Relationship Among Orangestriped Oakworm (Lepidoptera: Saturniidae) Frass Length, Frass Production, Host Plant, and Defoliation[1]

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ABSTRACT Defoliation of urban oak trees by the orangestriped oakworm, *Anisota senatoria* (J. E. Smith), and associated frass has become a significant problem in southeastern Virginia. Measurements of frass length and production provided a decision-making guideline for *A. senatoria* management. Frass length was used to differentiate *A. senatoria* instars reared on *Q. palustris* (Muenchhausen), pin oak. Host plants significantly affected *A. senatoria* frass length and production per larva and host plants should be considered when determining instars. Frass length was longer and frass production higher when larvae were reared on *Q. nigra* (water oak), *Q. phellos* (willow oak), *Q. coccinea* (scarlet oak), and *Q. palustris* compared with six other species. Frass length was shorter in second, fourth, and fifth instars when larvae were reared on *Q. alba* (white oak) compared with six, eight, and five other species, respectively. Landscape fabrics were used to collect frass and recovered 90% of all frass deposited. Frass production on small pin oaks (mean ht = 2.1 m, mean diameter at breast ht = 6.3 cm) was significantly correlated with defoliation. An aesthetic injury level of 25% defoliation resulted in frass collections of 2.2 g per tree.

KEY WORDS Insecta, *Anisota senatoria,* frass, landscape fabrics, instar determination, host plants.

Orangestriped oakworm, *Anisota senatoria* (J. E. Smith), has caused significant defoliation of *Quercus* species planted in the urban landscape of southeastern Virginia (Coffelt and Schultz 1990). A citizen survey indicated *A. senatoria* frass was a serious problem (Coffelt and Schultz 1991). Frass was observed by 84% of the citizens and 61% thought frass and crawling larvae were more significant than defoliation. Lepidopterous larvae produce large fecal pellets that often fall to the ground beneath the host plant. Pellet counts can give estimates of larval populations (Koehler 1987). Larval densities of gypsy moth, *Lymantria dispar* (L.) (Liebhold and Elkinton 1988a, b), European spruce sawfly, *Gilpinia hercyniae* (Hartig) (Morris 1949), and pine sawflies (*Neodiprion* spp.) (Green and DeFreitas 1955) were estimated using frass drop and frass production measurements. Volney et al. (1983) studied the relationship between California oakworm, *Phryganidia californica* (Packard), frass and larval activity. They found collecting *P. californica* frass on sticky cards was an accurate

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sampling method that could be used to estimate larval populations and facilitate control decisions. Furthermore, frass size can be used to estimate instar distribution (Bean 1959, Liebhold and Elkinton 1988a).

Adult *A. senatoria* eclose from overwintering pupae in late June to late July and mate on grass blades or tree trunks. Yellow eggs are oviposited during July on leaf undersides on terminal twigs in masses of 200-700. Oaks (*Quercus* sp.) are preferred hosts, but birch (*Betula* sp.), hazelnut (*Corylus*), hickory (*Carya*), and maple (*Acer*) also are attacked. Early instars are gregarious and skeltonize leaves, whereas fourth and fifth instars consume entire leaves except the main vein. During September, larvae migrate from defoliated trees and burrow 7-10 cm in the soil and pupate. There are one and possibly two generations per year, depending on location (Hitchcock 1958). Coffelt and Schultz (1993) found a second generation occurred from September to December in Virginia Beach, VA.

The objectives of this study were to determine *A. senatoria* instars by measuring frass length, relate frass length and production with oak species, and determine the relationship between defoliation and the amount of frass collected on a landscape fabric.

