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Management strategies of aphids (Homoptera: Aphididae) as vectors of pepper viruses in western Massachusetts.

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MANAGEMENT STRATEGIES OF APHIDS (HOMOPTERA: APHIDIDAE) AS VECTORS OF PEPPER VIRUSES IN WESTERN MASSACHUSETTS

A Dissertation Presented

by

Dario Corredor

Submitted to the Graduate School of the
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DOCTOR OF PHILOSOPHY

May 1988

Entomology

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Approved as to style and content by:

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Entomology

To Consuelo, Paula and Anamaria

whose love and support helped

me through all these years.

ACKNOWLEDGEMENTS

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ABSTRACT

MANAGEMENT STRATEGIES OF APHIDS (HOMOPTERA: APHIDIDAE) AS VECTORS OF PEPPER VIRUSES IN WESTERN MASSACHUSETTS

MAY 1988

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Directed by: Professor David N. Ferro

Potential aphid vectors of nonpersistent viruses of green pepper Capsicum annuum L. were monitored by the use of color traps at the University of Massachusetts Research Farm at Sunderland, MA. Yellow pan traps were used to determine the main species landing on green pepper plants.

Nonpersistent viruses are mainly vectored in peppers by two colonizing species of aphids, the green peach aphid, Myzus persicae (Sulzer) and potato aphid, Macrosiphum euphorbiae (Thomas). Foliage mimic traps (peak reflectance of 14% at 550 nm) were used to monitor the number of alate aphids landing in pepper plots. It appears that initial spread of pepper viruses could be by non-colonizing species, such as Cavariella sp. and Capitophorus eleagni (Del Guercio) as the colonizing aphid species were in low numbers at this time. Reflective mulch alone or in combination with a highly refined summer oil may reduce the spread of viruses when compared to oil alone or the control. The number of alighting aphids was lower in mulch treatments in 1982 but not in 1981. The yield of marketable fruit was highest for the mulch treatments.

Yellow, ermine lime ceramic tile and green foliage mimic traps were compared. The mean number of aphids caught increased as the trapping surface increased for yellow and foliage mimic traps. Trap background significantly influenced the number of aphids caught per trap. When yellow or foliage mimic traps were placed over reflective mulch, virtually no aphids were trapped. Yellow traps placed over soil background, caught more potato aphid than when placed over a given foliage mimic background. When the foliage mimic traps were placed over soil and foliage mimic background, there was no difference in the number of green peach aphid and potato aphid caught. Higher numbers of miscellaneous aphids were trapped over soil.

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CHAPTER I

INTRODUCTION

Yellow Pan Traps

Many researchers have reported on the behavioral response of aphids to visible light spectrum (Broadbent 1948, Moericke 1951, 1955, 1969, Kennedy and Stroyan 1959, Kring 1967, 1970 and others). Kennedy et al. (1961) suggested that the primary function of color vision in flying aphids is to distinguish plants from the sky, besides any subsidiary discrimination among plants and soils. Such a primary discrimination could be achieved by a differential response to spectral wavelengths longer or shorter than 500 nm.

It has been proposed that the flight behavior of migrant aphids has two different moods (Moericke 1955). A distance-flight mood occurs when the aphid takes off attracted by the shortwave light from the sky. Conversely, the development of a negative response to shortwave light is thought to terminate the distance-flight and to drive the aphids to an alighting-flight mood in which the flying aphids are attracted to longwave radiation. Kennedy et al. (1961) stated that there is a delicate balance between the upward pull of the skylight and the downward pull of the longwave radiation from plants and soil. The change in behavior from distance-flight to alighting-flight might be due to a relative strengthening of the positive response to longwave radiation reflected and emitted by plants and soil. Aphids in the distance-flight mood take off in a fast, obstacle-avoiding flight towards the open sky (Kennedy and Troyan 1959). During the alighting-flight mood aphids may land on plants, taste them and resume flight. These plant-visiting flights far outnumber first flights (Kennedy and Troyan 1959). Kennedy and Booth (1963) demonstrated that the sequence of take offs and alightments in a flight chamber could be repeated until the aphid becomes exhausted. Re-take-offs by Aphis fabae Scopoli in a flight chamber were as vigorous as the first take off.

Species of aphids in the alighting mood are preferentially responsive to yellow and green colors. This response orients them to the green plants. As there is little variation in the hue of most green plants, it is doubtful aphids have used hue to discriminate between host and non-host plant species (Moericke 1969). However, specific spectral sensitivity might be a lot more precise than suspected (Cartier 1966). For most aphid species, a stronger behavioral response to yellow color over green color has been reported (Kennedy et al. 1961, Moericke 1955, 1969, Kring 1967, Roach and Agee 1972).

Several species have been reported to be more attracted to unsaturated hues (Kennedy et al. 1961, Moericke 1969, Kring 1967). Moericke (1969) stated that some differences reported in the response of aphid species to yellow pan traps (Eastop 1955, Heathcote 1957) might be due to differences in tints of the different yellow paints.

Since Moericke (1951,1955) showed yellow hue to strongly attract many aphid species, yellow pan traps (Moericke traps) have been widely used to trap alate aphids for taxonomic purposes and to estimate the size of aphid populations landing on agricultural crops. Although the usefulness of yellow pan traps for some agricultural situations is remarkable, in other situations these traps do not fit well the purpose of the trapping. For example, seed potato growers in Holland utilize yellow pan traps to estimate the size of summer aphid populations. Yet the same traps are of little value in estimating the size of spring populations (Hille Ris Lambers 1972). Byrne and Bishop (1979) found in Idaho potato crops that the number of aphids caught in yellow pan traps was of little value with respect to predicting future population trends. However, Bacon et al. (1976) showed the incidence of potato leaf roll virus (PLRV) in California potato fields appeared to be correlated with number of alate aphids captured in Moericke traps. Zettler et al. (1967) and Heathcote et al. (1969) used yellow water pan traps and yellow sticky traps respectively to catch aphids that were crop pests or potential vectors of viruses.

As yellow hues attract some species of aphids more than others (Eastop 1955, Heathcote 1957, Roach and Agee 1972, Taylor and Palmer 1972), giving a skewed measure of alate aphid populations, it is clear that yellow pan traps are more valuable as a tool to monitor and determine the species flying over a given area rather than providing an absolute estimate of densities of aphids landing within the crop. Ferro et al. (1980) showed that yellow pan traps were very effective at monitoring alate aphids in a sweet corn crop in Massachusetts.

Irwin (1980) found some species of aphids were more abundant in yellow pan traps than on green horizontal ermine traps placed above the canopy of soybeans. A skewed measure of aphid populations alighting on crops is not appropriate for studying aphids as potential colonizers and virus vectors. For this reason, other parameters need to be monitored: landing rates, staying times and take-off rates (Irwin 1980). To design an aphid trapping system to study the epidemiology of viruses, the usefulness of the system should be based on the accuracy of the trap in estimating the number of individuals alighting per unit area of crop foliage. Such a trap, ideally, should replicate in an exact way the hue, saturation and intensity of the crop foliage under study and should be placed within the canopy to minimize differences in background and height relative to the growing crop. Irwin (1980) designed the horizontal ermine trap to provide a more accurate estimate of aphids landing on soybean crops. So far, this method has proven to be extremely useful, but it is expensive and the spectral characteristics of the ceramic tile can not be easily controlled.

Background may have a considerable effect on trap efficiency. Broadbent (1948) and Moericke (1955) reported that yellow pan traps were more effective in trapping alate aphids when the traps were surrounded by soil than when surrounded by vegetation. Similar results were obtained by Heathcote (1957), Smith (1969) and Gonzalez and Rawlins (1968) when they placed yellow water pan traps on bare ground to catch aphids. In addition, Heathcote (1969) found that aphids settled preferentially on yellow traps placed in a "gappy" rather than "thick" vegetation.

Despite the abundant and varied literature on yellow traps for catching alate aphids, there is a real need to improve methods for quantifying the number of alighting aphids within a crop relative to the epidemiology of viruses, aphid population dynamics and the efficiency of aphid trapping systems within any agricultural scenario.

Cucumber Mosaic Virus and Vectors

Although most viruses infecting peppers are common in most locations, often the virus most prevalent in one location may be rare or absent in another. Thus, although tobacco etch virus (TEV) and potato virus Y (PVY) seem to be the most prevalent viruses in peppers in California (Makkouk and Gumpf 1974) and Florida (Zitter 1980), cucumber mosaic virus (CMV) and tobacco mosaic virus (TMV), among others, are rarely a problem in these states. In New Jersey and Illinois TEV is the most prevalent virus while PVY was rare or completely absent in peppers and TMV, CMV and PVY were of secondary importance (Weinbaum and Milbrath 1976, Steepy et al. 1967). On the other hand in Southern Canada and Northern Italy CMV and TMV were by far the most prevalent viruses in peppers, while PVY, TEV and alfalfa mosaic virus (AMV) were found much less frequently (Lana and Peterson 1980, Conti and Masenga 1977).

Cucumber mosaic virus (CMV) causes serious losses on several vegetables and other crops, particularly cucurbits, spinach, tomato and pepper, throughout the world and in the Northeastern United States (Komm and Agrios 1978). Several strains of CMV cause symptoms on pepper. These symptoms may vary from slight to severe mottling of leaves, with or without brown ring or lines. They may also involve various degrees of stunting of plants, and production of fewer fruit, which usually show distortion and uneven ripening and are generally unmarketable (Francki et al 1979, Simons 1957). Similar and usually indistinguishable symptoms on peppers are caused by three other viruses: tobacco etch virus (TEV), potato virus Y (PVY) and tobacco mosaic virus (TMV). All four viruses are often present in the same field and combinations of them are sometimes present in the same pepper plant (Zitter 1980, Anderson and Corbett 1957).

