Optimal Soil Placement and Application Method of Admire* for Sweetpotato Whitefly Control in Head Lettuce

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Abstract

The effects of Admire formulation and soil placement on colonization by sweetpotato whitefly, *Bemisia tabaci* (Gennadius), at three plant growth stages of lettuce, *Lactuca sativa* L., were evaluated in experimental and commercial lettuce plots in 1993-1994. We also evaluated the effects of Admire treatments on yield response and incidence of chlorosis associated with whitefly control. Admire placement had a significant affect on whitefly colonization in lettuce throughout the experimental period. Whitefly densities on lettuce varied at each plant stage relative to depth of placement within the lettuce seed bed. Applications made to the soil surface and at 1.5 inch sub-seed furrow followed by irrigation, provided the most consistent control of whitefly nymphs in both small plot and on-farm lettuce plots. These Admire soil treatments also prevented reductions in head size and incidence of leaf chlorosis associated with whitefly colonization in lettuce. *Our data suggest that incorporation of Admire into the upper 1.5 - 2 inches of soil below the seed furrow is optimal for absorption and translocation by lettuce roots.* Admire soil treatments may provide a more environmentally suitable and effective alternative to control of whiteflies in lettuce than is currently possible with foliar insecticide reatments.

Introduction

The sweetpotato whitefly, *Bemisia tabaci* (Gennedius) - B strain, also known as the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, is a major economic pest of several vegetable crops. Head lettuce, *Lactuca sativa* L., grown in Arizona and southern California is particularly susceptible to whitefly feeding injury during September and October when populations migrate onto newly emerging seedlings from surrounding cotton, *Gossypium hirsutum* L., and melon, *Cucumis melo* L., crops. Management of whitefly populations on fall grown lettuce crops normally requires multiple applications of foliar insecticides to suppress adult populations. Because *B. tabaci* adults feed and oviposit predominantly on the abaxial surfaces of leaves, a large proportion of the eggs and nymphs infesting lettuce plants are protected from insecticide sprays. Consequently, once immature stages have colonized plants, control is very difficult to achieve. An effective systemic insecticide would alleviate the spray coverage problems associated with control of whiteflies with foliar insecticides in lettuce.

Admire, a new chloronicotynal insecticide, has activity against many economically important insect pests such as aphids, whiteflies and thrips. It has good systemic activity in the plant, and may be appropriate for soil applications in some crops. However, because Admire is relatively immobile in the soil, efficient plant uptake is dependant on precise placement of the chemical within the root zone. Thus, the systemic activity of Admire against insects may vary depending on the crop, formulation, and application method. For example, soil applications of a flowable formulation of Admire prevented green peach aphid, *Myzus persicae*, populations from contaminating lettuce heads at harvest. Similarly, the systemic activity of Admire can be affected by the depth of placement in crop root zones. However, no information is available concerning the effects of Admire formulation, methods of application and depth of soil placement for protecting lettuce from *B. tabaci*. The objective of this study was to determine the effects of Admire formulation and depth of soil placement on the colonization of sweetpotato whitefly, crop yield, and incidence of chlorosis in head lettuce.

Materials and Methods

Effects of Soil Placement and Formulation, 1993. Lettuce 'Desert queen' was direct seeded at a depth of 1.5-2.0 mm on September 9, 1993 into double row beds at the University of Arizona Yuma Agricultural Center, Yuma AZ. Plots consisted of four beds 25 m long and spaced 1 m apart. Plots were bordered by two unplanted buffer rows. The lettuce plots were established with overhead sprinkler irrigation. After stand emergence, all plots were furrow irrigated until harvest. The soil type of the research site consisted of a Gadsden clay (< 0.05% organic matter). Normal cultural practices were used in preparation and maintenance of experimental plots.

The study was conducted as a 2 x 4 factorial experiment, with Admire formulation and soil placement as main effects, in a randomized complete block design. The two Admire formulation treatments were a flowable (Admire 2F, Bayer Co, Kansas City, MO) and a granular (NTN33893 2.5G, Bayer Co., Kansas City, MO). The soil placement treatments consisted of Admire applied at a rate of 0.34 kg (AI)/ha at several depths in the soil in the following manner: 1) 6 inch sub-seed furrow prior to planting; 2) 3 in sub-seed furrow prior to planting; 3) directly on the soil surface at the seed line immediately following planting; and 4) an untreated control. All treatment combinations were randomly assigned to each of four blocks.

