Flight Phenology of *Circulifer tenellus* and Other Leafhoppers in San Joaquin Valley Citrus Groves[1]

G. N. Oldfield, R. K. Yokomi, D. A. Golino, and D. J. Gumpf

ABSTRACT. Flight activity of *Circulifer tenellus* (Baker) and several other leafhoppers was monitored along the southeastern and southern edges of the San Joaquin Valley of California with yellow sticky cards placed in young and mature citrus groves, and in a sunny rangeland habitat of *C. tenellus* in 1982 and 1983. The number of *C. tenellus* trapped in young citrus groves was approximately 35-fold greater than that in mature groves over the 2-yr survey period. Numbers of trapped *C. tenellus* were at least 10-fold higher in the fall than in the spring, especially in young groves, and remained high for approximately 2 months. Although most *C. tenellus* trapped on sticky traps were males, nearly equal numbers of each sex were collected by suction directly from citrus in a young grove. Eight percent of the *C. tenellus* collected from citrus in the fall were naturally inoculative for *Spiroplasma citri*, the citrus stubborn disease agent. The high catches of male *C. tenellus* indicated that males responded differently to sticky traps than did females. Many more *C. tenellus* were trapped in the middle of a rangeland breeding site than at the edge of the rangeland next to a mature citrus grove or within the grove. These data indicated that young citrus trees probably receive many more inoculations of *S. citri* than do trees in mature groves, and that the closed canopy of mature trees may act as an entry barrier to *C. tenellus*. Overall, *Empoasca* spp. was the most frequently caught group of leafhoppers; *Dalbulus maidis* (DeL. et Wolc.) and *Macrosteles* spp. also frequently outnumbered *C. tenellus* on the traps, especially in mature groves, and could play a role in spreading spiroplasmas to citrus. *Scaphytopius acutus delongi* (Young) was virtually absent from traps in most groves during most periods.

Index words. beet leafhopper, stubborn disease, *Spiroplasma citri*, sticky traps, flight phenology.

Five North American leafhopper species have been identified as vectors of *Spiroplasma citri*, the citrus stubborn disease agent (2, 3, 4, 5, 6) under experimental conditions. Two of these species, *Scaphytopius acutus delongi* (Young) and *Circulifer tenellus* (Baker), the beet leafhopper, are found in citrus groves in the San Joaquin Valley. *Scaphytopius acutus delongi* reproduces on citrus, whereas *C. tenellus* reproduces on a wide variety of herbaceous plants, some of which are hosts of *S. citri*. Only *C. tenellus* has been found naturally inoculative in the San Joaquin Valley (7). Nevertheless, there are few data to indicate whether *C. tenellus* feeds on citrus in the field. During late October 1981, we observed adult *C. tenellus* congregating on young citrus trees, but not in adjacent mature citrus groves at the University of California Field Station at Lindcove, Tulare County. This is a report of a subsequent investigation of the flight phenology of *C. tenellus* and several other leafhoppers in the southern and southeastern citrus-growing areas of the San Joaquin Valley.

MATERIALS AND METHODS

Leafhopper flight activity was monitored in 1982 and 1983 with yellow plastic cards (21.6 x 35.4 cm) coated with Tanglefoot[R]. To compare the seasonal flight activity of the beet leafhopper in citrus, the traps were placed vertically 0.3 m above the ground (8) just outside the skirt of citrus trees. Four locations separated by about 40 km along an approximately north-south line were selected as sample stations to test the influence of tree canopy size on *C. tenellus* activity. Each site consisted of a young sweet orange grove (1-3 yr old) adjacent to a mature grove. Traps were set at five-tree and five-row intervals in three rows of four traps per grove at adjacent corners of each paired ma-

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ture and young grove site and were changed biweekly. The four locations were: 1) Lindcove (Tulare Co.); 2) Porterville (Tulare Co.); 3) Edison (Kern Co.); and 4) a site approximately 40 km southwest of Edison referred to hereafter as Southwest Valley (Kern Co.). A fifth sample station was established east of Highway 65 northwest of Oildale (Kern Co.) at an abandoned rangeland which was a spring and winter breeding site for *C. tenellus* and an adjacent mature citrus grove. At this location, four traps were placed at each of the following sites: 1) within the rangeland breeding area 50 m from the grove edge; 2) on the edge of the breeding site next to the grove; 3) five trees inside the grove; and 4) ten trees inside the grove. The traps in each set were placed at five-tree intervals and at distances equal to the distance between five trees inside and outside the grove, respectively. The numbers of trapped adults of *C. tenellus*, *Dalbulus maidis* (DeL. et Wolc.), *S. acutus delongi*, *Macrosteles* spp., and *Empoasca* spp. were recorded for each of the groves throughout 1982-83.

