LEAF FEEDING INJURY TO CITRUS BY ROOT WEEVIL ADULTS: LEAF AREA, PHOTOSYNTHESIS, AND WATER USE EFFICIENCY

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ABSTRACT

The purpose of this study was to quantitatively determine citrus leaf consumption by Artiopus floridanus Horn, the little leaf notcher, and the effect of feeding injury on net CO₂ assimilation and water use efficiency. Feeding by either male or female weevils began at the margin of the citrus leaf and progressed inward. Male, female, and mixed adult populations of A. floridanus, when previously fed normally or starved, consumed an amount of leaf tissue over time which was directly proportional to population density. Populations of 1 or 5 weevils per leaf consumed less than 5% of the total leaf area after 72 h whereas 15 weevils consumed up to 40% of the leaf area during the same period. Feeding by female weevils generally reduced leaf area more than that by males. Leaf area consumed per weevil per day did not change with differing population levels. There was no evidence of sexual interference with feeding behavior. None of the leaves exposed to weevil feeding sustained injury to the midvein and, therefore, no abscission was observed.

Net gas exchange was reduced by the amount of leaf area consumed. CO₂ assimilation, transpiration, and water use efficiency were evaluated using the remaining tissue of injured leaves. Net gas exchange rates of leaves injured by previously fed weevils did not change consistently with percentage leaf area consumed. In leaves more severely injured by starved female populations, water loss increased proportionally more than photosynthesis declined, resulting in up to a 20% decrease in water use efficiency. Thus, interactions between feeding injury and drought stress may be especially important.

Resumen

El propósito de este ensayo fue para cuantificar el área de hojas de cítricos consumidas por Artiopus floridanus Horn, y el efecto de este daño en la asimilación neta de CO₂ y la eficiencia del uso del agua. El consumo de las hojas de cítricos por gorgojos machos o hembras, comenzó en el marjón, progresando hacia el interior de la hoja. Machos, hembras, y poblaciones mixtas de adultas de A. floridanus, cuando se alimentaron normalmente o se dejaron sin comida, consumieron una cantidad de tejido de hojas directamente proporcional a la densidad de la población. Poblaciones de 1 a 5 gorgojos por hoja consumieron menos de un 5% del área de las hojas después de 72 horas, mientras que 15 gorgojos consumieron on 40% del área de las hojas durante el mismo período. La alimentación de gorgojos hembras generalmente redujeron el área de las hojas más que los machos. El área de las hojas consumidas diariamente por los gorgojos no cambió con distintos niveles de poblaciones. No hubo evidencia de interferencia sexual con el comportamiento de alimentación. Ninguna de las hojas expuestas a los gorgojos sostuvieron daños en la nervadura central, de aquí que no se observó abscisión.
El intercambio neto de gas fue reducido por la cantidad del área de la hoja consumida. Asimilación de CO₂, transpiración, y la eficiencia del uso del agua, fueron evaluadas usando los tejidos remanentes de las hojas dañadas. La proporción de intercambio neto de gas no cambió consistente-mente con el porcentaje del área consumida de la hoja. En hojas más severa-mente dañadas por poblaciones hembras previamente sin alimentos, la pérdida de agua aumentó proporcionalmente más que la fotosíntesis de-clinó, resultando en un decreto de un 20% en la eficiencia del uso del agua. La acción recíproca entre daños causados por la alimentación y la tensión producida por sequías, pudiera ser especialmente importante.

The common species of root weevils occurring on Florida citrus are the Fuller's rose beetle, Pantomorus cervinus (Boheman), the little leaf notcher, Articus floridanus Horn, the citrus root weevils, Pachneus opalus (Oliver) and Pachneus litus (German), and the West Indian sugarcane rootstock borer weevil, Diaprepes abbreviatus (L.) (Schroeder and Beavers 1977). All species appear to have a broad host range and are generally localized in their distribution on citrus and other plants at locations throughout the State.