All applications of the Admire flowable treatments were applied with water and delivered at 140 liters/ha total volume. The flowable formulation treatments placed below the surface at 3 and 6 inches were applied by injecting the material into the soil through long, narrow shanks adjusted to deliver the solutions at their precise locations in the soil. The soil surface application was applied as a five cm band through a CO_2 delivered spray system using 8003 flat-fan nozzles centered on the seed line. The granular Admire formulation was applied to the soil using a standard granular applicator (Gandy Co., Owatonna, MN) with narrow shanks adjusted to deliver the granules at their precise locations in the soil. The soil surface application of the 2.5 G formulation was applied by dispersing the granules directly on the soil, centered on the seed line, in a five cm band. No other pesticides were applied to the plots except *Bacillus thuringiensis* (Javelin®, Sandoz Agro Inc, Des Plaines, IL), that was applied to all plots on a weekly basis for control of lepidopterous larvae.

Effects of Soil Placement, 1994. Lettuce 'Desert queen' was direct seeded at a depth of 1.5-2.0 mm on September 1, 1994 into double row beds at the University of Arizona Yuma Agricultural Center, Yuma AZ. Plots consisted of four beds 30 m long and spaced 1 m apart. Plots were bordered by two unplanted buffer rows. The lettuce was germinated using overhead sprinkler irrigation and was furrow irrigated thereafter until harvest. The soil type of the site was a Gadsden clay (< 0.05% organic matter). Methomyl (Lannate®, DuPont, Wilmington, DE) was applied 7 and 12 Sept, and *Bacillus thuringiensis* (Xentari®, Abbott Labs, Chicago, IL) was applied on Sept 23, 30 to all plots for control of lepidopterous larvae.

A randomized complete block design with four replications was used. Soil placement treatments consisted of Admire (Admire F) applied at 0.34 kg (AI)/ha to the soil in the following manner: 3 inch sub-seed furrow prior to planting; 1.5 inch sub-seed furrow prior to planting; and directly on the soil surface at the seed line immediately following planting. Also included were a standard foliar insecticide treatment that consisted of weekly applications of a mixture of bifenthrin (Capture 2EC®, FMC Corp, Philadelphia, PA) at 0.09 kg [AI]/ha and endosulfan (Gowan Endosulfan 3EC®, Gowan Co., Yuma, AZ) at 1.1 kg [AI]/ha; and an untreated control. Methodology for application of Admire treatments was similar to that used in 1993. In the foliar standard treatment, five applications were made at 7-d intervals beginning on 18 Sep. Applications were made with conventional application equipment configured with Twin-Jet flat-fan nozzles (TJ 8004VS; Spray Systems Co, Wheaton, Il) spaced at 50 cm intervals. Each nozzle was calibrated to deliver 22.0 ml/s, providing an application volume of 386 liters/ha at 207 KPa and 8.3 km/h.

On-Farm Validation. During the fall of 1994, large-scale commercial field tests were conducted in lettuce fields (12-20 ha) near Wellton, AZ, owned and managed by Barkley Co. of Arizona (Somerton, AZ). Plots were 0.5 ha, arranged in a randomized complete block design, and replicated seven times (3.5 ha per treatment) with different fields as replicates. 'Desert queen' lettuce was direct seeded at a depth of 2.0-3.0 mm on 7-9 Sept into fields where the soil type was predominantly a Rositas sandy loam and located within a 5 km growing area. Three treatments were evaluated in each field: (1) Admire 2F applied 1.5 inch sub-seed furrow just prior to planting; 2) Admire 2F applied directly on the soil surface at the seed line immediately following planting; and 3) an untreated control. The rate and application methods of Admire were similar to the aforementioned tests except that sprinkler irrigation was not initiated until 12-24 hours after the application of the surface band treatment.