Materials and Methods

1989 field experiments. Fifteen *Quercus palustris* Muenchhausen (pin oak) were planted in November, 1988, at the Hampton Roads Agricultural Experiment Station (HRAES), Virginia Beach, VA and were used in 1989 field experiments. Trees had a mean diameter at breast height (dbh) of 5.7 ± 0.2 cm and mean height of 1.7 ± 0.04 m in 1989. *Anisota senatoria* egg masses were collected from Norfolk, VA and pinned to leaf undersides on 25 July with one egg mass per tree. Egg masses were equivalent in size and averaged 493 eggs (Coffelt and Schultz 1993). Egg masses were examined daily and eclosion date recorded. A circular piece of polypropylene landscape fabric (DeWitt Co. Inc., Sikeston, MO) was placed beneath the canopy of each tree to collect fallen frass. The soil beneath the fabric was leveled and a slight inward slope was constructed to facilitate frass collection. Each landscape fabric section measured 2.62m^2. When at least 60% of the larvae per tree had molted to the next instar, frass was swept into paper bags and air-dried (Bean 1959). Gregarious larvae from the same egg mass all molted within 24 hours; therefore, frass collections were from each instar. Percentage defoliation was visually estimated (Coffelt and Schultz 1990) on 24 August after all larval feeding had ceased.

Anisota senatoria frass was separated from other debris in the bags and weighed to the nearest 0.01 g. Subsamples of 25 pellets from each tree and instar were taken and each pellet length was measured to the nearest 0.01 mm using an ocular micrometer (Bean 1959, Volney et al. 1983, Liebhold and Elkinton 1988a).

1990 laboratory experiments. *Anisota senatoria* eggs were pinned on leaf undersides of 11 *Quercus* species cuttings. Upon egg eclosion, larvae were removed with a probe to establish five per cutting. Cuttings were taken from *Quercus* species planted in 1985 at the HRAES. Cuttings were placed in 100-ml water-filled cups that were positioned in 19 × 11 cm plastic boxes. Boxes were placed in an environmental chamber maintained at 26.4°C (L) and 21°C (D) and

a photoperiod of 16:8 (L:D). Five replications per host plant were established. *Quercus* cuttings used were: *Q. acutissima* Carruth. (sawtooth oak), *Q. alba* L. (white oak), *Q. bicolor* Willd. (swamp white oak), *Q. coccinea* Muenchhausen (scarlet oak), *Q. falcata* Michx. (southern red oak), *Q. macrocarpa* Michx. (bur oak), *Q. nigra* L. (water oak), *Q. palustris* (pin oak), *Q. phellos* L. (willow oak), *Q. prinus* L. (chestnut oak), and *Q. rubra borealis* (Michx. f.) Farw. (northern red oak).

When at least 60% of the larvae had molted to the next instar, frass was collected from the boxes and air-dried. Larvae in the same group all molted within 24 hours; therefore, frass collections were from each instar. Frass length and weight were measured as previously described.

Total frass production per host plant was calculated. Late instars (fourth and fifth) were used to calculate frass production per larva. Mean frass production per larva was calculated for each host by dividing the total frass produced (g) by the number of late instars alive at experiment conclusion. Frass from each of the five replications was combined to give one total frass value from each host. Therefore, because frass production per replicate was not recorded and only a single value was obtained, statistical analysis was not calculated for frass production.

1990 field experiments. Eighteen *Q. palustris,* planted at the HRAES, were used in 1990 field experiments. Trees had a mean dbh of 6.3 ± 0.2 cm and a mean height of 2.1 ± 0.05 m. In 1989 field experiments, placement of one egg mass per tree resulted in complete defoliation by the third instar. Therefore, in 1990 field experiments, eggs from egg masses were removed with a probe to establish 194 viable eggs per mass (approximately 40% of the eggs in an egg mass). This provided sufficient foliage for larval development to the fifth instar. Egg masses were pinned to leaf undersides. All eggs hatched and 194 first instars were available at the beginning of experiments. Eggs eclosed on 21 and 26 July, and the number of live larvae was recorded per tree on 4, 15, and 18 August. The same landscape fabrics were used on the ground to collect frass in 1989 and 1990. Percentage defoliation was visually estimated (Coffelt and Schultz 1990) on 31 August after all larval feeding had ceased. Frass from larvae that fed from late July to late August was collected on 31 August and weighed. Some frass fell outside the fabric perimeter. This frass was collected from each tree with a brush along the entire periphery of the fabric, placed in paper bags, and weighed. The accuracy of the landscape fabric for collecting frass was determined.