Injury to the citrus plants results from larval feeding on roots and adult feeding on leaves. No quantitative data are available on the annual economic loss to citrus caused by the larvae and adults. Adult weevils are foliage feeders and cause a characteristic notching of the leaf margins (Bullock 1971). The notching pattern is usually characteristic of the species and all weevil species prefer to feed on new growth. There appears to be no preference for citrus variety and interestingly, foliar feeding has been observed to occur mainly at night. McCoy et al. 1985, found that adult A. floridanus consumed significantly more citrus leaf area in total darkness compared to 12 h light and darkness or constant light. In addition, the life expectancy of adult weevils is relatively long, about 160 days.

Other than the obvious reduction of leaf surface area by adult weevil feeding, little is known about the effect of leaf feeding injury on citrus leaf physiology. In apple leaves, no reduction in net photosynthesis occurs until 10% of the leaf area is removed (Hall and Ferree 1976). In addition, injury to large leaf veins results in lower photosynthesis than interveinal injury and the amount of cut leaf surface exposed is more important than the area removed (Ferree and Hall 1981). The purpose of this study was to determine quantitatively the leaf consumption rate by different popula-tions of adult A. floridanus and their effect on photosynthetic CO₂ assimilation, transpiration rate, and water use efficiency of citrus leaves.

MATERIALS AND METHODS

HOST PLANTS

Eleven-month-old Duncan grapefruit (Citrus paradisi Macf.) seedlings approximately 45 cm in height were grown in the greenhouse under 50% shade cloth and natural photoperiods. Plants were placed in a plant growth chamber at a constant temperature of 25°C, 50% relative humidity, and a 12-h photoperiod for 5 days to precondition plants for experimentation. All feeding experiments were conducted under these conditions.
INSECTS

A wild population of approximately 2,000 adult A. floridanus was collected randomly from navel orange (Citrus sinensis L.) and Australian pine (Casuarina spp.) foliage in the vicinity of Wabasso, Fla. Weevils were held in a styrofoam cooler at 20 to 25°C for transport to Lake Alfred. In the laboratory, cohorts of 300 to 350 adult weevils were placed in a modified 10-gal aquarium fixed with a screen cover and held at 27 to 28°C. Weevils were fed newly expanded citrus foliage for approximately 2 weeks until used for experimentation. During the first week, approximately 20% of the adult weevils died; thereafter, <5% of the remaining weevils died.

Weevils were prepared for feeding experiments as follows: 350 adult male and female weevils were sexed on the basis of courtship behavior and held separately in styrofoam containers without food for 5 days. This starving treatment was intended to enhance uniformity of subsequent feeding rates. Moisture was supplied to the weevils through cotton dental wicks inserted in 1-oz plastic cups containing water. In addition, 2 mixed adult populations of 300 weevils (starved or fed) were held in the same manner. The 4 treatments consisted of: a) fed male and female, b) starved male and female, c) starved male, and d) starved male.

To estimate the rate of citrus leaf consumption by a given population of adult weevils in time, the following experiments were performed: Randomly selected populations of 1, 5, 10, and 15 weevils from each experimental population were placed in 80-mesh nylon bags enclosing single attached 6-month-old citrus leaves. Prior to weevil exposure, the surface area of each leaf was determined using a Li-Cor portable leaf area meter. Treatments were replicated 3 times. Feeding was permitted for 24, 48, and 72-h in plant growth chambers. Thus, weevil-days (individuals x days) varied from 1 to 45.

HOST-PLANT RESPONSES

Leaf consumption was determined by remeasuring the surface area of the leaf and calculating the difference before and after exposure. Data were expressed as a percentage of leaf area consumed per population group. Leaf consumption per weevil over time, both within and between treatments for each experiment, were tested for significance using linear regression analysis and t-test.