Assessment of *B. tabaci* Colonization and Lettuce Yields. Lettuce plants were sampled for immature *B. tabaci* densities three times each season, based on crop phenology. Twenty basal leaves from the center rows of each plot were collected randomly from ten lettuce plants at: thinning stage (4-leaf stage; 21 days after planting), heading or "rosette" stage (leaves begin to cup inward to form heads; 50 days after planting), and harvest (mature heads; 69-77 days after planting). Samples were taken to the laboratory where six 1-cm^2 areas were selected randomly on each leaf, and the numbers of all immature stages of sweetpotato whiteflies were counted using a stereo microscope and recorded. Total life stages on each leaf were grouped into eggs, crawlers and small nymphs (first and second instar nymphs), large and red-eyed nymphs (third and fourth instar nymphs), and eclosed pupal cases. Immature densities were grouped into eggs and nymphs for samples collected from the on-farm validation study. Lettuce was harvested from three m of one bed of each plot. Weight (kg) and diameter (cm) were measured for each head and averaged for each plot. Leaf chlorosis resulting from whitefly feeding was quantified (SPAD Index) with a nondestructive chlorophyll meter (model SPAD-502, Minolta Corp., Ramsey, N.J.) by measuring relative leaf chlorophyll level from 20 wrapper leaves per plot at each plant growth stage.

Results

Effects of Soil Placement and Formulation, 1993. Factorial analyses of variance indicated that the effects of Admire formulation on immature whitefly densities were not significant at each plant growth stage in 1993. Interactions between the effects of Admire formulation and soil placement were only significant for egg densities at thinning and harvest. The mean number of eggs/cm^2 in the soil surface treatment was significantly lower than the untreated control, except when flowable formulation was used at thinning (Table 1). The mean number of eggs in the3 in sub-seed furrow were not different from the soil surface plots at thinning when the granular formulation was used.

Effects of soil placement on density of sweetpotato whitefly nymphs were significant in most cases. The mean numbers of nymphs per cm^2 in the soil surface plots were significantly lower than the untreated control at each lettuce growth stage, except at thinning when numbers of large and red-eyed nymphs did not differ among the treatments (Fig. 1). Mean numbers of nymphs measured at harvest in the 3 in sub-seed furrow treatment were significantly lower than the untreated control, and similar to the soil surface treatment. Nymph densities in the 6 inch sub-seed furrow treatment did not differ from the untreated control at any plant growth stage. Eclosed pupal cases were only detected on leaves at harvest, and effects of placement were not significant.

Admire formulations did not have a significant effect on lettuce yields. Similarly, interactions between the effects of placement and formulation were not detected among the treatments. In contrast, depth of soil placement had a significant effect on lettuce head wt and diameter. The mean wt per head in the soil surface and 3 inch sub-seed furrow plots was significantly greater than in the untreated control plots (Table 2). However, the soil surface application was the only Admire treatment that yielded larger head diameters than the untreated control. The mean number of heads per plot among treatments were not significantly different.

Effects of Soil Placement, 1994. The effects of soil placement on sweetpotato whitefly colonization at each plant stage are shown in Fig.2. At thinning, the mean number of eggs per cm^2 were similar in the soil surface and sub-seed furrow treatments and were significantly lower than the untreated control. Mean numbers of crawlers and small nymphs were lower in the Admire and foliar standard treatments than in the untreated control, but the soil surface treatment provided the most significant reduction in mean nymph densities. The mean numbers of large and red-eyed nymphs, and eclosed pupal cases per cm^2 did not differ among treatments at the thinning and heading stages.

At the heading stage, the mean numbers of eggs, and crawlers and small nymphs per cm^2 in the Admire soil surface and sub-seed furrow plots were significantly lower than in the untreated control plots. Egg densities measured in the foliar standard treatment were significantly lower than all other treatments, but mean densities of crawlers and small nymphs in the foliar standard plots were not different from the soil surface and sub-seed furrow plots.