CMV is a single stranded RNA virus with an extremely wide host range; 191 susceptible plant species in 40 families have been reported (Price 1940). CMV has been found to be one of the most important viruses affecting cucurbits in Massachusetts (Komm and Agrios 1978). CMV overwinters in perennial weeds and cultivated crops (Bruckart and Lorbeer 1976, Feldman and Gracia 1972, Tolimson at al. 1970, Anderson 1959) and is transmitted in a nonpersistent manner by more than 60 species of aphids (Kennedy et al. 1962). Simons (1955,1966) and Zitter (1975) found feeding acquisition times of less than 30 seconds to be optimal for transmission. The probability of transmission increases if aphids have fasted for a short time before acquisition-probing occurrs in diseased tissue (Bradley 1952, Nault and Gyrisco 1966).

Great differences in the transmissibility of several strains of CMV by aphids have been reported (Badami 1958, Norman and Pirone 1968, Swenson et al. 1964). CMV transmission by aphids has been considered to be inefficient and erratic (Stimmann and Swenson 1967). Transmission efficiency of CMV can also vary with host plant species (Simons 1955,1957) and the aphid species involved (Simons 1959,1966). Simons (1966) found that differences in transmission efficiency of CMV on peppers among clones of a given aphid species were almost as great as those found among aphid species. He reported a transmission efficiency of 5 to 68% for apterous _Aphis gossypii_ Glover, 27 to 60% for apterous _Myzus persicae_ (Sulzer) and 5 to 22% of green clones of apterous _Macrosiphum euphorbiae_ (Thomas), while pink forms of potato aphid did not transmit the virus. Most of the transmission studies have been done with laboratory populations of apterous aphids (Simons 1955, 1957, 1959, 1966, Pirone 1964 and many others). Although laboratory tests of various aspects of virus transmission are important, it is even more important to study this in the field. Irwin and Goodman (1981) studied field transmission of mosaic soybean virus (SMV) by trapping field populations of alate aphids which were taken to the laboratory for infectivity studies.

Mineral Oil

Bradley et al. (1962) showed mineral oil to interfere with transmission of nonpersistent viruses. Bradley (1963) also showed that contacts of 1-2 seconds between the labium of aphids and oil-treated leaves impeded the acquisition or inoculation of potato virus Y (PVY). Oil does not appear to denature virus particles. Its effect could involve adherence of the virus to the aphids' stylets or interference with the ingestion or egestion process (Simons and Zitter 1980). Probing behavior did not differ for aphids probing on plants with or without an oil film (Peters and Lebbink 1973). Simons et al. (1977) showed that antitransmission activity of oil was associated with oil located over the anticlinal area of epidermal cells. Despite the considerable research effort to elucidate the mechanisms of action of oils, the present knowledge about inhibition of stylet borne viruses is far from clear. Vanderveken's (1977) review on oils for inhibiting nonpersistent viruses spread covers these topics in detail.

Although most studies showed oil to be effective in controlling non persistent viruses, Zitter and Everett (1979) reported oil sprays to be effective in reducing the spread of tomato yellows virus, a persistent virus. The successful use of oil to control the spread of nonpersistent viruses in the field was first reported by Loebenstein et al. (1966). Low volume spraying of 5 to 10% oil emulsions reduced CMV infection by 80 to 90% on green peppers in Israel. Simons and Zitter (1980) reported on the limited commercial value of oils primarily because of phytotoxicity and ineffectiveness. In this paper they discussed oil formulations and application techniques specifically designed to control aphid borne virus diseases, and report on the effective use of oil sprays to control several viruses on a variety of vegetable crops, including control of tobacco etch and potato Y viruses on green pepper in Florida. Ferro et al. (1980) showed the number of corn plants infected by maize dwarf mosaic virus (MDMV) was significantly less for plants receiving applications of mineral oil than plants left untreated and plants having only an aphicide treatment.

Reflective Mulch

Kring (1964) reported that when he placed unpainted aluminum pans around yellow pan traps aphids avoided the yellow traps and stated that this repellency was due to the reflection from the aluminum surface. Smith et al. (1964) tested foliage sprays of aluminum on Gladiolus and hypothesized that the reflecting radiation repelled alate aphids and resulted in fewer aphids colonizing plants. Adlerz and Everett (1968) reported aluminum foil to delay the onset of watermelon mosaic virus epidemic up to 20 days. Smith and Webb (1969) reviewed the use of reflective surfaces to control insect transmitted viruses and concluded that more research was needed before the strategy could be fully exploited for insect and disease management.

Wolfenbarger and Adlerz (1971) reported that aluminum mulch reduced the number of aphids alighting on squash and tomato by 90 to 100%. George and Kring (1971) reported similar results in Connecticut on summer squash. Black and Rolston (1972) showed aluminum mulch plots had fewer aphids and reduced virus spread on green peppers.

Wyman et al. (1979) used mineral oil sprays and plastic mulches on summer squash and found that oil reduced watermelon mosaic virus spread and mulches greatly reduced the influx of alate aphids into plots. Nawrocka et al. (1975) reported that plastic mulches reduced the number of winged aphids captured and CMV infection in lettuce. No significant virus reduction was noted in any of the plots treated with oil sprays.

CHAPTER II

YELLOW PAN TRAPS FOR MONITORING APHIDS ALIGHTING ON GREEN PEPPER IN WESTERN MASSACHUSETTS

Introduction

Species of aphids in the alighting mood preferentially respond to yellow and green colors and, through this response, orient to green plants. As there is little variation in the hue of most green plants, it is unlikely that aphids are capable of discriminating between subtle differences in hue and intensity to accurately respond to a specific host plant color (Moericke 1969). Since the pioneer work by Moericke (1951, 1955) which showed that yellow hue strongly attracts many species of aphids, yellow pan traps have been widely used in many parts of the world to estimate the relative abundance and size of aphid populations and to determine the species of yellow-responsive alate aphids flying over reflective surfaces, soil and crop canopies.

Although the trapping efficiency of yellow pan traps for obtaining relative estimates of aphid population densities is good in some agricultural situations, it is not sufficient for determining abundance of the different aphid species in other situations. Seed potato growers in Holland claim a high trapping efficiency of yellow pan traps for estimating the size of summer populations of aphids, yet the same traps have failed to estimate the size of the spring populations (Hille Ris Lambers 1972). As yellow attracts some species of aphids more than others (Eastop 1955, Heathcote 1957, Roach and Agee 1972, Taylor and Palmer 1972, Kring 1972) trapping data may provide a skewed measurement of population abundance, and for this reason yellow pan traps are more valuable as a tool for monitoring and determining the species of alate aphids flying over a given area than the species that actually land within a crop canopy.

The aphid/virus complexes of several vegetables constitute a major pest problem limiting vegetable production in the Northeastern United States It is well known that nonpersistent viruses can be transmitted by alate aphids during the probing phase of the host selection process. Green pepper, Capsicum annuum L., is a valuable crop in the Northeast and is plagued by a number of aphid species and viruses. One of the most prevalent viruses in green pepper is cucumber mosaic virus (CMV) which has been assumed to be spread by the green peach aphid, Myzus persicae (Sulzer) and the potato aphid, Macrosiphum euphorbiae (Thomas). These aphids are known vectors of cmv in other areas. Ferro et al. (1980) showed yellow pan traps to be very effective at monitoring these species in sweetcorn in the Northeast. In spite of the economic importance of the CMV/aphid complex on green peppers in Massachusetts, there is no information about the aphid species that may be responsible for the spread of the virus in this crop nor about their seasonal flight activity.

To my knowledge, there is only one study (Gonzalez and Rawlins 1968) published on the seasonal abundance of alate aphids caught within an agricultural cropping system in the Northeast. Leonard (1966) published a list of 164 aphid species caught in yellow pan traps in Massachusetts. However, no information on relative abundance or seasonal activity was presented. In the summers of 1981 and 1982 I studied the species composition and relative abundance of aphids trapped in yellow pan traps placed within the canopy of green pepper plots.

Materials and Methods

Green pepper plants (CV. "Lady Bell") were transplanted to the experimental field (University of Massachusetts Research Farm, Sunderland, MA) in the first week of June in 1981 and 1982. Each plot consisted of six raised beds 18m long by 7.2m wide. Plant spacing in 1981 was 60 cm between plants and 60 cm between rows in each bed and 1.2m between beds. In 1982, only one row of transplants were placed in each bed of 45 cm between plants and 1.2m between beds. Three yellow pan traps 19.5 cm x 19.5 cm and 5 cm deep filled with soapy water and glycerine were placed at the canopy level in the center of each of four plots. The interior of the pan trap was painted with Federal Safety Yellow (Rustoleum) which has about 70 percent reflectance at a wavelength of 550 nm. Aphids were collected weekly for ten weeks and were identified using the aphid keys of Hottes and Frison (1931) and Palmer (1952). The scientific names were updated to conform to the list of Smith and Parron (1978). The number of plants showing viral symptoms was determined through visual observation of the plants at monthly intervals during the 1982 growth season.

