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Temporal Occurrence, Sampling, and Within-Field Distribution of Aphids[1] on Broccoli in Coastal California[2]

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ABSTRACT

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Aphid occurrence, population dynamics, and sampling procedures were studied in three consecutive broccoli plantings in southern California. *Myzus persicae* (Sulzer) was dominant during the fall and spring, and *Brevicoryne brassicae* (L.) was prevalent in winter. *B. brassicae* was the primary aphid contaminant of broccoli heads in all crops. *Hyadaphis erysimi* (Kaltenbach) and *Macrosiphum euphorbiae* (Thomas) occurred at low population levels and were of minor importance. Aphid distribution was aggregated when densities were low [$\log(x + 1) < 1.0$ per plant] but became random as populations increased. Sampling procedures based on 10-plant samples were useful in estimating aphid populations when densities exceeded a $\log(x + 1)$ value of 0.65 per plant. Aphid parasitization did not exceed 6% of available hosts in any planting and was not a major mortality factor.

Broccoli, *Brassica oleracea* L., has become a major agricultural commodity in California, with economic returns averaging in excess of $100 million annually (Anonymous 1979). Since broccoli production in California accounts for more than 90% of the total U.S. production (Reed and Horel 1979), interest in documenting insect pest species and developing biological information suitable for use in integrated pest management (IPM) programs has increased substantially during the last few years. The impact of various levels of lepidopterous larval populations on broccoli yield in California was studied by Wyman and Oatman (1977). Larval populations reaching nine per plant in the preheading stage did not significantly reduce yields. Kennedy and Oatman (1976) determined some of the major insect pests and evaluated the use of *Bacillus thuringiensis* Berliner and pirimicarb as selective pesticides for pesticides IPM in broccoli. They reported that aphids were the most frequent contaminant of harvested broccoli and must be controlled before head formation to reduce contamination. However, no attempts have been made to develop statistically acceptable sampling plans or to obtain basic biological information on the population dynamics, occurrence, and distribution of key insect pests on broccoli. Therefore, this study was conducted to determine the temporal and spatial occurrence of aphids on broccoli during the critical preheading stage and to evaluate sampling plans for monitoring aphid populations.

Materials and Methods

All experiments were conducted in three successive 0.4-ha plantings of 'De Cicco' broccoli at the University of California's South Coast Field Station, Orange County. Each broccoli planting was direct-seeded in single-row beds, sprinkle irrigated until emergence, and furrow irrigated thereafter. Row centers were 0.76 m apart in the fall, and 1.0 m apart in the winter and spring. The fall crop was planted on 22 August 1980, thinned on 9 to 10 September, and harvested 27 October. Winter plantings were seeded 11 November 1980, thinned on 15 December, and harvested 5 February 1981. The spring crop was planted on 20 February 1981, thinned on 26 March, and harvested 8 to 9 May. Four treatments were evaluated. Treatments consisted of unsprayed control plots, plots sprayed only after head formation had begun, plots sprayed when aphid numbers reached 100 per plant, and plots treated when aphid populations exceeded 5 to 10 per plant. Six-row plots, 20 m long, were replicated six times for each treatment and arranged in a randomized complete block design, with at least 5 m of untreated rows separating replicates. A buffer of at least 7 m of broccoli and 10 m of bare earth surrounded the entire test area to help reduce any "edge effect" or influence of windbreaks as reported by Lewis (1969).

Ten plants from the inside four rows of each plot were sampled for aphids by a stratified random sampling plan, except on 9 September, when 15 plants per plot were sampled. Each plant was assessed for numbers of alatae, apterae, and parasitized aphids. Sample numbers listed in Table 1 refer to aphid counts from all treatments which had not had pesticide applied before the specified sampling date. All broccoli plantings were monitored weekly from thinning until head formation. In the six untreated plots (60 plants), aphid species were counted separately to determine temporal occurrence and dominance. Table 1 gives sampling dates, temperature data, and related plant growth parameters.

Yields were measured by weighing 20 to 50 primary heads per replicate. Leaves were stripped off and stalks were trimmed to 10 cm before weighing. Maximum and minimum temperatures as well as wind velocity and direction were monitored daily.