Mean egg densities in the foliar standard treatment were significantly lower than any other treatment at harvest (Fig. 2). All insecticide treatments had significantly lower numbers of crawlers and small nymphs, and large and red-eyed nymphs per cm^2 than the untreated control. However, mean nymph densities in the foliar standard treatment were significantly lower than the Admire soil treatments and untreated control. The mean number of pupal cases per cm^2 were significantly greater in the untreated control than in all other treatments. There were no differences in the mean number of pupal cases per cm^2 between the Admire soil treatments and the foliar standard.

Difference in the mean number of lettuce heads per plot did not differ significantly among treatments (Fig. 2). Differences in mean head weight and diameter among the soil surface, sub-seed furrow and the foliar standard treatments were not significant. Head weight and head diameter in the soil surface, sub-seed furrow and foliar standard plots were significantly greater than in the control plots. Relative leaf chlorophyll levels, as indicated by SPAD index values, were not significantly different among treatments at the thinning and heading stage. However at harvest, SPAD values were significantly higher in the 1.5 inch sub-seed furrow treatment and the foliar standard than in all other treatments.

On-Farm Validation, 1994. The mean number of eggs per cm^2 was significantly lower in the soil surface and 1.5 inch sub-seed furrow Admire plots than in the untreated control plots at each plant growth stage (Fig-2 A,B,C). Similarly, the mean number of nymphs was significantly lower in the soil surface and 1.5 inch sub-seed furrow Admire plots than in the untreated control plots at each plant stage. Mean lettuce yields were significantly greater in the soil surface and 1.5 inch sub-seed furrow Admire plots than in the untreated control plots (Fig 2 D). Mean SPAD values measured at thinning and heading were not significantly different among the treatments. Mean SPAD values at harvest were significantly higher in the soil surface (33.6 $\pm$ 1.0) and 4 cm sub-seed furrow plots (32.3 $\pm$ 1.2) than in the untreated (26.5 $\pm$ 0.7) plots.

Discussion

These data clearly show that the use of Admire as a soil incorporated insecticide treatment is an effective method to prevent significant whitefly colonization in head lettuce. Whitefly densities on lettuce plants varied relative to the availability of Admire at the soil-root interface, regardless whether the flowable or granular formulation was used. Consequently, the relationship between lettuce root distribution, and depth of Admire placement within the seed bed had an important influence on the root uptake and systemic activity of the chemical in the plant. Lettuce plants tend to concentrate their root mass within the upper 6 inches of the seed bed. The primary (tap) root of seedling plants can be found deep in the soil and the initial secondary (lateral) roots form in the upper 5-10 cm of soil upon emergence of true leaves. Measurements of seedling lettuce roots during this study indicated that tap roots averaged 8.2 $\pm$ 0.3 cm (n=20) in length and lateral roots (1-3 mm) had started to grow from the upper 1-2inches of the tap root when the cotyledons first emerged. Our results show that Admire applied to the soil surface and hydrologically moved downward into the root zone with sprinkler irrigation, or placed 1.5 inch sub-seed furrow at planting, significantly prevented whiteflies from colonizing lettuce plants at each plant growth stage. The maximum depth to which the surface application was moved into the root zone is not known, but our data suggests that the Admire was dispersed within the top 1.5-2 inches below the seed during early plant growth (Table 3, Fig 2). These results are consistent with similar studies where aphid colonization was prevented in head lettuce following soil surface band and sub-seed furrow applications of Admire. Apparently, the placement or movement of Admire into the soil, 1.5-2 inches below the seed, is optimal for absorption and translocation by lettuce roots prior at thinning and heading. In contrast, the failure of Admire placed 3 inchsub-seed furrow to reduce whitefly colonization at thinning suggests that placement at this depth was not sufficient for absorption by the tap root, and too deep for adequate uptake by the lateral roots. Furthermore, Admire placement below 3 inches was not efficiently taken up by the plant and thus did not prevent whitefly colonization at any plant stage.