Data from 1989 field and 1990 laboratory experiments were subjected to analysis of variance (ANOVA) and means separated by Student-Newman-Keuls test (Steel and Torrie 1980, SAS Institute 1985). Field data in 1990 were analyzed by simple linear regression (SAS Institute 1985).

Results and Discussion

1989 field experiments. Frass length was an accurate indicator of *A. senatoria* instars (Table 1). There were significant differences ($P < 0.001$) in frass length and frass production among instars. Frass from first instars had a mean length of 0.58 ± 0.03 mm and frass from fifth instars had a mean of 3.33 ± 0.09 mm.

Table 1. Mean frass length and total frass produced by *A. senatoria* instars, 1989 field experiments.*

Instar	Frass Length (mm)	*n*	Total Frass Produced†	*n*
First	0.58 ± 0.003 e	15	4.96 ± 0.33 c	15
Second	1.06 ± 0.01 d	9	12.63 ± 1.76 c	15
Third	1.64 ± 0.02 c	11	35.54 ± 3.89 c	15
Fourth	2.57 ± 0.05 b	11	233.65 ± 17.5 b	11
Fifth	3.33 ± 0.09 a	6	340.33 ± 70.8 a	6

* Means (± SEM) within columns followed by the same letter are not significantly different ($P > 0.05$) (Student-Newman-Keuls test) (SAS Institute 1985).

† Total frass produced by instar of an *A. senatoria* group with an estimated initial mean population size of 485 larvae.

In this study, measurements of frass length estimated the instar distribution of *A. senatoria* when larvae were reared on *Q. palustris*, grown in Virginia environmental conditions, and population densities averaged 493 eggs. Coffelt and Schultz (1992) reported that 98.3% of *A. senatoria* eggs hatched. Therefore, 485 first instars were initially available in 1989 field experiments. Frass measurements may vary with factors that affect size of individuals, such as host plant, host quality, and population density (Lance et al. 1986, Liebhold and Elkinton 1988a). Total frass production by instar indicated that fifth instars produced the most frass (Table 1) and that about 92% of the total frass was produced by the last two instars.

Trees were evaluated for the amount of defoliation after all larvae had migrated from trees and pupated. All of the trees were 90-100% defoliated, but larvae had sufficient foliage to complete development because defoliation was less than 90% when larvae were departing from trees that were used for frass collections. Larvae from trees that were not used in 1989 experiments migrated to the trees used for frass collections and continued to feed and defoliate the trees 90-100%.

1990 laboratory experiments. Host plants significantly affected *A. senatoria* frass length ($P < 0.001$) (Table 2). Frass length was significantly longer in first instars when larvae were reared on *Q. nigra* compared with ten other species; in second and fourth instars when larvae were reared on *Q. nigra, Q. phellos, Q. coccinea,* and *Q. palustris* compared with six species; and in fifth instars when larvae were reared on *Q. nigra* and *Q. coccinea* compared with six species. Frass length was significantly shorter in second instars when larvae were reared on *Q. alba* compared with six other species, in fourth instars compared with eight species, and in fifth instars compared with five species.

Table 2. Influence of *Quercus* species on mean length of *A. senatoria* frass and frass production per larva, 1990 laboratory experiments.

