VERTICAL DISTRIBUTION OF *PSYCHODA ALTERNATA* (DIPTERA: PSYCHODIDAE) IN SOIL RECEIVING WASTEWATER UTILIZED FOR TURF CULTIVATION

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ABSTRACT. Vertical distribution of immature *Psychoda alternata* in soil to a depth of 15 cm was studied in Jacksonville, FL. Samples were randomly taken from large circular land areas receiving a brewery wastewater utilized for commercial turf cultivation and included turfed and bare habitats. Total organic matter was quantified at various soil depths. Overall, 88.5 and 95.8% larvae and 91.3 and 94.0% pupae were recovered from the top 2.5 cm of soil at turfed and bare habitats, respectively. The highest concentration of total organic matter at both habitat types was in the top 2.5 cm. There were strong positive relationships between the number of larvae and pupae and total organic matter, indicating highest concentrations of immatures in nutrient-rich topsoil with an abundant supply of larval food. We suggest that insecticidal treatment directed against immature *P. alternata* breeding in such habitats need not penetrate to a depth of more than a few centimeters to affect almost all of the population of this pestiferous insect.

INTRODUCTION

Psychoda alternata Say, which breeds in semiaquatic habitats, occurs in a variety of sources such as hay infusion (Haseman 1907), decaying vegetables, cow and horse dung (Turner 1925) and seaweed piles (Saunders 1928). It is one of only 3 species in its subfamily able to live under heavily polluted conditions, and capitalizes on the rich energy resources available in biological filter beds of sewage treatment plants; populations reach such levels that it is commonly known as the "trickling filter fly" (Quate 1955). The tolerance of *P. alternata* for strong sewage allows it to thrive free from interspecific competition in many habitats heavily polluted with organic material (Rutz et al. 1980). In biological filter beds, the larvae may perform an important function by grazing on the algal scum or "zöoglea" that covers the stones of the filter beds and thus prevent clogging. However, the adults from such sources emerge in large numbers and can become a nuisance in the vicinity of their breeding sites (Tomlinson and Stride 1945, Woods et al. 1978). This type of a problem exists in one situation in Jacksonville, FL, where 6–8 million liters of wastewater derived daily as a by-product of a beer brewing process are discharged through pivot irrigation systems onto large circular land areas to cultivate turf. The nutrient-rich wastewater, discharged over several hundred ha, creates favorable conditions for the development of very large populations of *P. alternata*. Large numbers of adults disperse to neighboring residences, posing considerable distress to local inhabitants.

This study reports the vertical distribution of immature *P. alternata* in the irrigated soil. Concentrations of total organic matter distributed vertically in the soil were determined and correlated with the populations of *P. alternata*. An understanding of this aspect of the ecology of *P. alternata* is essential for the development of control measures against the pest.

MATERIALS AND METHODS

The turf farm is located at approximately 80°46′ W longitude and 30°31′N latitude, Duval County, FL. At the farm, several areas ranging from 6 to 40 ha are under turf cultivation. Each cultivated area receives approximately 123,000 liters/ha of the wastewater 2–3 times a week discharged through a long large boom containing several nozzles and moving at a set speed in a circular manner.

Under each pivot, there is an elaborate network of underground drains approximately 60 cm above the water table, which is ca. 1–1.5 m below the surface. The subterranean drains collect and carry any leached wastewater into ditches situated at the periphery of each pivot. The ditches empty into small man-made ponds. Some ditches and ponds are equipped with release gates used when necessary. The soil under the pivots was considered to be the primary breeding source of *P. alternata*, with turfed and bare sites which were apparently the 2 distinctly different types of *P. alternata* habitats.

Soil samples from the turfed and bare habitats under various pivots were randomly obtained by driving a 3.8-cm (inner diam) plexiglass core tube (Ali 1984) into the ground to a depth of 20–25 cm with a rubber mallet. The collected column of soil was extracted from the tube with a plunger and its upper 15 cm length was separated and fractioned into 2.5-cm-long sections and transferred into 6 separate, labeled poly-

Table 1. Vertical distribution of *Psychoda alternata* larvae and pupae and percent total organic matter in soil (turf and bare habitats) in large circular land areas cultivated to turf in Jacksonville, FL (October 1989–February 1990).

Soil depth (cm)	Mean no. ± SD of immature *Psychoda alternata* per 10 cores[a] or mean % concentration of total organic matter per 5 cores						
	L1[b]	L2	L3	L4	Total larvae[c]	Pupae[c]	% organic matter
			TURF				
0.0–2.5	1.0 ± 0.8	5.0 ± 3.3	28.0 ± 11.3	88.7 ± 31.4	122.7 a	38.7 a	2.60 ± 1.07
2.5–5.0	1.0 ± 1.4	5.3 ± 7.5	3.0 ± 2.9	3.8 ± 5.2	13.0 b	2.0 b	1.59 ± 0.14
5.0–7.5	0.0 ± 0.0	0.7 ± 0.9	0.3 ± 0.5	1.0 ± 1.4	2.0 b	0.7 b	1.26 ± 0.17
7.5–10.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.5	0.0 ± 0.0	0.3 b	1.0 b	0.95 ± 0.12
10.0–12.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.5	0.3 b	0.0 b	1.25 ± 0.12
12.5–15.0	0.0 ± 0.0	0.3 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.3 b	0.0 b	1.22 ± 0.12
			BARE				
0.0–2.5	33.3 ± 38.7	163.3 ± 187.4	70.7 ± 18.5	74.3 ± 95.2	341.7 a	30.0 a	3.36 ± 0.32
2.5–5.0	0.3 ± 0.5	4.7 ± 3.3	4.7 ± 3.7	2.0 ± 0.0	11.7 b	1.3 b	2.22 ± 0.02
5.0–7.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.8	1.0 c	0.0 b	1.99 ± 0.30
7.5–10.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 1.4	1.0 c	0.3 b	1.83 ± 0.18
10.0–12.5	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.5	1.0 ± 1.4	1.3 c	0.3 b	2.02 ± 0.28
12.5–15.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 c	0.0 b	1.52 ± 0.16

