tests.

Scale densities

The mean number of adult female scale covers per 25-cm^2 area was counted on each tree of 30 paired trees. The pairs were randomly selected from the 50 paired trees for scale density measurements. For each pair, the distance (in number of rows) from the eastern edge of the field was measured. First, scales were counted on the upper and lower surfaces of each tree in the pair. The lower surface was the surface extending half way around the tree circumference on the side of the trunk closer to the ground as a result of leaning. The upper surface was the opposite half of the circumference of the trunk. Scales were counted in three randomly selected 25-cm^2 areas on the upper surface and three randomly selected 25-cm^2 areas on the lower surface by placing a sheet of A4 (210 × 297 mm) paper with a 5 cm × 5 cm rectangle cut out over the trunk on each selected area. Scale counts were done along the tree trunk between 30 cm and 100 cm above the ground. This range was selected because scale densities appeared to be more evenly distributed in this part of the trunks. Differences in scale densities on the upper and lower surfaces within trees, and between TR1 and TR2 trees using the mean scale density of upper and lower surfaces were tested using paired t-tests. A full factorial regression was performed on scale densities to evaluate the effects of 1) distance from eastern edge of the field and 2) the cumulative leaning angle (sum of TR1 and TR2 trees) of the paired trees. All statistical analyses were done using JMP 7.0.1 software (SAS Institute, 2007).

Prevalence of paired trees

For purposes of extrapolating study results to other papaya fields, the percentages of single and paired trees in papaya fields in east Big Island was determined by evaluating 1000 tree planting holes in 10 randomly selected rows (100 tree planting holes/row) at the principal study site and in each of four other papaya orchards within a ≈ 10 km radius.

Results

Tree leaning

The mean (± SE) angle of declination from the vertical was 2.2 ± 0.3° in single trees and 6.6 ± 0.5° and 21.4 ± 0.9° in TR1 and TR2 trees, respectively. Both TR1 and TR2 trees leaned significantly more than single trees (for TR1, $t = 7.49$, $P < 0.0001$, $df = 98$ for TR2, $t = 19.87$, $P < 0.0001$, $df = 98$). For each pair, TR2 trees leaned significantly more than TR1 trees ($t = 13.19$, $P < 0.0001$, $df = 29$).

Scale densities

Total scale density was significantly higher on TR2 trees (48.5 ± 8.2 scales/25-cm^2 area) than on TR1 trees (8.7 ± 2.1 scales/25-cm^2 area) ($t = 5.31$, $P < 0.0001$, $df = 29$). The upper surfaces of TR1 and TR2 trees combined had significantly higher scale densities (51.1 ± 9.0 scales/25-cm^2 area) than the lower surfaces (6.1 ± 1.1 scales/25-cm^2 area) ($t = 5.42$, $P < 0.0001$, $df = 59$) (Table 1).

Effects of distance and leaning angle on scale densities

Distance (measured in rows, with rows spaced ≈ 3.5 m) from the eastern edge of the field had a significant effect on mean scale densities in paired trees ($F = 9.68$, $P = 0.0045$, $df = 1$). Cumulative leaning angle (TR1 leaning angle + TR2 leaning angle) had a significant effect on mean scale densities in tree pairs ($F = 6.89$, $P = 0.0144$, $df = 1$). Distance and cumulative leaning angle had no significant interaction ($F = 1.75$, $P = 0.1977$, $df = 1$) (Fig. 1).

Percentage of paired trees

In the orchard where scale counts were taken, an average of 16.2 ± 2.0% of tree planting holes had paired trees. The mean (± SE) percent of paired trees in the five orchards sampled was 12.1 ± 0.9% (range 5.7% to 16.2%).

Discussion

The data collected during this observational study demonstrated that papaya trees with higher deviations from the vertical reference line (i.e. more leaning) were infested by white peach scale at higher rates than trees that had less deviation from the vertical position (Figs. 1 and 2). Scale densities were also a function of position within the field as papaya trees closer to the eastern edge of the field generally had higher densities than trees further from the field edge. Scale crawler dispersal between orchards and among trees within an orchard can occur via aerial dispersal (reviewed in Gullan and Kosztarab, 1997), which may explain why the distance from the infestation origin affected scale densities with lower infestation rates observed at greater distances from the origin. It must be noted that differences in scale densities at different locations of the field may be the result of other factors such as different predator densities at different locations, this, however, was not investigated. The paired planting of the trees allowed for direct comparison between scale infestations and tree leaning in a paired design at given locations within the field. Trees in each pair were at the same location within the orchard, so differences seen in scale densities between the trees of the pair were not an effect of distance from source but rather the effect of different degrees of leaning.