Quercus sp.	Mean ± SEM pellet length (mm)* Instars					Mean Production per larva (g)
	First	Second	Third	Fourth	Fifth	
nigra	0.55 ± 0.02 a	0.79 ± 0.01 ab	1.21 ± 0.02†	2.62 ± 0.06 a	3.41 ± 0.10 a	3.45
phellos	0.53 ± 0.01 ab	0.82 ± 0.04 ab	1.23 ± 0.01	2.50 ± 0.02 ab	3.26 ± 0.10 ab	3.08
coccinea	0.49 ± 0.01 bc	0.85 ± 0.01 a	1.26 ± 0.03	2.44 ± 0.05 b	3.41 ± 0.05 a	2.46
falcata	0.48 ± 0.01 bc	0.77 ± 0.01 b	1.35 ± 0.01	2.55 ± 0.04 ab	3.12 ± 0.11 a-d	2.29
macrocarpa	0.48 ± 0.01 bc	0.70 ± 0.02 cd	1.13 ± 0.01	2.07 ± 0.03 de	2.89 ± 0.03 cde	1.66
prinus	0.47 ± 0.01 c	0.70 ± 0.01 cd	1.16 ± 0.04	2.24 ± 0.01 c	2.84 ± 0.06 de	2.07
bicolor	0.46 ± 0.01 c	0.68 ± 0.01 cd	1.09 ± 0.01	2.25 ± 0.04 c	2.96 ± 0.07 b-e	1.76
palustris	0.46 ± 0.01 c	0.81 ± 0.02 ab	1.27 ± 0.03	2.43 ± 0.06 b	3.16 ± 0.10 abc	2.36
acutissima	0.45 ± 0.02 c	0.68 ± 0.01 cd	1.15 ± 0.05	2.06 ± 0.01 de	2.71 ± 0.05 e	1.73
rubra‡	0.44 ± 0.01 c	0.75 ± 0.01 bc	1.12 ± 0.02	2.14 ± 0.03 cd	2.98 ± 0.01 b-e	2.65
alba	0.43 ± 0.007 c	0.64 ± 0.005 d	1.04 ± 0.02	1.04 ± 0.02 e	1.94 ± 0.01 e	2.30

* Means within columns followed by the same letter are not significantly different ($P > 0.05$) (Student-Newman-Keuls test) (Sas Institute 1985).
† Means were not significantly different (SNK).
‡ *Q. rubra borealis.*

Frass production per larva was affected by host plant (Table 2). There was a trend for higher frass production per larva when reared on *Q. nigra, Q. phellos, Q. rubra borealis, Q. coccinea,* and *Q. palustris. Quercus palustris* and *Q. phellos* are heavily defoliated by *A. senatoria* in southeastern Virginia, and *Q. nigra* are commonly attacked (Coffelt and Schultz 1990, Coffelt 1992).

These data indicated that frass length and production differed according to oak species consumed by *A. senatoria* larvae. Leaf quality (physical and chemical properties) of the different host plants probably influenced larval feeding, utilization, and consequent frass production. Differences in *Quercus* leaf chemistry have been shown to influence *A. senatoria* larval growth (Lawson et al. 1982). For example, frass length was shorter when larvae were reared on *Q. alba* possibly because of differences in leaf chemistry compared to the other *Quercus* species. Lawson et al. (1982) found that the relative growth rate of *A. senatoria* larvae was significantly lower when reared on *Q. alba* compared to four other species. They attributed this to a low nitrogen utilization efficiency by larvae and a low nitrogen accumulation rate when fed *Q. alba.* Larval host plants should be considered when measuring frass pellets for instar distribution.

1990 field experiments. Volney et al. (1983) stated that experiments that are designed to correlate frass production with defoliation are needed in the urban landscape. Field experiments conducted in 1990 determined this relationship. There was a significant ($P < 0.0001$) linear relationship between frass production and percentage defoliation (Fig. 1), and the coefficient of determination was relatively high ($r^2 = 0.62$). A 25% aesthetic injury level was established for *A. senatoria* damage (Coffelt and Schultz 1990). Defoliation of 25% or less was tolerable to most citizens (Coffelt and Schultz 1991). Based on the regression equation in Fig. 1, 2.2 g of frass collected during larval feeding would indicate 25% *Q. palustris* defoliation. Therefore, frass collections could be used as a decision-making guideline for *A. senatoria* control on small *Q. palustris* trees (mean height and dbh = 2.1 ± 0.05 m and 6.3 ± 0.2 cm). Small *Q. palustris* are frequently attacked in the urban landscape and these results may have application in urban forestry. However, results may differ depending on the *Quercus* species. Data were not collected on leaf biomass and application to larger sized trees cannot be made. This limits the usefulness of this technique in integrated pest management programs.