Circulifer tenellus was collected directly from young citrus with a D-Vac^{R} vacuum insect collector at the Southwest Valley grove site. These adults were caged individually on Madagascar periwinkle plants for a 3-day inoculation feeding period to determine if they were inoculative for *S. citri*. The periwinkle indicators were examined daily over a 3-month period for symptoms of *S. citri* infection. Confirmation of infection was made by culturing the stubborn agent from symptomatic periwinkle plants (1).

In the autumn of 1986, we again placed yellow sticky cards at the same locations within the young grove at the Southwest Valley site, and we collected *C. tenellus* by D-Vac^{R} from the trees to determine the sex ratio of the insects collected directly from young trees.

RESULTS

***Circulifer tenellus* in mature and young groves.** Although the number of *C. tenellus* trapped on sticky cards varied greatly among the four pairs of mature and young groves, they were trapped more in the young citrus groves than in the adjacent mature groves (Table 1). The total number trapped in the young groves exceeded the number trapped in the mature groves by approximately 23-fold in 1982, and by 84-fold in 1983. During both years most *C. tenellus* were trapped from September through November in the young groves. In 1983, a small peak of *C. tenellus* flight activity in mature groves occurred in April and May, but the numbers of trapped leafhoppers were still approximately 9-fold less than those captured in young groves and almost none were trapped in mature groves after June.

Throughout the trapping period, approximately 10-fold more males than females were trapped at the four San Joaquin Valley grove sites (Figs. 1A, 1B, 1C, 1D). This predominance of males on traps was especially high at the Southwest Valley young grove (Fig. 1A), where numbers exceeded 200/trap during a 2-week period in late October 1982. During the fall of 1983, trapped males peaked at approximately 20/trap/2-week period which was much lower than in the previous fall, but they still constituted virtually all of the *C. tenelus* trapped.

The other three sites had similar patterns of fall peaks of trapped males. In 1982, male catches at Lindcove increased to 3.5/trap in early October and remained at this level for several weeks (Fig. 1B). This peak began about a month earlier in 1983 and then dropped to zero in early November. In 1982, at Porterville, the autumn peak of trapped males in the young grove reached 4.5/trap in late November and numbers remained at this level through early De-

TABLE 1
NUMBER OF LEAFHOPPERS TRAPPED PER 4-WEEK PERIOD IN YOUNG VS. MATURE CITRUS GROVES IN THE SAN JOAQUIN VALLEY, CALIFORNIA

	Total no. leafhoppers trapped[z]									
	Circulifer tenellus Grove		*Empoasca* pp. Grove		*Dalbulus maidis* Grove		*Macrosteles* spp. Grove		*Scaphytopius acutus delongi* Grove	
Month	Young	Mature	Young	Mature	Young	Mature	Young	Mature	Young	Mature
1982										
May	255	8	768	508	2	0	149	154	3	2
Jun	241	19	1582	626	6	0	111	208	3	3
Jul	34	5	2823	2281	479	7	107	43	10	3
Aug	130	30	3691	7449	4748	97	423	113	6	7
Sep	1989	90	3602	5491	2041	312	222	56	8	4
Oct	3340	80	2030	12074	617	122	107	49	20	18
Nov	474	45	581	2258	24	8	43	8	14	1
Dec	211	15	159	1302	3	3	6	3	1	0
Year total	6674	292	15236	31989	7920	549	1168	634	65	38
1983										
Jan	11	9	98	327	0	0	1	0	0	0
Feb	6	3	168	472	0	1	1	0	0	0
Mar	6	0	477	205	2	2	123	70	0	0
Apr	81	20	891	522	4	122	645	210	0	0
May	317	26	822	472	0	700	1273	472	0	0
Jun	85	2	1373	711	0	346	590	307	1	0
Jul	273	4	2360	2160	245	78	402	75	5	1
Aug	297	2	3072	3803	1947	133	501	139	11	4
Sep	219	2	2276	3181	2301	385	903	170	11	7
Oct	1354	1	2163	2940	932	312	122	33	124	43
Nov	2611	0	362	2245	39	62	15	7	52	13
Dec	528	0	347	1306	6	1	4	7	15	1
Year total	5788	69	14409	18344	5476	2142	4580	1490	219	69
Grand total	12462	361	29645	50333	13396	2691	5748	2124	284	107