Pirimicarb (0.28 kg of AI/ha), used to minimize aphid damage in the yield tests, was applied to the fall crop on 12, 19, and 26 September and 2 October, to the winter crop on 8 January, and to the

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Table 1.—Ambient temperatures, plant growth data, and sampling information for aphids associated with fall, winter, and spring broccoli in coastal California[a]

Crop	Sampling date[b]	n	$\bar{x}$ Plant height (cm)	$\bar{x}$ No. of leaves/plant	$\bar{x}$ Weekly temperature and range (°C)	Log ($\bar{x}$ + 1) aphids/plant	CV[c]
Fall	9 Sept.	360	10.0 ± 0.6	4.9 ± 0.1	18.1 ± 0.9 (24.4-10.5)	0.65 ± 0.18	27.6
	16 Sept.	240	14.0 ± 1.8	6.0 ± 0.7	18.4 ± 1.2 (27.2-9.4)	1.83 ± 0.06	32.2
	23 Sept.	240	17.9 ± 1.0	7.0 ± 0.2	19.1 ± 2.5 (32.2-10.5)	2.18 ± 0.18	8.3
	30 Sept.	120	26.5 ± 2.2	11.2 ± 1.1	18.8 ± 1.9 (31.1-10.5)	2.32 ± 0.06	3.0
	7 Oct.	60	41.2 ± 1.5	19.2 ± 3.0	19.3 ± 1.3 (30.5-11.7)	1.95 ± 0.18	9.4
Winter	15 Dec.	240	6.0 ± 0.7	4.6 ± 0.2	13.9 ± 2.3 (27.2-6.5)	0.34 ± 0.17	50.3
	22 Dec.	240	9.1 ± 0.6	5.4 ± 0.2	13.3 ± 2.9 (28.3-2.8)	0.26 ± 0.15	58.6
	29 Dec.	120	13.6 ± 1.0	6.1 ± 0.2	14.2 ± 2.6 (29.9-3.9)	0.42 ± 0.22	52.8
	5 Jan.	120	19.2 ± 2.2	8.0 ± 0.6	13.9 ± 2.9 (29.4-5.5)	0.79 ± 0.09	11.4
	12 Jan.	120	22.5 ± 1.7	11.6 ± 0.6	13.6 ± 2.5 (23.9-2.8)	1.07 ± 0.14	13.1
	19 Jan.	120	28.9 ± 1.9	18.5 ± 1.5	13.7 ± 0.6 (22.2-6.7)	1.15 ± 0.21	18.4
Spring	26 Mar.	240	8.8 ± 0.6	5.8 ± 0.1	13.3 ± 1.8 (22.2-6.1)	0.44 ± 0.13	30.5
	3 Apr.	240	12.8 ± 0.9	7.2 ± 0.4	12.2 ± 1.2 (21.6-3.8)	0.84 ± 0.17	20.3
	8 Apr.	240	17.6 ± 0.3	8.1 ± 0.6	15.6 ± 2.4 (30.0-5.0)	1.17 ± 0.18	15.5
	15 Apr.	120	23.4 ± 0.8	12.5 ± 0.5	15.0 ± 1.3 (21.6-7.7)	1.61 ± 0.12	7.5
	22 Apr.	120	35.2 ± 1.3	20.1 ± 0.8	14.8 ± 2.0 (25.0-6.1)	1.76 ± 0.10	5.7

[a]Values represent means ± SD.
[b]Samples taken between thinning and heading.
[c]CV, Coefficient of variation.

spring crop on 3 and 10 March. Aphid densities of 5 to 10 per plant were treated on each date listed; aphid densities of 100 per plant were sprayed on 2 October. *B. thuringiensis* (16.03 BTU/kg) was applied at 1.12 kg/ha when two or more larvae per plant were found, so as to reduce damage caused by lepidopterous larvae during the preheading period. Applications were made to the fall crop on 12, 19, and 26 September, to the winter crop on 2 January, and to the spring crop on 3, 10, and 30 March. After head formation, methomyl was applied at 1 kg of AI/ha to limit aphid damage to the preheading stage. Control plots were not treated. Insecticides were applied by a tractor-mounted row crop sprayer, and Biofilm® (0.04%) was included in all sprays as a spreader-sticker. The number of hollow cone nozzles per row varied from 1 to 5 depending on plant height, and carrier varied from 282 to 934 liters/ha. Nozzle pressure was adjusted from 4.2 to 7.1 kg/cm^2 as plant height and foliage density increased.

Statistical Analysis

Variance in aphid counts was stabilized with the log(x + 1) transformation as suggested by Hayman and Lowe (1961) and Taylor (1970). On each date, normality was confirmed by the Proc Univariate Normal procedure of the Statistical Analysis System (SAS) (Helwig and Council 1979). Yield data were compared between treated and untreated plots by analysis of variance, and regression analysis was performed with the Proc GLM program of SAS. The Proc means procedure of SAS produced mean aphid counts per plant and the coefficient of variation listed in Table 1. Lloyd's "Patchiness Index" was calculated as described by Lloyd (1967).