Results and Discussion

The most common species of alate viviparous female aphids trapped in the yellow pan traps placed in pepper plots are listed below. Species rarely trapped were not identified. Species include: *Aphis citricola* Van der Goot, spirea aphid; *Aphis craccivora* Koch, cowpea aphid; *Aphis fabae* Scopoli, bean aphid; *Aphis gossypii* Glover, cotton aphid/melon aphid; *Aphis maidi-radicis* Forbes; *Aphis nerii* Fonscolombe, oleander aphid; *Aphis rubifolii* (Thomas); *Aphis rumicis*

L., dock aphid; Aphis spiraephila Patch, spiraea aphid; Aphis spp.; Aspidaphis sp.; Capitophorus elaeagni (DelGuercio), oleaster thistle aphid; Cavariella sp.; Chaitophorus sp.; Dactynotus sp.; Drepanaphis sp.; Hyalopterus atriplicis L., boat gall aphid; Kaltenbachiella sp.; Macrosiphum euphorbiae (Thomas), potato aphid; Macrosiphum pallens Hottes and Frison; Monellia sp.; Myzocallis punctata (Monell); Myzocallis sp.; Myzus persicae (Sulzer), green peach aphid; Periphyllus sp.; Phorodon sp.; Rhopalosiphoninus sp.; Rhopalosiphum enigmae Hottes and Frison; Rhopalosiphum maidis (Fitch), corn leaf aphid; Rhopalosiphum padi (L.), oat bird cherry aphid; Therioaphis trifolii (Monell), yellow clover aphid; Tinocallis sp.; Uroleucon pseudambrosiae (Olive).

Flight activity of all aphid species based on yellow pan trap catches in 1981 and 1982 are very similar for both years (Fig. 1); however, greater numbers were captured in 1981. M. euphorbiae and M. persicae, the only two species colonizing green peppers in this area, accounted for most of the aphids trapped between 24 July and 4 September (Figs. 2 & 3). A group of miscellaneous species in the genus Aphis (Fig. 4) and H. atriplicis (Fig. 5) also were abundant during this period in 1981 and 1982. From late June to late July C. elaeagni (Fig. 6) and Cavariella sp. (Fig. 7) were the most predominant species. Other species (Fig. 8 to 15) showed variable peaks during the two seasons.

The rate of viral symptom appearance measured in the 1982 season (Fig. 16) showed 1% of green pepper plants infected by July 29, 11% by August 5, 34% on August 13, 89% on August 21 and 100% infection on the last day of August. Viral symptoms usually appear

Figure 1. Total weekly number of alate aphids captured per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.

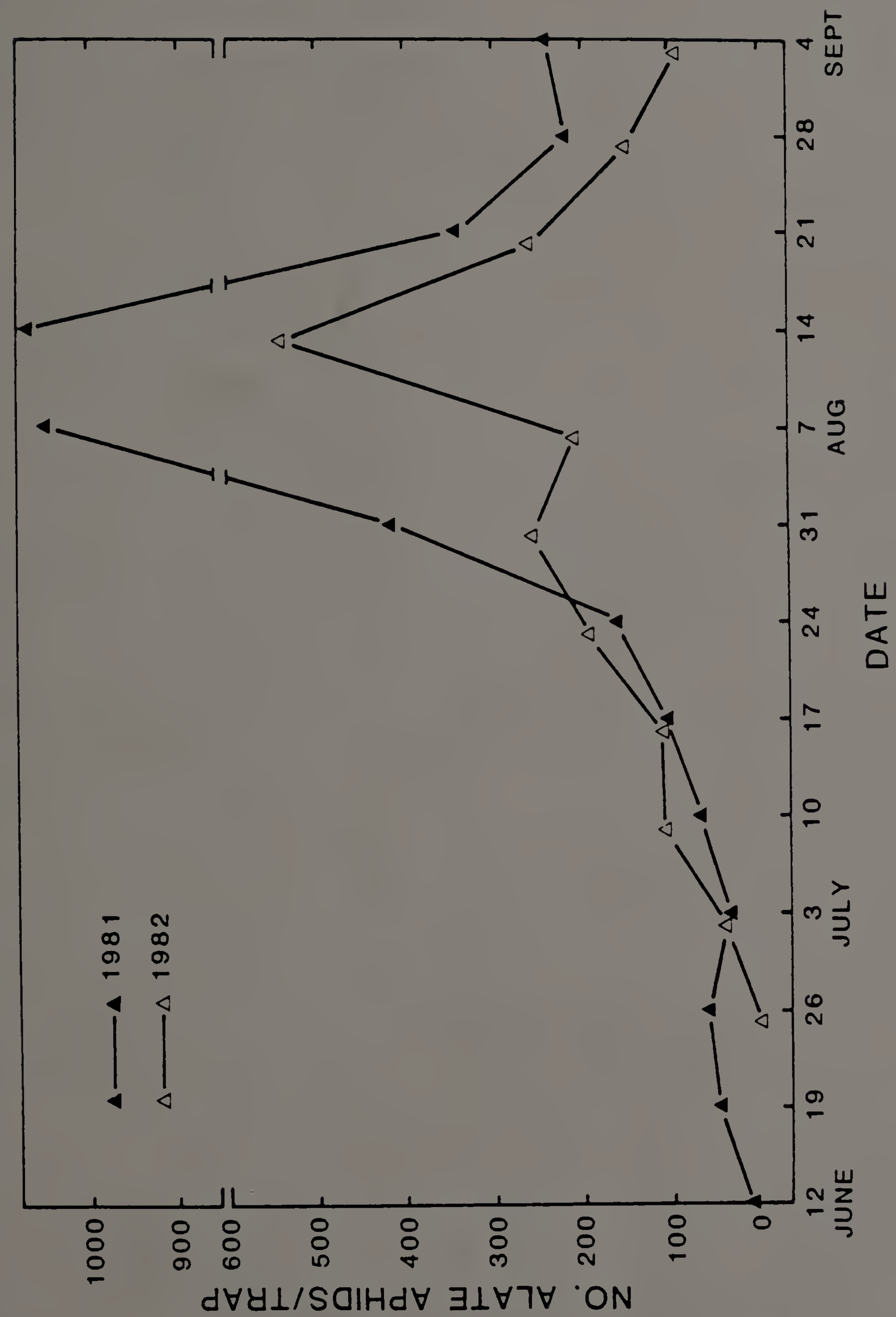
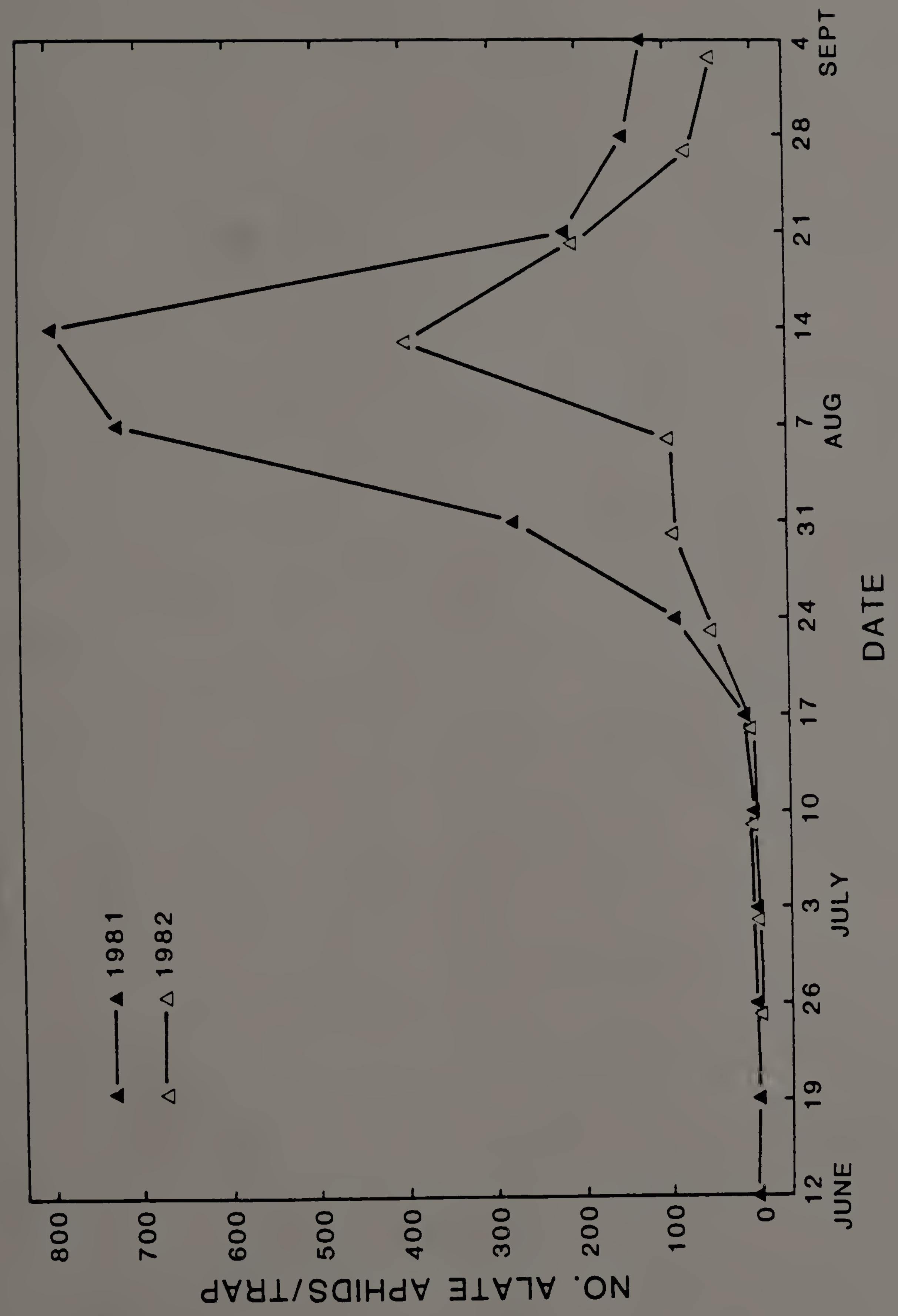
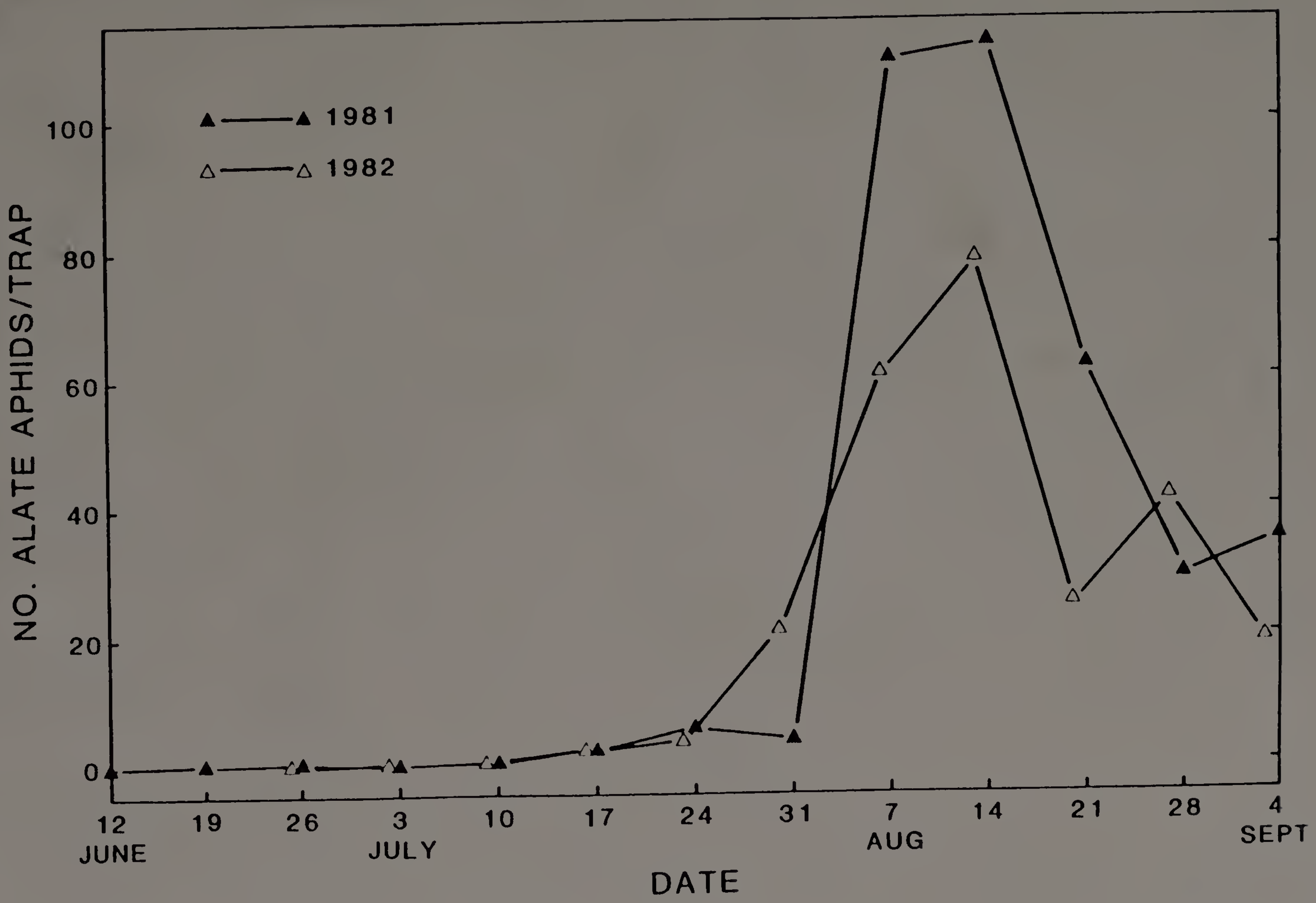