Admire soil treatments prevented reductions in head size and the incidence of chlorosis associated with whitefly on lettuce. Head weight and diameter varied with Admire placement and incorporation in the seed bed. Greatest head size was consistently observed in the soil surface and sub-seed furrow applications where significant whitefly colonization was prevented. It is unlikely that the Admire had any physiological influence on lettuce growth or head size, exclusive of whitefly control. This is further supported by the similarities in whitefly colonization and lettuce yields observed between the Admire and foliar standard treatment. Incidence of chlorosis in lettuce relative to Admire soil placement was more variable than were the measurements of head size. SPAD values measured in the small plot study were greatest in the 4.0 sub-seed furrow and foliar standard treatments, and values measured in the soil surface plots did not differ from the untreated control. However, in the on-farm evaluation, SPAD values for the surface band and 1.5 inch placement were similarly greater than the control. Differences in soil types, fertilization, irrigation, and other environmental factors at the small plot and on-farm experimental sites may account for this variability in measurements of chlorosis.

Stand establishment of lettuce crops during September and October in Arizona and southern California normally coincides with large migrations of whiteflies from adjacent crops. Protection of emerging seedlings from sweetpotato whitefly is critical for producing marketable crops. The yield responses to Admire observed in these studies are of practical significance in commercial lettuce production because decisions to control whiteflies are usually based on the growers perception of the insects potential to reduce head size and cause chlorosis of leaves. With optimal soil placement and incorporation, prophylactic application of Admire can protect early growth stages of lettuce from colonizing whitefly populations. Collectively, these results on efficacy against whitefly, reduction in head size and incidence of plant chlorosis, demonstrates that placement or incorporation of Admire within the upper 3-4 cm of the soil appears to be optimal for systemic activity of the compound in head lettuce. Validation of soil surface and sub-seed furrow applications in commercial lettuce fields further support this conclusion. Although both of these application methods will provide comparable control of whiteflies, potential problems associated with off-target movement, ease of application, worker exposure, and photodegredation of Admire are less likely to occur with the sub-seed furrow placement. However, it should be noted that prophylactic applications of Admire, regardless of placement, increase the potential for development of Admire resistance in whitefly and aphid populations. Finally, soil incorporation of Admire at planting provides a more environmentally suitable and effective alternative to control of whiteflies under high-risk situations in lettuce (Kerns and Palumbo 1995), than is currently possible with foliar insecticide treatments.

Table 1. Mean eggs (±SEM) per cm^2 per leaf on lettuce plants treated with flowable and granular formulations of Admire relative to soil placement at the thinning and harvest stages of plant growth, YAC, 1993

	Thinning		Harvest	
Placement	Flowable	Granular	Flowable	Granular
Soil surface	10.2 ± 2.4 a	8.1 ± 1.9 b	2.1 ± 0.2 b	1.8 ± 0.2 b
Sub-seed furrow, 3 in	14.5 ± 3.6 a	11.1 ± 2.3 b	2.6 ± 0.7 ab	2.3 ± 1.5 ab
Sub-seed furrow, 6 in	20.6 ± 2.1 a	22.7 ± 5.5 a	3.0 ± 0.3 ab	3.0 ± 0.3 a
Untreated control	14.6 ± 1.7 a	21.1 ± 2.0 a	3.3 ± 0.3 a	5.3 ± 0.6 a

Means within columns followed by the same letter are not significantly different (LSD; $P<0.05$).

Table 2 . Lettuce yields in response to 3 different placements of Admire in the soil, YAC 1993

Placement	No. heads/ 4 m	Wt/head, kg	Head diam., cm
Soil surface	21.0 ± 1.2 a	0.76 ± 0.01 a	15.7 ± 0.3 a
Sub-seed furrow, 3 in	20.8 ± 1.6 a	0.71 ± 0.03 a	14.7 ± 0.3 b
Sub-seed furrow, 6 in	20.7 ± 0.7 a	0.69 ± 0.02 ab	14.6 ± 0.4 b
Untreated control	21.8 ± 0.5 a	0.65 ± 0.03 b	14.5 ± 0.3 b

Means within columns followed by the same letter are not significantly different LSD; $P<0.05$.