Results and Discussion

Temporal Occurrence of Aphid Species

The green peach aphid (GPA), *Myzus persicae* (Sulzer), was the dominant aphid species throughout most of this study (Fig. 1–3). During the fall and spring plantings, GPA accounted for ca. 70% of the total aphid populations. Only when cool weather occurred during December and January did the cabbage aphid, *Brevicoryne brassicae* (L.), predominate. As mean temperatures increased during March and April, GPA rapidly regained numerical superiority. In spite of relatively high GPA pressure

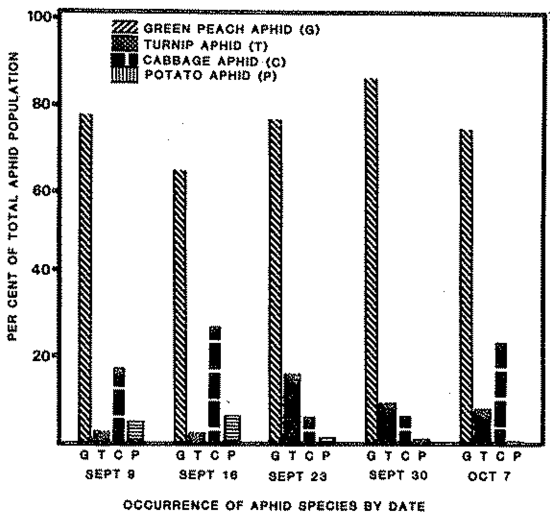

FIG. 1.—Relative dominance of aphid species occurring on fall broccoli in Orange County, Calif.

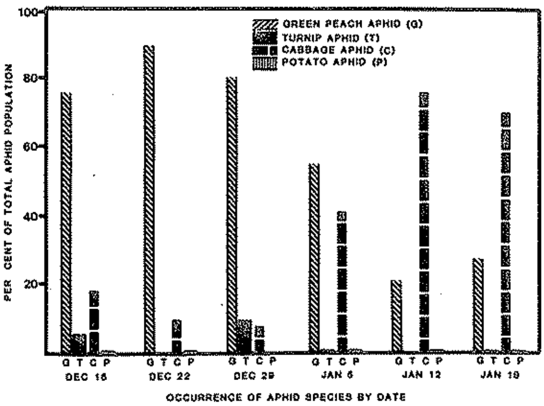

FIG. 2.—Relative dominance of key aphid species occurring on winter broccoli in Orange County, Calif.

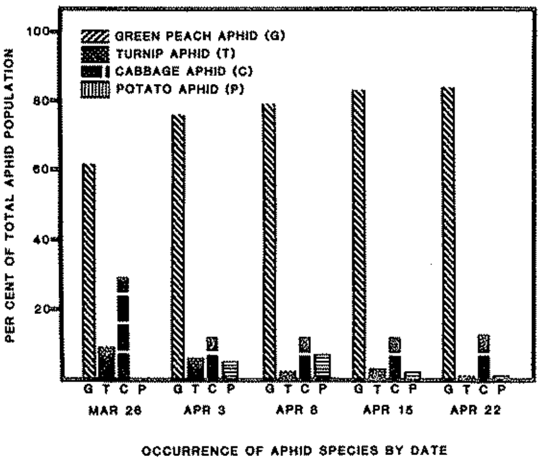

FIG. 3.—Relative dominance of key aphid species occurring on spring broccoli in Orange County, Calif.

in the fall crop and small to moderate populations in the spring planting, there were no significant differences in yield between untreated control plots and all other treatments, including plots which were treated weekly with pirimicarb whenever aphid populations exceeded 5 to 10 per plant. Thus, economic injury levels of aphids for yield were not reached, and insecticide treatments for aphid densities of less than 100 per plant were not justified by yield losses. Pirimicarb effectively reduced aphid populations by at least 95% for each application. Unusually warm weather during head development in the winter crop caused bolting, and comparative yield data could not be collected.

Despite the numerical superiority of GPA, *B. brassicae* was the most important aphid species on broccoli. *B. brassicae* occurred primarily on the highest and youngest leaves and readily migrated into the developing heads. In all plantings, *B. brassicae* was the most prevalent aphid contaminant at harvest. This study corroborates the information reported by Kennedy and Oatman (1976) on the importance of *B. brassicae* as a contaminant of broccoli.