NO. ALATE APHIDS/TRAP
1000
900
600
500
400
300
200
100
0
1981
1982
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 2. Number of alate *Macrosiphum euphorbiae* (Thomas) caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.



NO. ALATE APHIDS/TRAP
800
700
600
500
400
300
200
100
0
1981
1982
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 3. Number of alate *Myzus persicae* (Sulzer) caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.



1981
1982
NO. ALATE APHIDS/TRAP
100
80
60
40
20
0
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 4. Number of alate Aphis spp. caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.

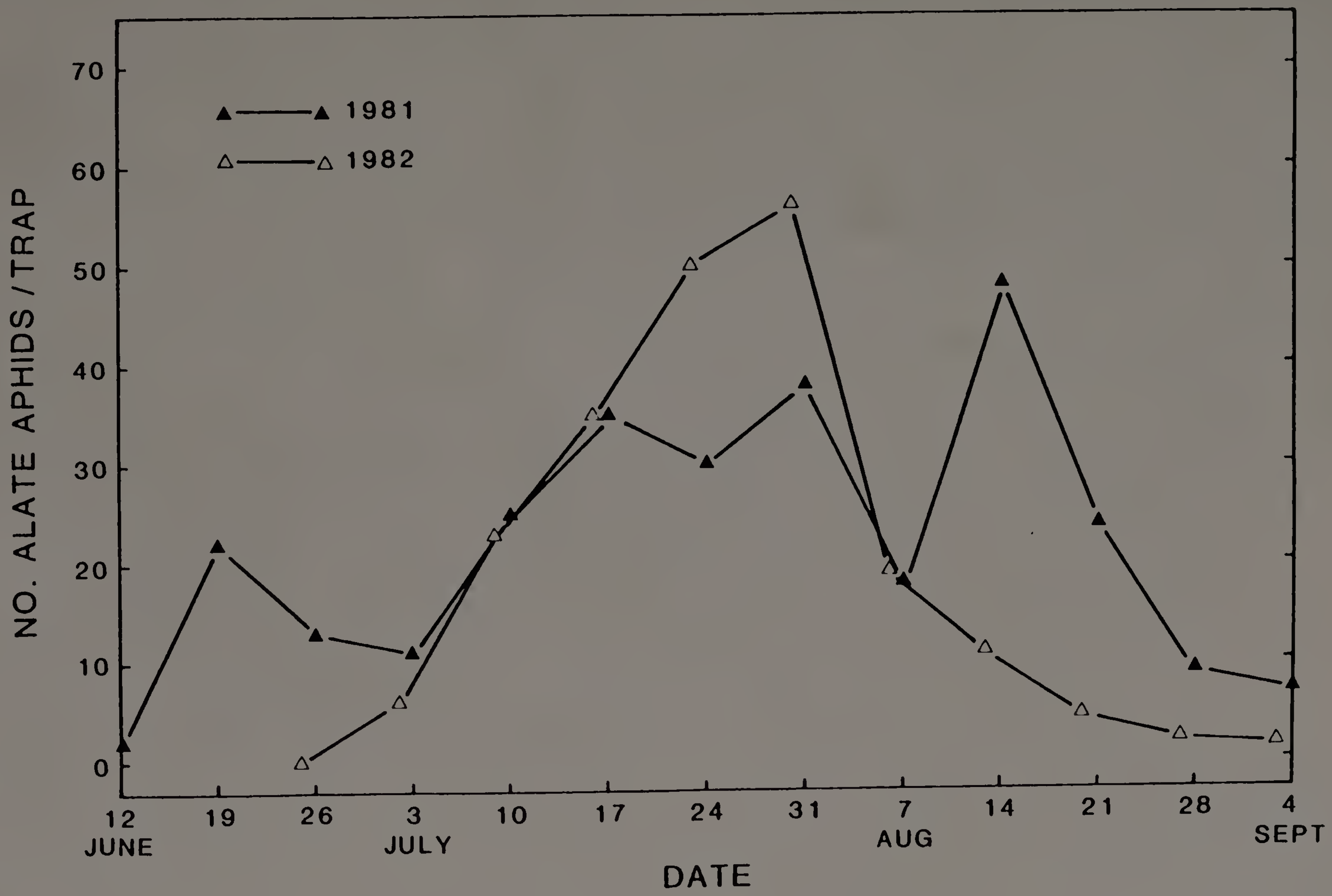
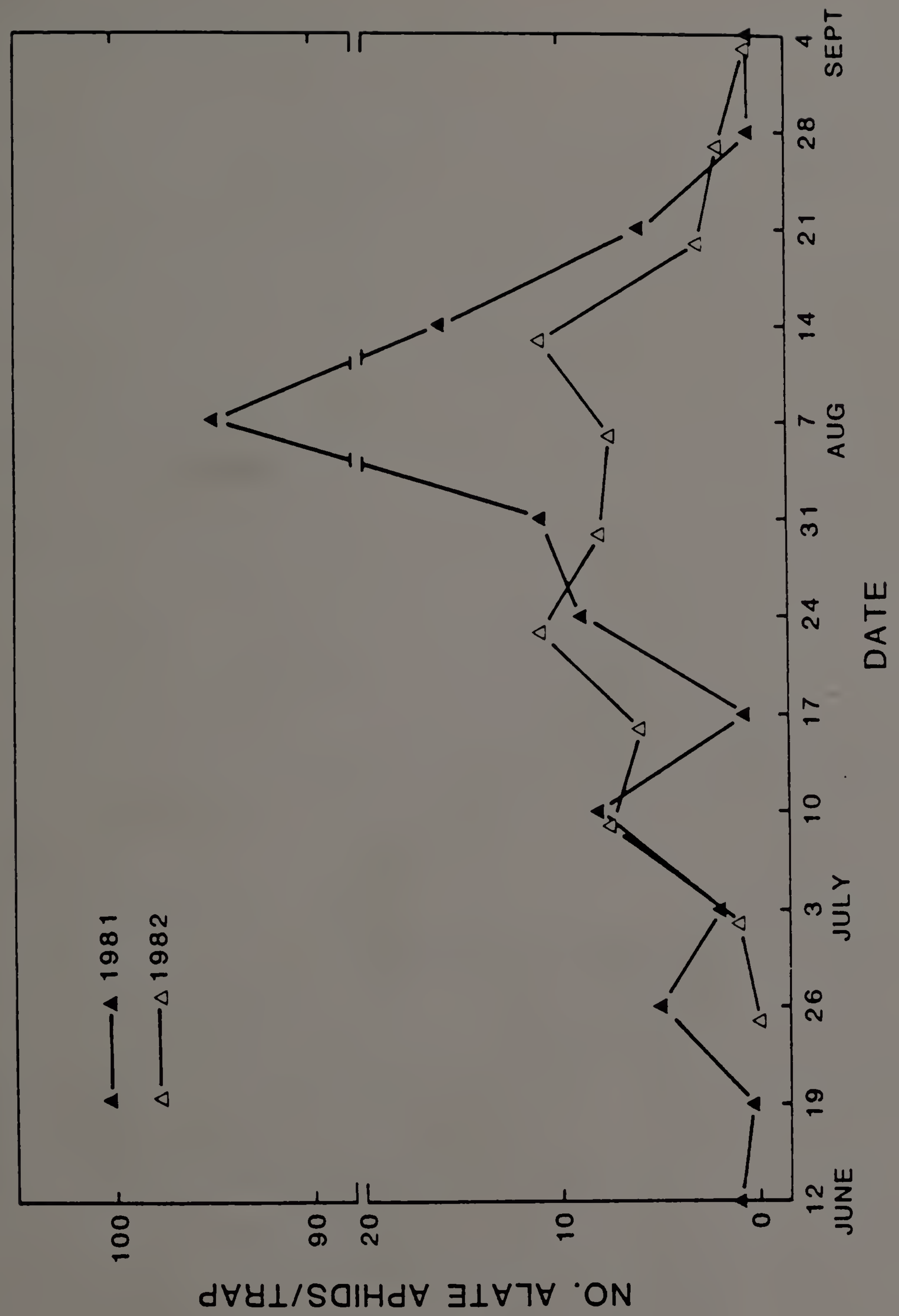
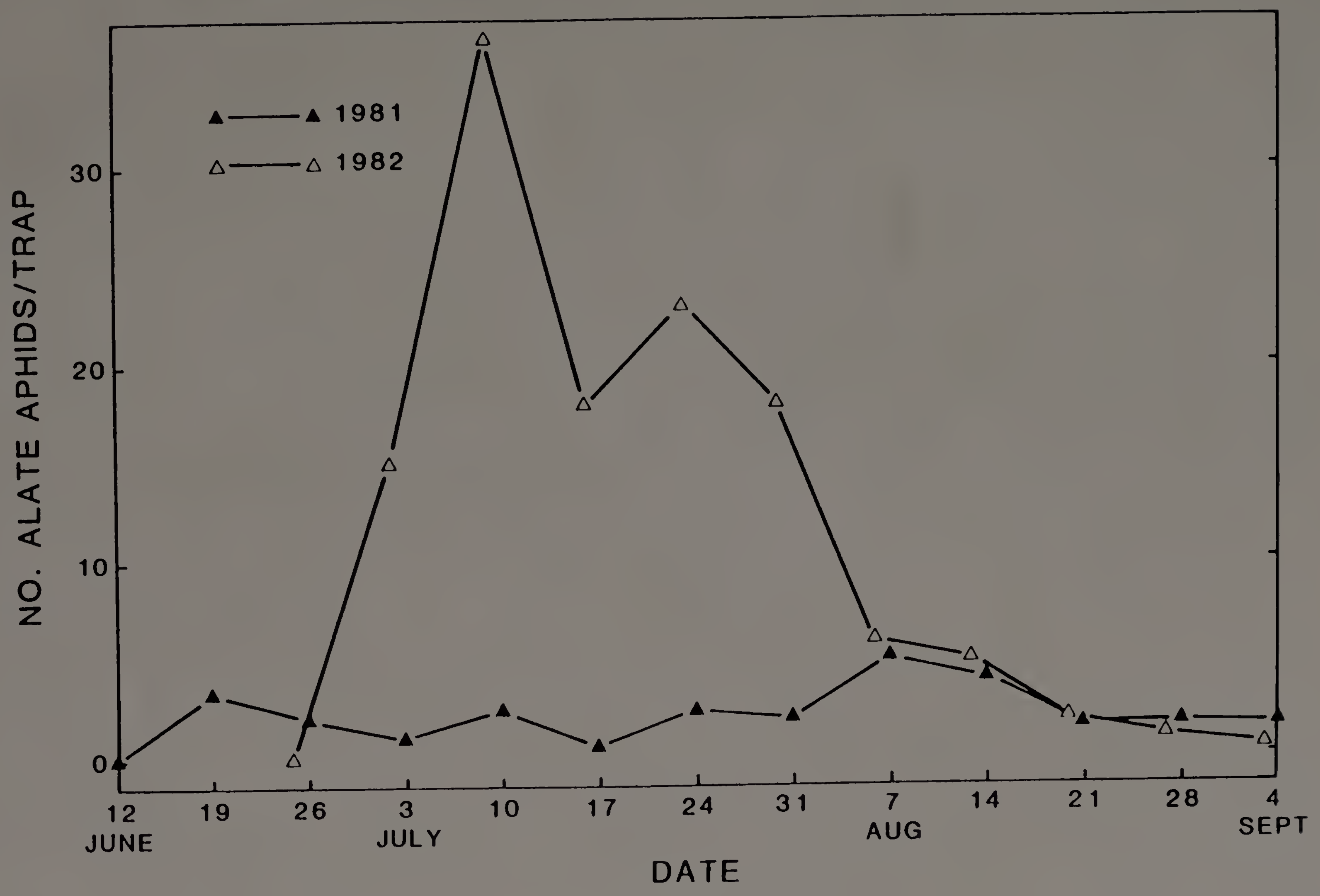

1981
1982
NO. ALATE APHIDS / TRAP
0
10
20
30
40
50
60
70
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 5. Number of alate *Hyalopterus atriplicis* (L.) caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.



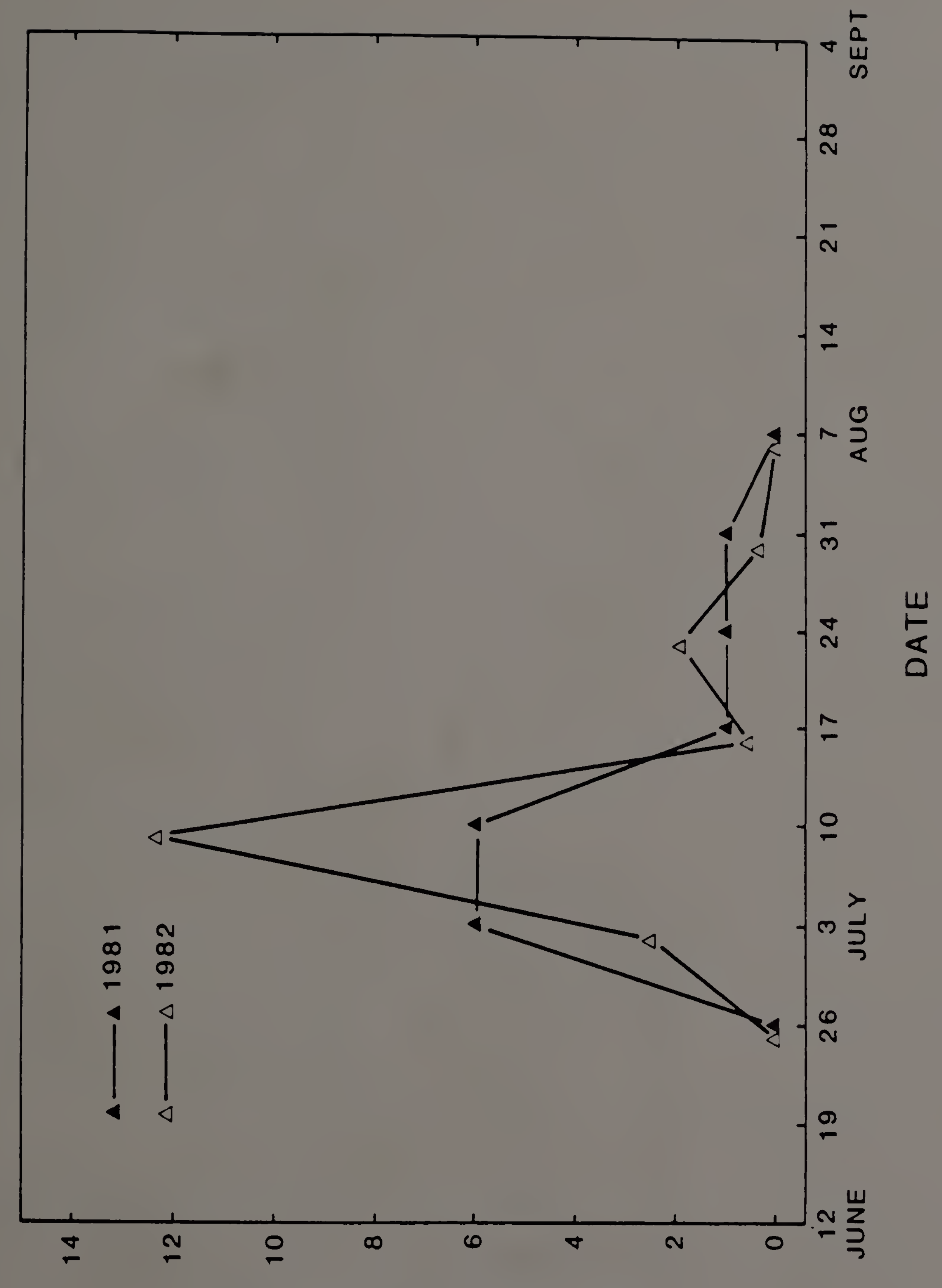
1981
1982
NO. ALATE APHIDS/TRAP
100
90
20
10
0
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 6. Number of alate Capitophorus elaeagni (Del Guercio) caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.