[z]Numbers indicate combined totals from 48 yellow sticky-card traps from four groves (12 traps per grove) from each category. Each site consisted of a young sweet orange grove (1-3 yr old) adjacent to a mature grove. Traps were set at five-tree and five-row intervals in three rows of four traps per grove at adjacent corners of each paired mature and young grove site.

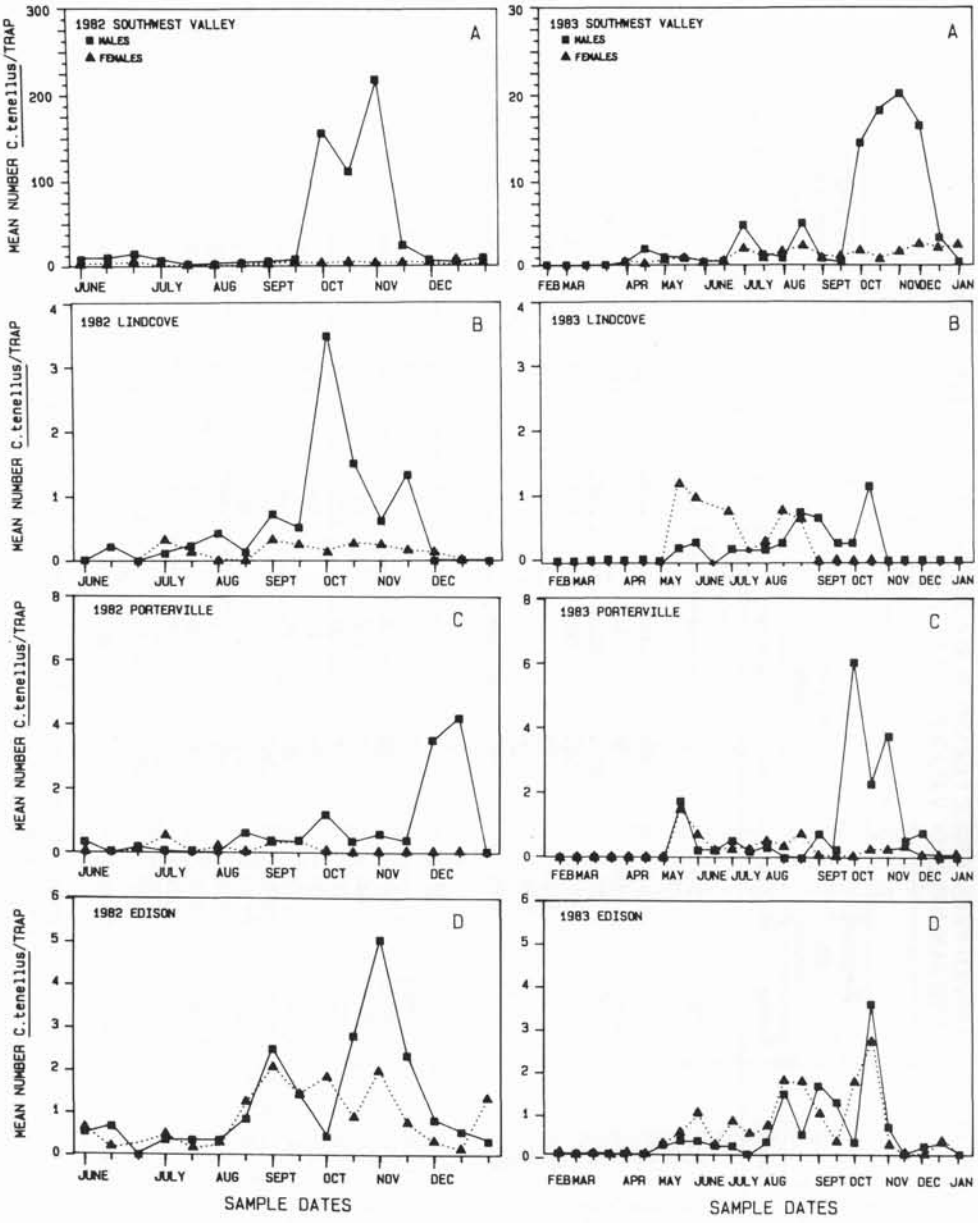

Fig. 1. Seasonal fluctuations in male and female flight activity of *Circulifer tenellus* trapped on yellow sticky cards in young citrus groves in the Central Valley of California during 1982 and 1983. A. Southwest corner of the San Joaquin Valley, Kern Co. B. Lindcove, Tulare Co. C. Porterville, Tulare Co. D. Edison, Kern Co. Note different scales.

cember before decreasing to zero by the end of the month (Fig. 1C). In 1983, male trap catches peaked at approximately 6/trap in early October and almost no males were trapped after late November. Similarly, at Edison during both years, the peaks in numbers of trapped males occurred during the fall (Fig. 1D). Females constituted a larger portion of the trapped leafhoppers at this location than at other sites, and, as elsewhere, most *C. tenellus* were trapped in the young grove. The overall profiles of the flight phenology of male and female *C. tenellus* were similar, but

those at Lindcove, Porterville, and Edison were 10- to 29-fold lower than at the Southwest Valley site (Figs. 1A, 1B, 1C, 1D). Although relatively few *C. tenellus* were trapped in mature groves, its pattern of flight activity at the various sampling sites was the same as that in young groves. Hence, the individual mature grove data are not shown.

During an 8-week period from early October to early December in 1986, we trapped 1,136 males and 73 females at the Southwest Valley grove. The trees were 4 yr old but they still covered only a small portion of the ground area. During the four 2-week trapping periods, males exceeded females on the traps by 7- to 43-fold. Collections from 50 trees each week with the insect vacuum during the same period netted only 28 males and 33 females. None of five males and one of seven females collected in October, and two of 25 males and one of 14 females collected in November transmitted *S. citri*. Those collected in December included one inoculative male of three tested, and no inoculative females of seven tested.