Photosynthetic CO₂ assimilation (A), transpiration rate (E), and water use efficiency (WUE = A/E) were calculated from CO₂ and H₂O vapor fluxes (Jarvis 1971) of each of the study leaves before and after the A. floridanus feeding experiments. Net gas exchange of CO₂ and H₂O vapor were measured in the laboratory using an open gas exchange system (Syvertsen 1984, Syvertsen and Smith 1983). All measurements were made under constant environmental conditions of saturating photosynthetic photon flux density (600-800 µmol s⁻¹ m⁻²), ambient air containing 340 ± 20 µl 1⁻¹ CO₂, leaf temperature of 26 ± 1°C, and absolute humidity difference from leaf to air of 6 ± 2 µg cm⁻². Preliminary measurements indicated that these conditions were near optima for maximum rates of net gas exchange. Net gas exchange rates after feeding injury were expressed as a percentage of the respective rates prior to the experiments.
RESULTS AND DISCUSSION

Typical patterns of leaf injury caused by the feeding of different numbers of adult weevils over 72-h periods are shown in Fig. 1. The leaf surface area removed by one weevil caged on a leaf for 72 h was approximately 4%. This feeding pattern and amount of injury per leaf is typical of a relatively low population density of *A. floridanus* adults common to citrus groves in the spring and summer.

In general, the percentage of the leaf area consumed increased significantly as the number of weevils per leaf increased (Fig. 2). This condition was most pronounced when sexually mixed populations and starved females only were tested in time. No effect of group behavior on feeding responses were observed since the rate of leaf consumption per weevil per day remained the same within cohorts.

In contrast to other treatments, increasing population densities of male weevils had little effect on the percentage of leaf area consumed over time (Fig. 2). This may be explained by the fact that the smaller adult male *A. floridanus* have fewer metabolic requirements such as egg production, and, therefore, eat less. There is no evidence to indicate any sexual interference in feeding behavior, since the mean of the combined rates of leaf consumption by individual starved males plus that of individual starved females, 0.57 [(0.32 + 0.82)/2 = 0.57], equals that of the starved mixed population (0.63, Table 1).

It is unclear how the 5-day starvation period prior to leaf exposure affected feeding behavior. This relatively long-lived insect apparently does not require frequent feeding as subsequent leaf consumption rates of starved and fed populations did not differ.

![Weevil Feeding Injury](image)

Fig. 1. Typical feeding injury patterns on mature grapefruit leaves by populations of 1 to 15 adult *A. floridanus* weevils after 72-hr (weevil-days = 0 to 45).
Fig. 2. The relationship between citrus leaf consumption over time by different cohorts of starved and fed populations of male and female *A. floridanus* adult weevils. Each point is the mean of 3 leaves and are connected for clarity. Slopes of linear regressions fitted to the raw data were separated with unlike letters using t-tests ($P<0.05$).

**TABLE 1. MEAN RATE (± 1 SD) OF PERCENTAGE LEAF AREA (l.a.) CONSUMED BY INDIVIDUAL ADULT *A. floridanus* WEEVILS PER DAY IN THE EXPERIMENTS DESCRIBED IN FIG. 2.**

<table>
<thead>
<tr>
<th>Condition</th>
<th>% l.a./weevil/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fed male, female</td>
<td>0.72 ± 0.14</td>
</tr>
<tr>
<td>Starved male, female</td>
<td>0.63 ± 0.26</td>
</tr>
<tr>
<td>Starved female</td>
<td>0.82 ± 0.18</td>
</tr>
<tr>
<td>Starved male</td>
<td>0.32 ± 0.15</td>
</tr>
</tbody>
</table>