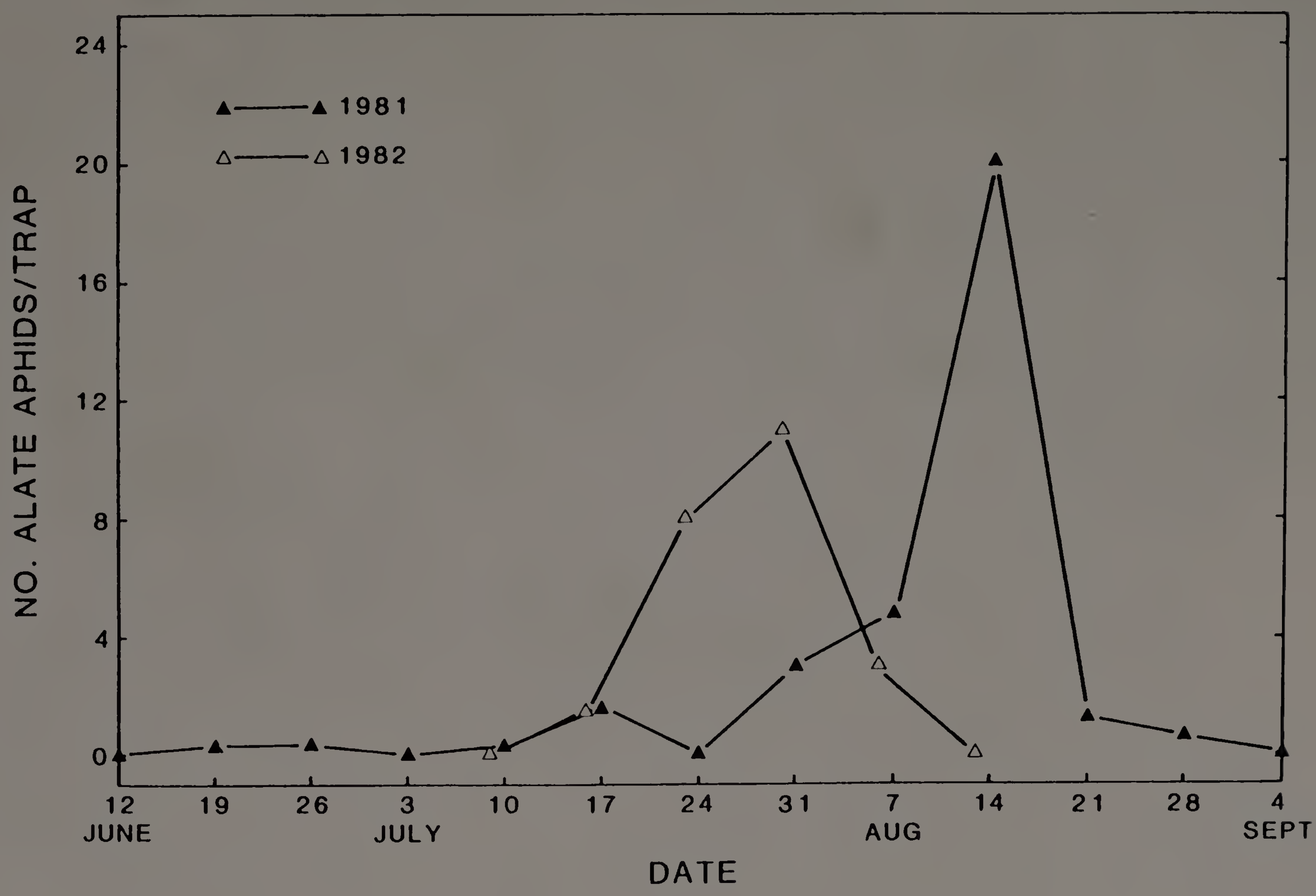
1981
1982
NO. ALATE APHIDS/TRAP
0
10
20
30
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 7. Number of alate Cavariella sp. caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.



NO. ALATE APHIDS/TRAP
0
2
4
6
8
10
12
14
1981
1982
12
19
26
3
10
17
24
31
7
14
21
28
4
JUNE
JULY
AUG
SEPT
DATE

Figure 8. Number of alate *Microsiphum pallens* Hottes and Frison caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.



24
20
16
12
8
4
0
NO. ALATE APHIDS/TRAP
1981
1982
12 JUNE
19
26
3 JULY
10
17
24
31
7 AUG
14
21
28
4 SEPT
DATE

Figure 9. Number of alate Uroleucon pseudambrosiae (Olive) caught per yellow pan trap in green pepper, Sunderland, MA 1981 and 1982.

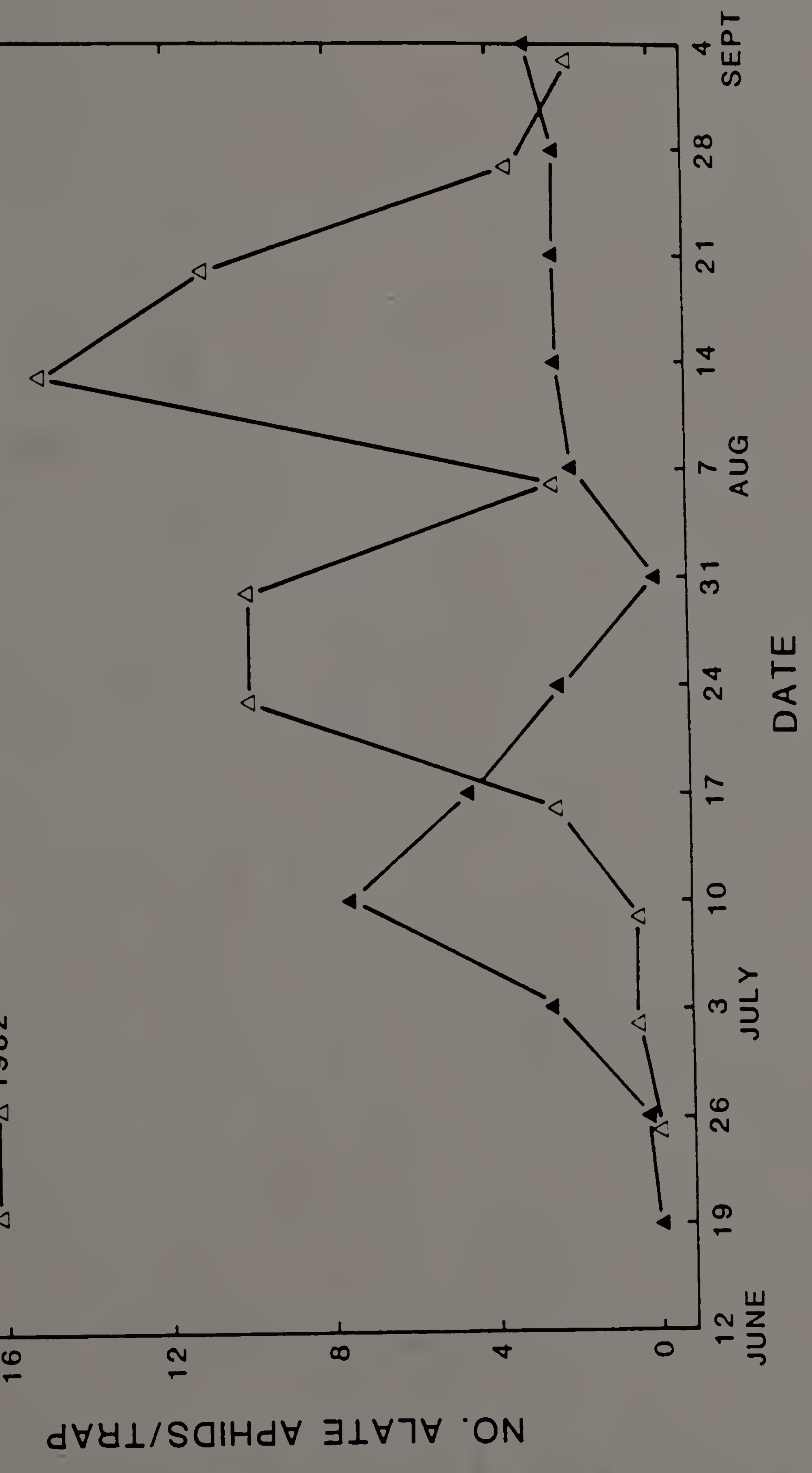

NO. ALATE APHIDS/TRAP
0
4
8
12
16
1981
1982
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 10. Number of alate Aphis nerii Fonscolombe caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.