The circular landscape fabric used in this study provided a reliable and efficient method to collect *A. senatoria* frass. The amount of frass that fell outside the perimeter of the 2.62 m^2 fabric in 1990 averaged 10.0 ± 4.0% (n = 18 trees). The landscape fabrics used in this study were durable over the two month sampling period and prevented weed growth (Derr and Appleton 1989). Landscape fabrics are porous and allow for exchange of water and air. During the few periods that rainfall occurred, water soaked through the fabric and frass remained on the fabric surface. The size and shape of *A. senatoria* frass appeared to be unaffected by rainfall. Bean (1959) found rainfall did not significantly alter *Choristoneura fumiferana* (Clemens), spruce budworm, frass pellet size and shape.

Frass has been sampled with circular cone-shaped traps (Bean 1959) and sticky cards placed in petri dishes attached to metal rods (Volney et al. 1983). Liebhold and Elkinton (1988a) tested five trap designs for collecting *L. dispar* frass and found a funnel trap was the most reliable and efficient. Although a

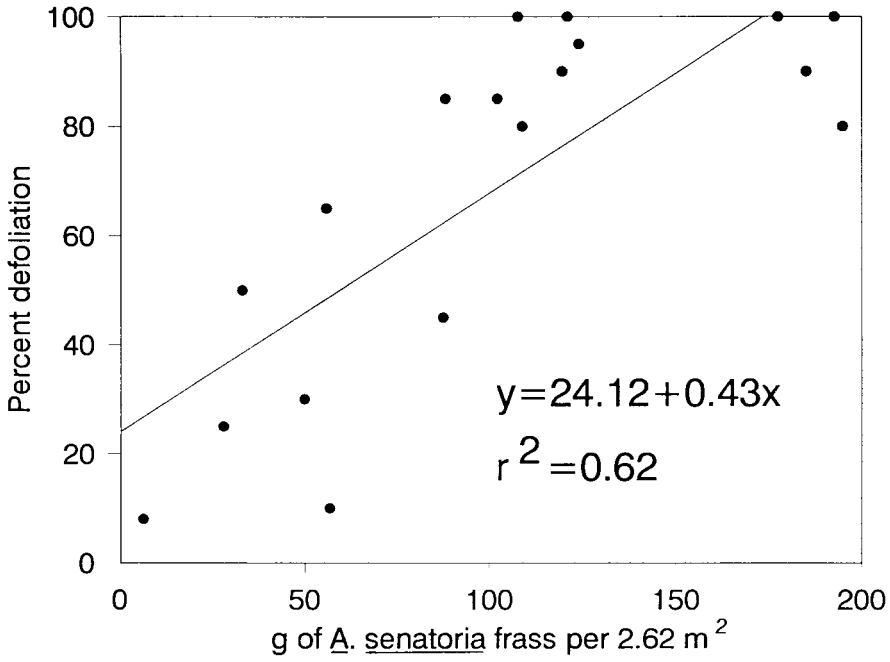

Fig. 1. Regression equation for the relationship between *A. senatoria* frass and *Q. palustris* defoliation, 1990.

comparison between funnel traps and fabrics was not conducted in this study, fabrics were an easy method to collect frass. The landscape fabric used in this study was an efficient method to collect frass and may have applications in other landscape entomology research. Fabrics are inexpensive, commercially available, and easy to install in an urban landscape. Observations were not made on the removal of frass by coprophagous arthropods, but this may be an important consideration when using landscape fabrics.

This study provided a decision-making guideline for *A. senatoria* populations. Measurements of frass length will indicate instar distribution and if frass collections show early instars are present, control strategies can be implemented. Frass production will indicate defoliation of small *Q. palustris;* however, additional research is needed to determine this relationship for larger sized trees.

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