Other leafhoppers associated with citrus. Members of the genus *Empoasca* far outnumbered all other leafhoppers on the traps in 1982 and 1983 in both young (15,236 and 14,409 leafhoppers, respectively) and mature (31,989 and 18,344, respectively) groves and were present throughout the season (Table 1). In contrast to the other leafhoppers, more *Empoasca* spp. were trapped in mature groves than in young groves. Flight activity of *C. tenellus* approached or exceeded that of *Empoasca* only in the young groves during the fall. During winter *Empoasca* spp. and *C. tenellus* were virtually the only leafhoppers trapped.

Dalbulus maidis, an important vector of the corn stunt spiroplasma, was trapped in large numbers ranging from 245 to 4,748/trap/4-week period from July to October in 1982 and 1983, and was trapped in larger numbers in young groves than in mature grove sites during this time period (7,920 vs. 549 and 5,476 vs. 2,142, respectively) (Table 1). Virtually no *D. maidis* were trapped after November.

Macrosteles spp. were also commonly trapped with peak flight activity earlier in the growing season than for most other leafhoppers, and decreasing earlier in the fall than the other leafhoppers in this study (Table 1). More *Macrosteles* were trapped in young groves than in mature groves during both years (1,168 vs. 634, 4,580 vs. 1,490, respectively).

Scaphytopius acutus delongi was not trapped frequently at any time in any grove and constituted only 0.06% and 0.2% of the total of counted leafhoppers trapped during 1982 and 1983, respectively (Table 1). During both years, more *S. acutus delongi* were trapped in young vs. mature groves (65 vs. 38 and 219 vs. 69, respectively). Very few of this species were collected before June.

***Circulifer tenellus* in mature grove and adjacent breeding area.** Very few *C. tenellus* were trapped either five rows or 10 rows inside of a mature grove adjacent to the spring and winter breeding area near Oildale during either 1982 or 1983 (Table 2). At the edge of the breeding area adjacent to the grove, more were trapped than inside the grove but the number was still 24-fold less in 1982 and 14-fold less in 1983 than in the middle of the breeding area about 50 m farther from the grove. In 1982, the numbers of *C. tenellus* were quite low on traps in the breeding area after June, but in 1983 they remained high throughout most of the year.