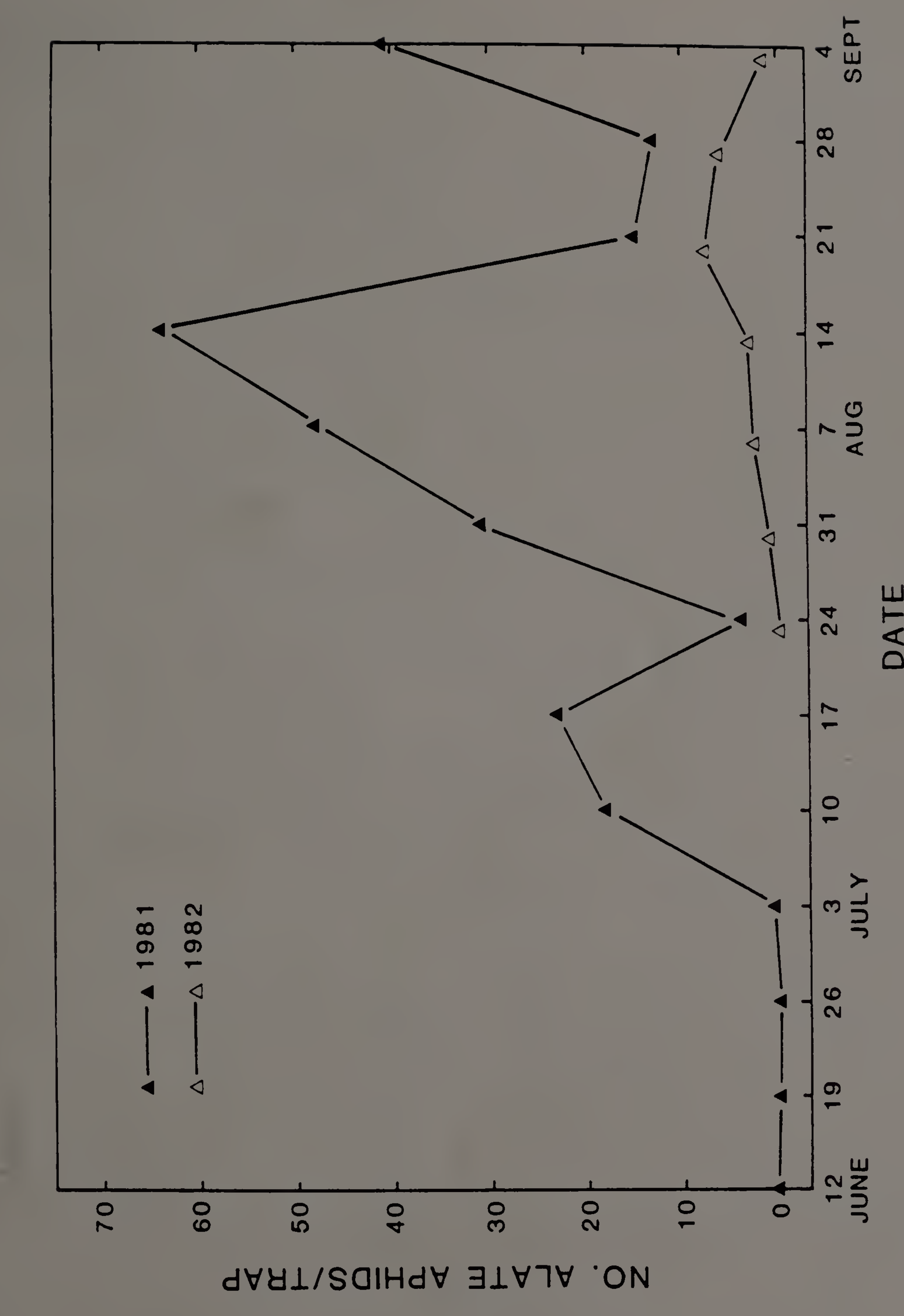

NO. ALATE APHIDS/TRAP
0
10
20
30
40
50
60
70
1981
1982
12 JUNE
19
26
3 JULY
10
17
24
31
7 AUG
14
21
28
4 SEPT
DATE

Figure 11. Number of alate *Rhopalosiphum maidis* (Fitch) caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.

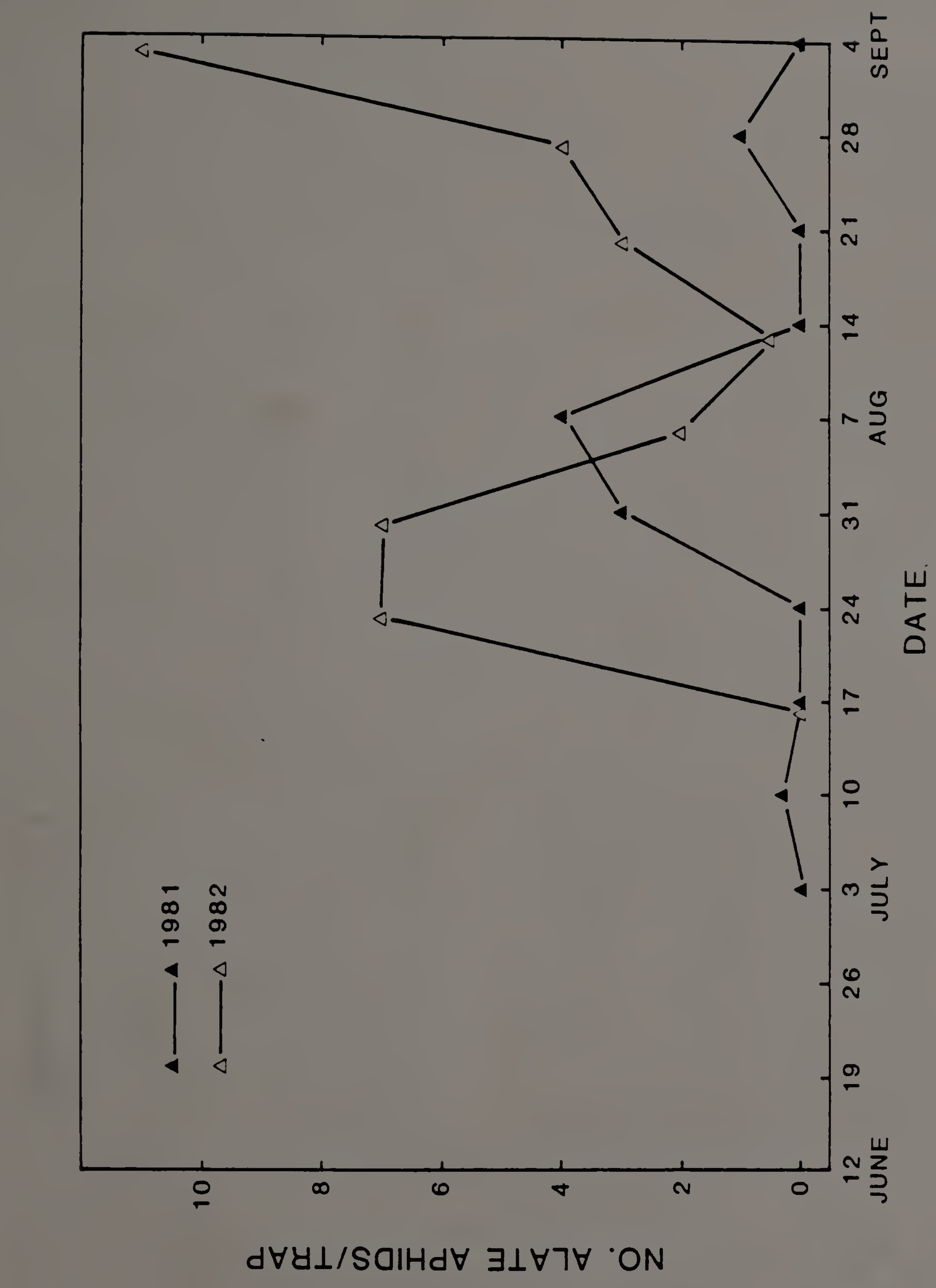

NO. ALATE APHIDS/TRAP
0
2
4
6
8
10
1981
1982
12 JUNE
19
26
3 JULY
10
17
24
31
7 AUG
14
21
28
4 SEPT
DATE

Figure 12. Number of alate *Aphis gossypii* Glover caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.