The turnip aphid, *Hyadaphis erysimi* (Kaltenbach), and the potato aphid, *Macrosiphum euphorbiae* (Thomas), were present at low population levels in all plantings (Fig. 1–3). Unlike *B. brassicae*, these species did not preferentially feed in the broccoli heads, and consequently were of minor importance. The red biotype of the potato aphid was the dominant form during the fall crop and early winter crop, which greatly facilitated identification and separation of species. The green biotype was prevalent throughout the remainder of the study and was separated from the other species on the basis of relative lengths and coloration of body, cornicles and legs, and size of antennal tubercles (Palmer 1952, Kono and Papp 1977). *M. ambrosiae* (Thomas), *Schizaphis graminum* (Rondani), and *Aphis spiraecola* Patch were occasionally encountered, but since these species do not accept broccoli as a host, temporal occurrences were not recorded.

Population Dynamics

A combination of environmental, behavioral, and developmental factors resulted in substantially lower aphid populations in the winter crop as compared with densities in fall or spring broccoli plantings (Table 1). Fluctuating temperatures during late December and January appeared to depress aphid migration into the winter crop. Early-morning temperatures were low (3 to 7°C) during crepuscular flight periods, and the subsequent rise in temperature was associated with an increase in wind velocity ($\bar{x}$ = 107 cm/sec) to levels which behaviorally affect aphid flight activity (Kennedy and Stroyan 1959, Woodford 1969, Dry and Taylor 1970). Also, cooler temperatures which occurred during the winter crop increased aphid developmental times and thereby reduced alatae production. Finally, the major migrations of aliencolae or alate viviparae may have occurred during the fall and spring. Mild winters, such as those in southern California, tend to suppress aphid sexual cycles and emphasize parthenogenetic reproduction (Hughes 1963).

In all plantings, alate migrants produced apterous viviparous females which rapidly increased nymphal populations. Relationships between alate and apterous aphid populations are diagrammed in Fig. 4, 5, and 6 for fall, winter, and spring crops, respectively. Increases in apterous aphid densities initially followed a sigmoid pattern in winter and spring plantings, but host plant carrying capacities were not reached and population growths did not level off. In the fall crop, migrant populations reaching four per plant within a week after thinning resulted in an almost linear increase in apterae. Apterous aphids averaged 200 per plant by week 3 postthinning (30 September), but high winds which lodged the broc-

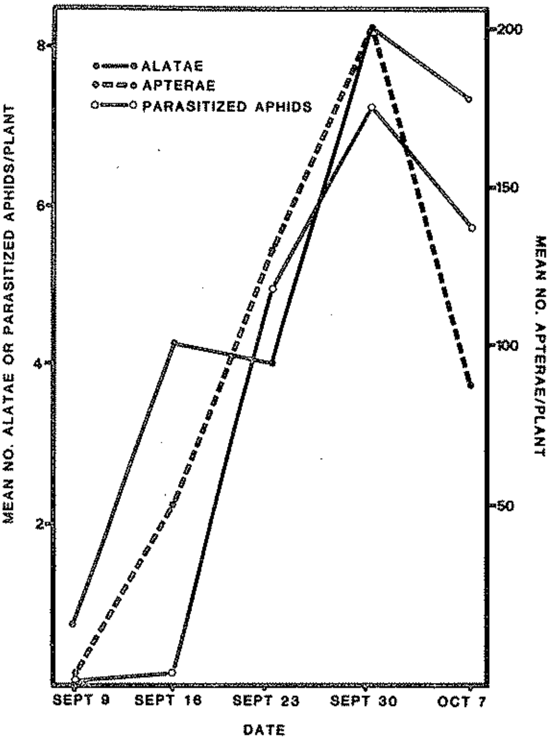

FIG. 4.—Occurrence of alatae, apterae, and parasitized aphids on fall broccoli between thinning and head formation.

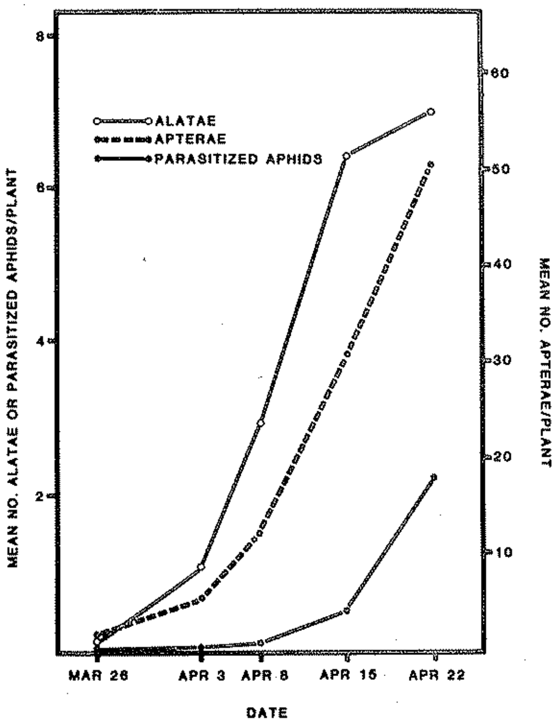

FIG. 6.—Occurrence of alatae, apterae, and parasitized aphids on spring broccoli between thinning and head formation.