The reason for higher infestation rates of trees with a higher degree of leaning was not investigated directly during this study. It seems logical, however, that airborne scale crawlers, having no directional control while being carried by wind as inert particles (Moran et al., 1982), would be more likely to be deposited on surfaces

Table 1
Tree leaning (degrees) and scale densities per 25-cm^2 area (mean ± SE).

	Leaning angle	Scale density
Single tree	2.2 ± 0.3	1.82 ± 0.44
Paired tree TR1	6.6 ± 0.5	8.7 ± 2.1
Paired tree TR2	21.4 ± 0.9	48.5 ± 8.2
Paired tree upper surfaces		51.1 ± 9.0
Paired tree lower surfaces		6.1 ± 1.1

See text for significant differences in scale densities as they relate to tree leaning.

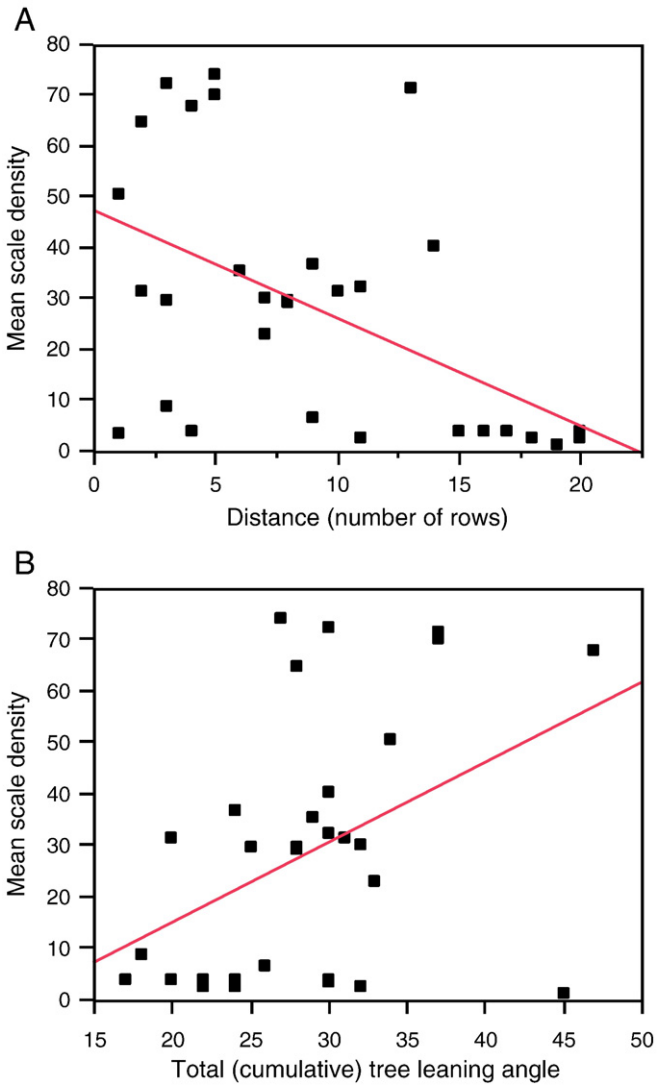

Fig. 1. Scatter plots showing the effects of (A) distance (rows) from eastern edge of field and (B) total (cumulative) tree leaning angle on mean scale densities per 25-cm^2 area on tree pairs. Both effects were significant at $\alpha = 0.05$ with no significant interaction. Regression lines were fitted to demonstrate the relationships between distance and mean scale densities (Mean scale density = 47.66–2.11*Distance, $r^2 = 0.25$) and between leaning angle and mean scale densities (Mean scale density = −15.90 + 1.55*Total angle in pair, $r^2 = 0.18$).

which are less vertical. The findings that the upper surfaces of leaning trees had higher scale densities than the lower surfaces may support this hypothesis but experimental studies are warranted to collect supporting data.

Our data show that tree leaning is enhanced when two papaya plants are allowed to grow in a single planting hole. Papaya growing recommendations in Hawaii aiming for optimal planting densities suggest thinning of plants so that only a single hermaphroditic tree is left in each planting hole (Nishina et al., 2000). The potential advantages to the grower of leaving some proportion of planting holes with two trees are not clear, but one disadvantage may have been revealed during this study: specifically that double planting results in tree leaning and tree leaning results in higher scale infestation rates. Our data show that leaving two trees in the same planting hole is relatively common. This may then accelerate the development of white peach scale infestation and, therefore, this practice should be strongly discouraged by crop advisors. To our knowledge, the association between the occurrence of paired trees and infestation by white peach scale has not been recognized previously.

Fig. 2. A tree pair demonstrating the phenomenon observed in this study. The tree to the right (TR2 tree) deviates from the vertical reference line at a much greater degree than the tree to the left (TR1 tree) and also has a clearly higher scale density.

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