[a] Each core 3.8 cm in diam and 2.5 cm deep.
[b] L1–L4: larval instars 1 to 4.
[c] Means in a column followed by the same latter are not significantly different ($P > 0.01$) as analyzed by ANOVA and Duncan's multiple range test.

thene bags. At each habitat, 10 such cores of soil were collected and the fractioned subcores of the same depth were pooled. Larval and pupal samples were collected on 3 occasions between October 1989 and February 1990. An additional 5 cores of soil from equivalent depths were collected each time for the determination of total organic matter at different depths.

In the laboratory, each soil sample collected for assessment of immature *P. alternata* population was washed through a series of U.S. standard sieves. Large pieces of vegetation were washed clean of soil and discarded. The residue on the finest screen (250-μm pore size, U.S. Standard sieve No. 60) was collected, preserved in 70% alcohol and examined under a binocular microscope (10× magnification) to identify and count psychodid larvae and pupae. Each sample was examined in parts by placing small portions in a 8.5-cm diam Petri dish with a 1-cm grid marked on the bottom. The taxonomic keys in Quate (1955) were used.

To determine total organic matter, soil samples were dried at 40°C and ground to pass through a 40-mesh sieve. The wet oxidation method of Nelson and Sommers (1982) was used to determine percent total organic matter in each sample.

Populations of total larvae and pupae of *P. alternata* at various soil depths were compared by analysis of variance and Duncan's multiple range test. A correlation analysis was performed to elucidate relationship between populations of immature *P. alternata* and the total organic matter at various depths.

RESULTS AND DISCUSSION

Among immatures of psychodids, only *P. alternata* larvae and pupae were recognized in the collected samples. The mean numbers of *P. alternata* per 10 soil cores taken at various depths are presented in Table 1; a total of 30 cores from each habitat were collected. Generally, the bare habitat supported higher populations of larvae than the turfed habitat. As expected, the first instars in both habitat categories occurred only in the top 5 cm of soil since the eggs are laid at or near the soil surface. Overall, 88.5% larvae and 91.3% pupae recovered from soil samples collected from turfed habitats were in the top 2.5 cm. At bare locations, the percentages for this upper most level were 95.8% larvae and 94.0% pupae. These proportions of larvae and pupae in the top 2.5 cm of soil were significantly different ($P < 0.01$) from those encountered in the various depths below 2.5 cm. The number of larvae or pupae collected 5 cm below the surface was <3% of the total larvae or pupae collected from either habitat. Negligible numbers occurred below 12.5 cm.

Mean values of percent total organic matter at different soil depths in turfed and bare habitats are shown in Table 1. The highest concentration of total organic matter was in the top 2.5 cm. The mean values of total organic matter, 3.36% in the top 2.5 cm soil and 2.22% in 2.5 to 5.0 cm soil depth in bare areas, were significantly different ($P < 0.01$). Below 5 cm from the surface, the total organic matter content did not significantly differ in the various depths sampled. In turfed sites, the mean value of total organic matter in the top 2.5 cm soil amounted to 2.6%.

Simple correlation analysis of *P. alternata* larval and pupal populations at various depths with the prevailing total organic matter concentrations showed strong positive relationship between the number of larvae and total organic matter ($r = 0.789$, $P < 0.01$, $n = 36$), and the number of pupae and total organic matter ($r = 0.584$, $P < 0.01$, $n = 36$). This indicates that the greatest numbers of immatures were located in the nutrient-rich topsoil which had more abundant larval food supply than the lower depths.

Also, the larva of *P. alternata* is air-breathing and amphipneustic. It bears nonfunctional anterior spiracles located on raised projections on the prothorax. The posterior spiracles are situated at the apex of a respiratory siphon on the eighth abdominal segment, equipped with hydrofuge hairs arising from 4 finger-like papillae. The larva of *P. alternata* must therefore maintain direct contact with the atmosphere to obtain oxygen. This requirement for atmospheric oxygen is also one of the most important factors regulating the vertical distribution. The oxygen is obtained either at the surface of the substrate or from air spaces within the medium in which it lives. The larva of *P. alternata* is apparently able to tolerate submergence in water for 24 h under normal conditions, although entrapment of an air bubble in the breathing tube may allow it to survive for twice as long (Fair 1934). The pupa is generally immobile, but is able to move if necessary by abdominal contractions. Pupal breathing is through paired thoracic horns.

Previous studies in which larvae, pupae and even adults of these insects have been reported at depths of 1 m or more (Solbe et al. 1967) refer to populations in sewage filter beds. In the filter beds, the substrate contains a higher concentration of air spaces than the often water-logged soil encountered in the study area. Larvae of *P. alternata* maintained in a laboratory colony in damp sand were observed to remain close to the surface at all times, with their bodies buried in the sand and the posterior siphon projecting at the surface (A. Ali, personal observation).

Observations on vertical distribution of immature *P. alternata* made in this study contrast with those of Solbe et al. (1967) made in water treatment plant filter beds, a more common source of such infestations. Based on our results, we suggest that insecticidal treatment directed against immature *P. alternata* in such habitats need not penetrate to a depth of more than a few centimeters to affect almost all of the pest population of this insect. This high concentration of immatures near the soil surface also makes the larvae and pupae of *P. alternata* particularly vulnerable to dry conditions as they require at least moderate amounts of moisture in their niches (Quate and Vockeroth 1981).

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