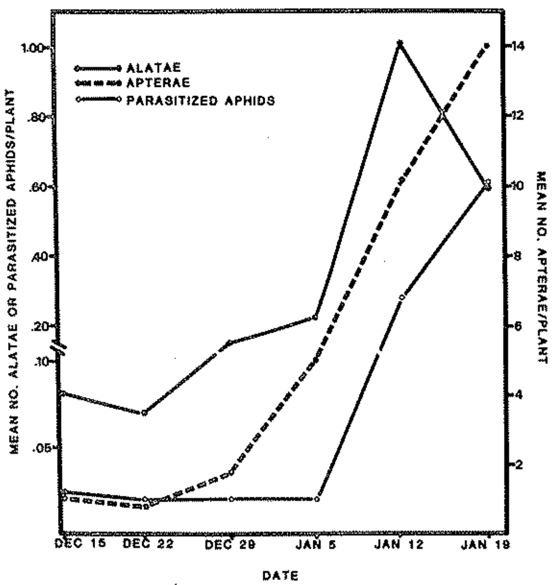

FIG. 5—Occurrence of alatae, apterae, and parasitized aphids on winter broccoli between thinning and head formation.

coli (gusts >52 km/h) and a rapid buildup in syrphid populations reduced alate and apterous aphid numbers (Fig. 4). Similarly, in the winter crop, environmental conditions during mid-January suppressed aphid migration into the study site, and numbers of alatae declined through natural attrition (Fig. 5).

Parasitism was not a major mortality factor for aphids during any broccoli planting studied (Fig. 4–6). At most, only 6% of the aphids were affected. The only parasite species reared from aphids in these experiments was a braconid, *Diaretiella rapae* (MacIntosh) ($n = 30$), which parasitized both *M. persicae* and *B. brassicae*. *D. rapae* has been reported attacking *B. brassicae* on cabbage in southern California (Oatman and Platner 1973) and *M. persicae* and *B. brassicae* in many other locations (Prethebridge and Mellor 1936, George 1957, Hafez 1961, Read et al. 1970). Hyperparasites were not identified, but studies by Oatman and Platner (1973) at the University of California's South Coast Field Station found that *Alloxysla brassicae* (Ashmead) was the most common hyperparasite present.

Aphid Sampling and Within-Field Distribution

Since aphid sampling techniques can be affected by aphid distribution, Lloyd's Patchiness Index was calculated to estimate the within-field distribution of aphids for each crop (Fig. 7). At low population levels, aphids were aggregated. As aphid density increased, distribution became random. Therefore, sampling techniques used for scouting aphid populations should be designed to account for a change in

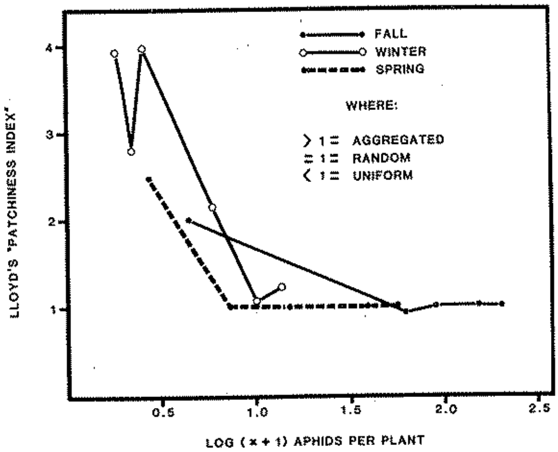

FIG. 7.—Aphid distribution in three consecutive broccoli plantings in coastal California.

distribution as aphid populations increase.

The 10-plant sampling unit effectively reduced variation in aphid counts when populations exceeded a log(x + 1) value of 0.65 (Table 1). As the number of aphids per plant increased, variation decreased. Thus, at higher population levels, fewer samples per ha would be required to assess aphid populations with statistically acceptable accuracy (10 to 20% error). However, this sampling method was both labor intensive and time consuming and would probably not be cost effective for scouting if aphid infestations were small.

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