<sup>1</sup>Mean slope of the 4 linear regression lines (1, 5, 10, and 15 weevils) from each feeding experiment.
Fig. 3. Percentage change of CO₂ assimilation, transpiration and water use efficiency of individual grapefruit leaves after 72 hr of feeding injury by populations of 1 to 15 adult A. floridanus weevils. Each bar represents mean values from 3 leaves; numbers above and below bars on transpiration data are the percentage leaf area consumed from 72-h values in Fig. 2.
Reductions in CO₂ assimilation and transpiration rates per leaf paralleled the leaf area consumed (data not shown). Net gas exchange rates of the remaining tissue of leaves injured by mixed populations of weevils did not change consistently with percentage of leaf area consumption (Fig. 3). Consequently, water use efficiency was not related to numbers of weevils. Although net gas exchange was measured 3 days after weevil removal, water loss from injured leaf tissue possibly enhanced measured rates of transpiration resulting in poor correlations between transpiration and leaf consumption. In addition, enhanced CO₂ diffusion into injured leaf cuticles could also account for the 2 treatments that had higher net CO₂ assimilation rates after feeding injury.

Net gas exchange from leaves injured by starved female weevils appear more closely related to amount of leaf consumption (Fig. 3). Transpirational water loss increased proportionally more than photosynthesis. This resulted in up to a 20% decrease in water use efficiency for populations greater than one weevil/leaf.

Citrus leaves are thicker near the midvein than near the leaf margins (Syvøertsen and Levy 1982) where typical adult weevil feeding occurs. The actual amount of leaf tissue removed per leaf surface area increases as feeding injury progresses from the leaf margin towards the midvein. This should have further compounded the impact of the higher amounts of feeding injury—but it did not. In addition, there are relatively few veins near the leaf margins which further minimizes the effect of weevil feeding on leaf responses.

In summary, the net gas exchange data point to the importance of measuring photosynthesis and transpiration of the remaining leaf tissue simultaneously after leaves have been injured by adult weevils. Maximum reduction in water use efficiency of about 20%, even after more than 40% of the leaf had been consumed, indicates that the loss of photosynthetic leaf surface area is relatively more important than changes in net gas exchange of the remaining tissues. None of the leaves sustained injury to the midvein; therefore, it is unlikely that even the leaves with the greatest injury would abscise. Nonetheless, the decreases in water use efficiency underscore the importance of water loss from injured leaves. Future studies should emphasize interactions among weevil feeding injury, host plant productivity and environmental stress, particularly drought stress.

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REFERENCES CITED


McCoy, C. W., C. Secretain, G. M. Beavers, and C. Tarrant. 1985. Labora-
Syvertsen & McCoy: Citrus Weevil Symposium


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**SAMPLING AND DISTRIBUTION OF ARTIPUS FLORIDANUS HORN (COLEOPTERA: CURCULIONIDAE) ON CITRUS AND WEED HOSTS**

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**ABSTRACT**

No correlation was found between adult populations of *Artipus floridanus* Horn observed on the foliage of navel orange trees and the number of adults emerging from the soil beneath the same trees. Only a few larvae were found in the root zones of selected trees after one year indicating that the low adult population collected from emergence traps during the year was an accurate index of population density per tree. Interestingly, teaweed and carpet grass found between the rows produced a significantly greater number of larvae per area than citrus.

A weak negative correlation was detected between leaf consumption by adult weevils and change in root volume after one year. Yet, there was no correlation between adult and larval populations and root volume or trunk diameter.

**Resumen**

No se encontró correlación entre poblaciones adultas de *Artipus floridanus* Horn observadas en el follaje de árboles de naranja navel y el número de adultos saliendo de la tierra debajo de los mismos árboles. Sólo se encontraron pocas larvas en las zonas de las raíces de árboles seleccionados después de un año, indicando que bajas poblaciones de adultos colectados en trampas de emergencia durante el año, fue un índice preciso de la densidad de la población por árbol. Interesantemente, las plantas “teaweed” y “carpet grass” que se encontraban entre las hileras de árboles, produjeron significativamente un número mayor de larvas por área que los cítricos.

Después de un año se detectó una débil correlación negativa entre el consumo de hojas por gorgojos adultos y cambios en el volumen de raíces.