Fig 1. Mean (± SEM) number of whitefly crawlers and small nymphs, and large and red-eyed nymphs per cm^2 of lettuce leaf at thinning (A), heading (B), and harvest (C), YAC, 1993

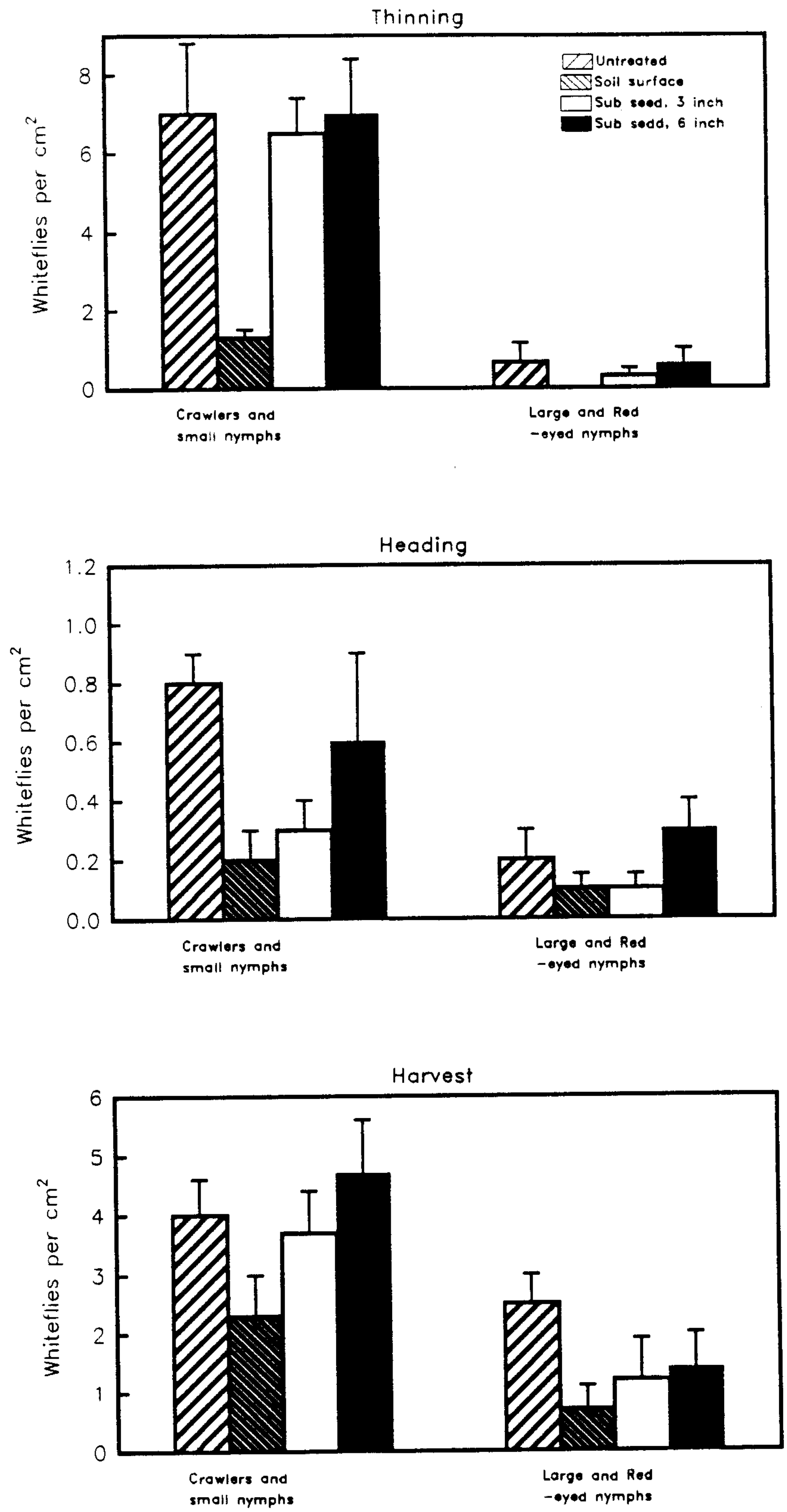

Fig 2. Mean (± SEM) number of whitefly eggs and nymphs per cm² area of lettuce leaf at thinning, heading , and harvest; and mean head wt, diameter, and chlorosis per plot , Yuma Ag Center, AZ, 1994.