DISCUSSION

The heavy flight activity of *C. tenellus* during the 3-month period in young citrus groves in the fall and the inoculativity 8% of males and females collected directly from young citrus in 1986 indicate a significant potential for spread of *S. citri* to young citrus trees by *C. tenellus* during that period of the year. Although males far

TABLE 2
NUMBER OF *CIRCULIFER TENELLUS* TRAPPED PER 4-WEEK PERIOD IN A RANGELAND BREEDING HABITAT IN RELATION TO A MATURE CITRUS GROVE NEAR OILDALE, CALIFORNIA DURING 1982-1983

Date	Total no. *Circulifer tenellus* trapped[z]			
	Rangeland middle	Edge, adjacent to mature citrus	Fifth row mature citrus	Tenth row mature citrus
1982				
May	92	7	0	0
Jun	391	3	1	0
Jul	29	7	0	1
Aug	17	0	0	0
Sep	26	3	1	0
Oct	26	2	0	0
Nov	14	0	0	0
Dec	11	3	0	0
Year total	606	25	2	1
1983				
Jan	0	0	0	0
Feb	0	0	1	0
Mar	0	0	0	0
Apr	1	5	1	0
May	259	11	3	0
Jun	147	7	0	0
Jul	335	5	0	0
Aug	172	12	0	1
Sep	159	10	1	1
Oct	62	12	1	0
Nov	412	16	0	0
Dec	443	81	0	1
Year total	1990	159	7	3
Grand total	2596	184	9	4

[z]Each of the four types of site had four yellow sticky-card traps. The traps in each set were placed at five-tree intervals and at distances equal to the distance between five trees inside and outside the grove.

outnumbered females on the traps, D-Vac[R] collections of a 1:1 ratio of males and females from young citrus trees at the site of greatest numbers of trapped males (Southwest Valley) suggest that the sex ratio in citrus may not be so heavily skewed towards males. Rather, this may reflect a tendency for males to take flight more readily, probably in search of females. Sweep net and D-Vac[R] collections of *C. tenellus* by the authors in the rangeland breeding areas near young groves, during the early winter, routinely garnered almost all females (unpublished data). We suggest that the preponderance of males on traps in fall may be connected with the different habits of the two sexes at this time. The low numbers of *C. tenellus* trapped in mature groves suggest that mature trees are probably subjected to much lower vector pressure. The extent to which vector pressure is reduced as trees mature and form a more closed canopy should be further investigated.

The failure to trap many *C. tenellus* in a mature grove adjacent to the breeding area is not especially surprising in light of the similarly small numbers trapped in other mature groves. However, the paucity of trapped *C. tenellus* at the boundary of the breeding area next to the mature grove was not anticipated. Perhaps the dark canopy of trees acts as a barrier to the movement of the leafhopper. More studies are needed to explain why so

few leafhoppers were trapped at the edge of the breeding area. If the close canopy of mature groves acts as a barrier to entry by *C. tenellus*, a crop or constructed barrier may have the same effect and could reduce the spread of *S. citri* into young groves.

Since the primary objective of this study was to study the flight phenology of *C. tenellus* in citrus, traps were set near the ground where previous studies had shown that the majority of the short-range flight of *C. tenellus* occurs (8). For this reason, the numbers of the other leafhoppers recorded from traps in this study may not be indicative of their actual activity in citrus in the San Joaquin Valley. Although *S. actus delongi* reproduces on citrus in the Valley, its numbers were especially low on traps set near the ground. Perhaps higher numbers would have been trapped if the sticky cards had been placed higher in relation to the tree canopy or if the trap had been a different color.

The collections of *Macrosteles* spp. in our surveys are noteworthy and suggest that it could also spread *S. citri* into citrus. Although one report from California suggested otherwise (7), *M. fascifrons* (Stål) transmitted *S. citri* from horseradish to certain noncitrus plants under experimental conditions in Illinois (3). The frequent occurrence of *D. maidis*, which is host-specific to corn for feeding and is an efficient vector the corn stunt spiroplasma, in San Joaquin Valley citrus groves was of interest because citrus environs may provide a suitable habitat for this insect. We did not, however, test whether *D. maidis* was inoculative for *S. citri*.

Although one species of Empoasca is known to transmit a mycoplasma-like organism, most species of this genus feed primarily in mesophyll tissue rather than in the phloem where *S. citri* is found and may not have much potential to transmit *S. citri*.

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