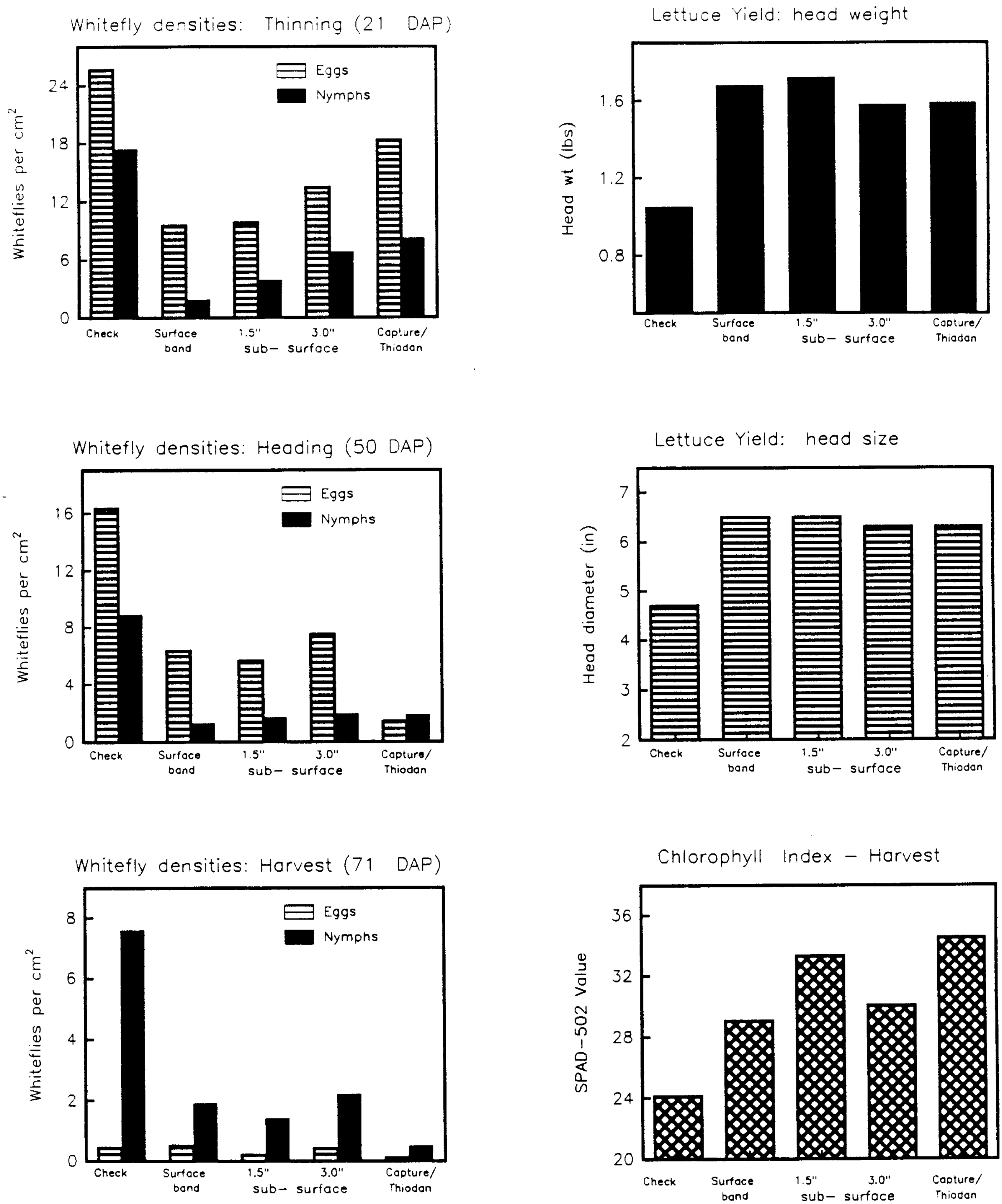

Fig 3. Mean (± SEM) number of whitefly eggs and nymphs per cm[2] area of lettuce leaf at thinning, heading , and harvest; and mean head wt, diameter, and chlorosis per plot , Dome Valley, AZ, 1994.