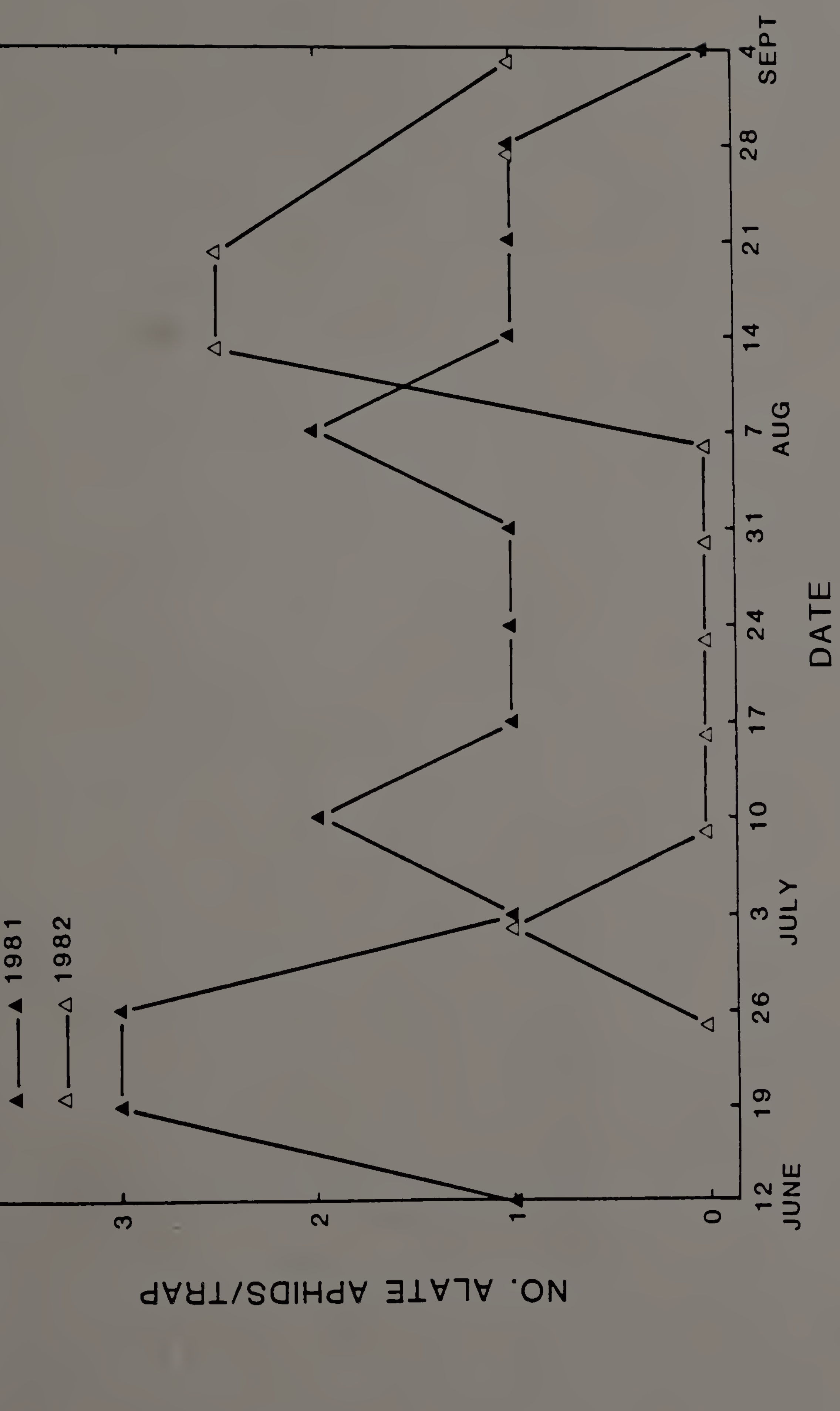

1981
1982
NO. ALATE APHIDS/TRAP
0
1
2
3
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 13. Number of alate *Aphis craccivora* Koch caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.

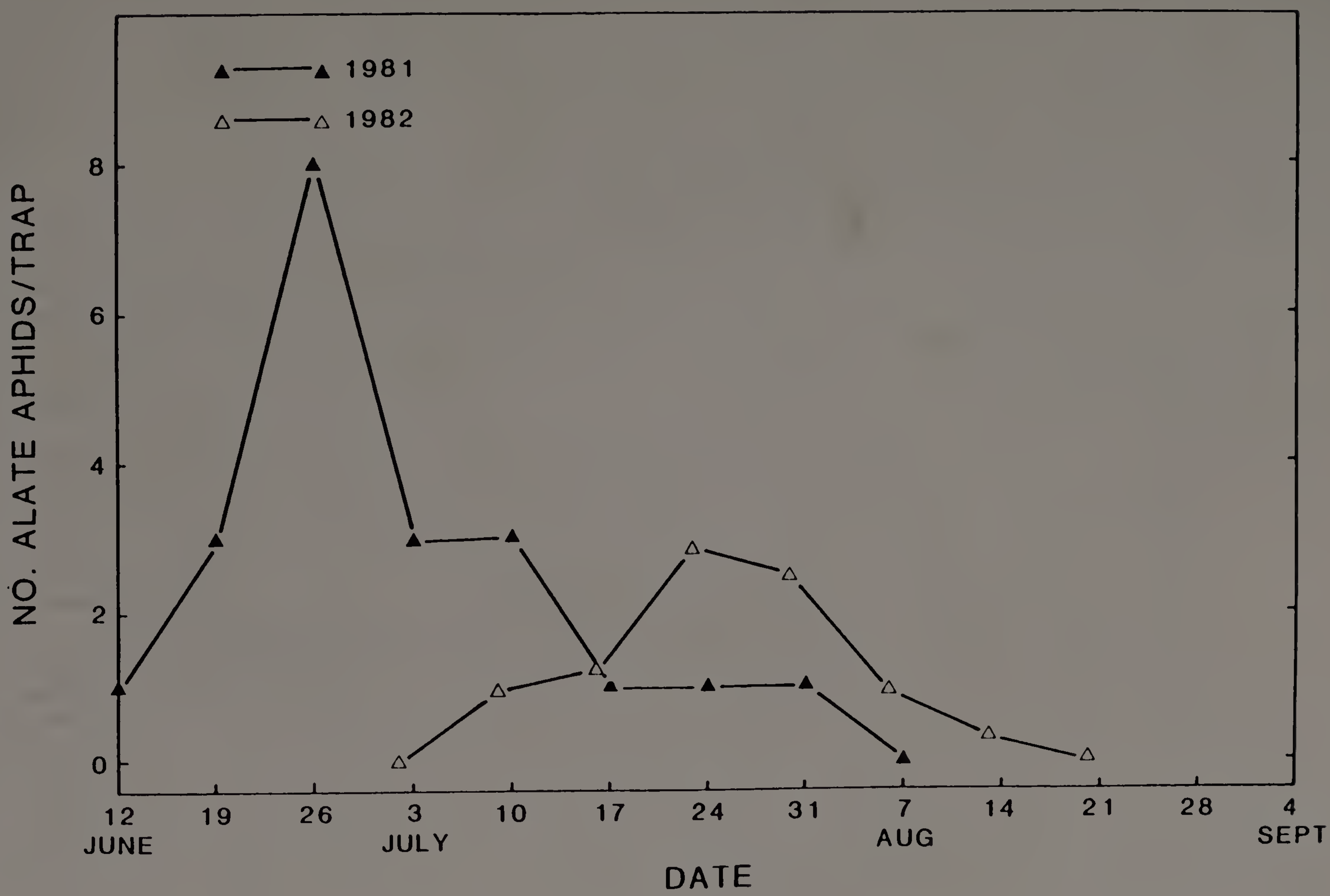

1981
1982
NO. ALATE APHIDS/TRAP
0
2
4
6
8
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 14. Number of alate Drepanaphis sp. caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.

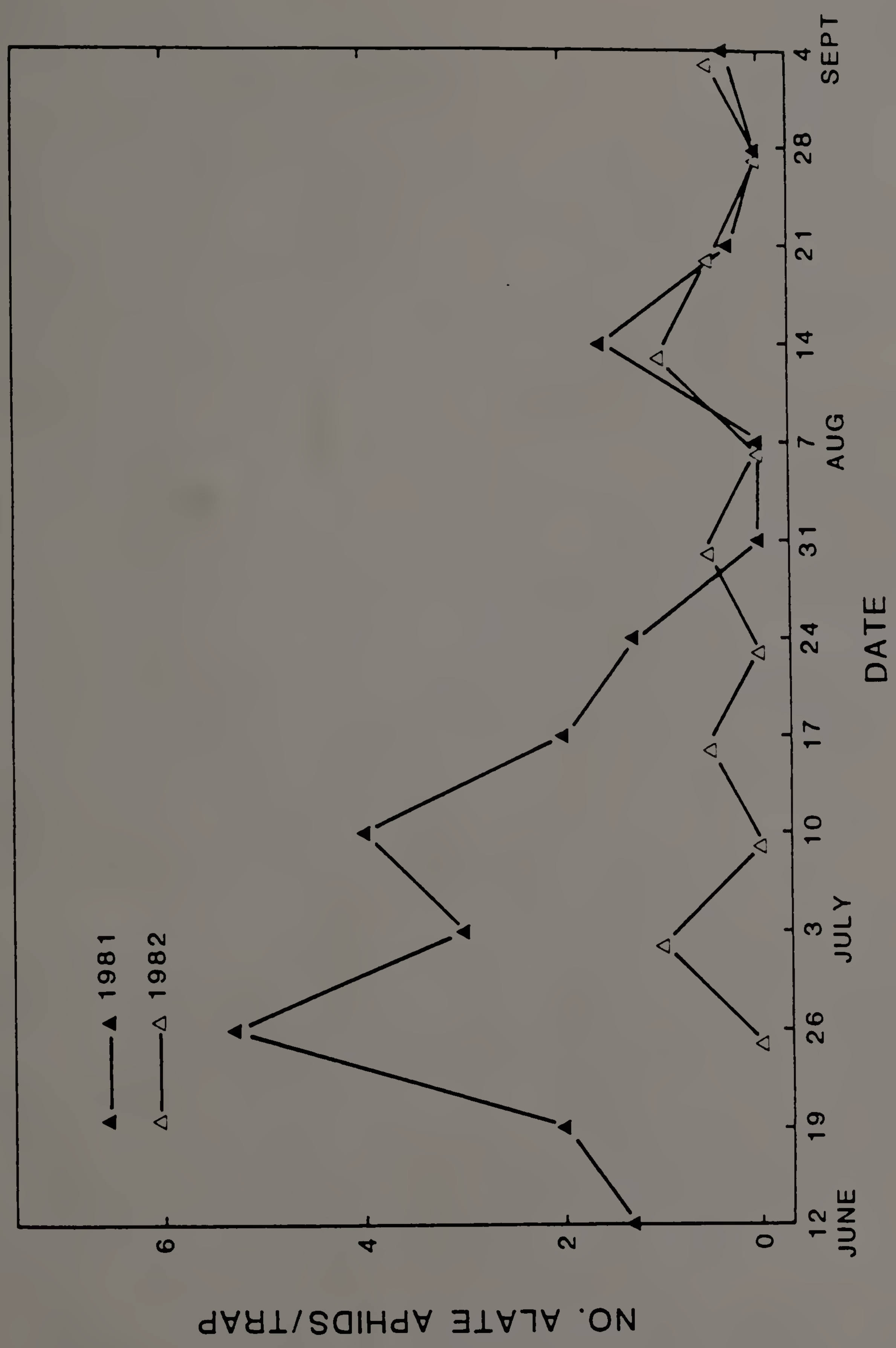

1981
1982
NO. ALATE APHIDS/TRAP
0
2
4
6
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 15. Number of alate Kaltenbachiella sp. caught per yellow pan trap in green pepper, Sunderland, MA, 1981 and 1982.

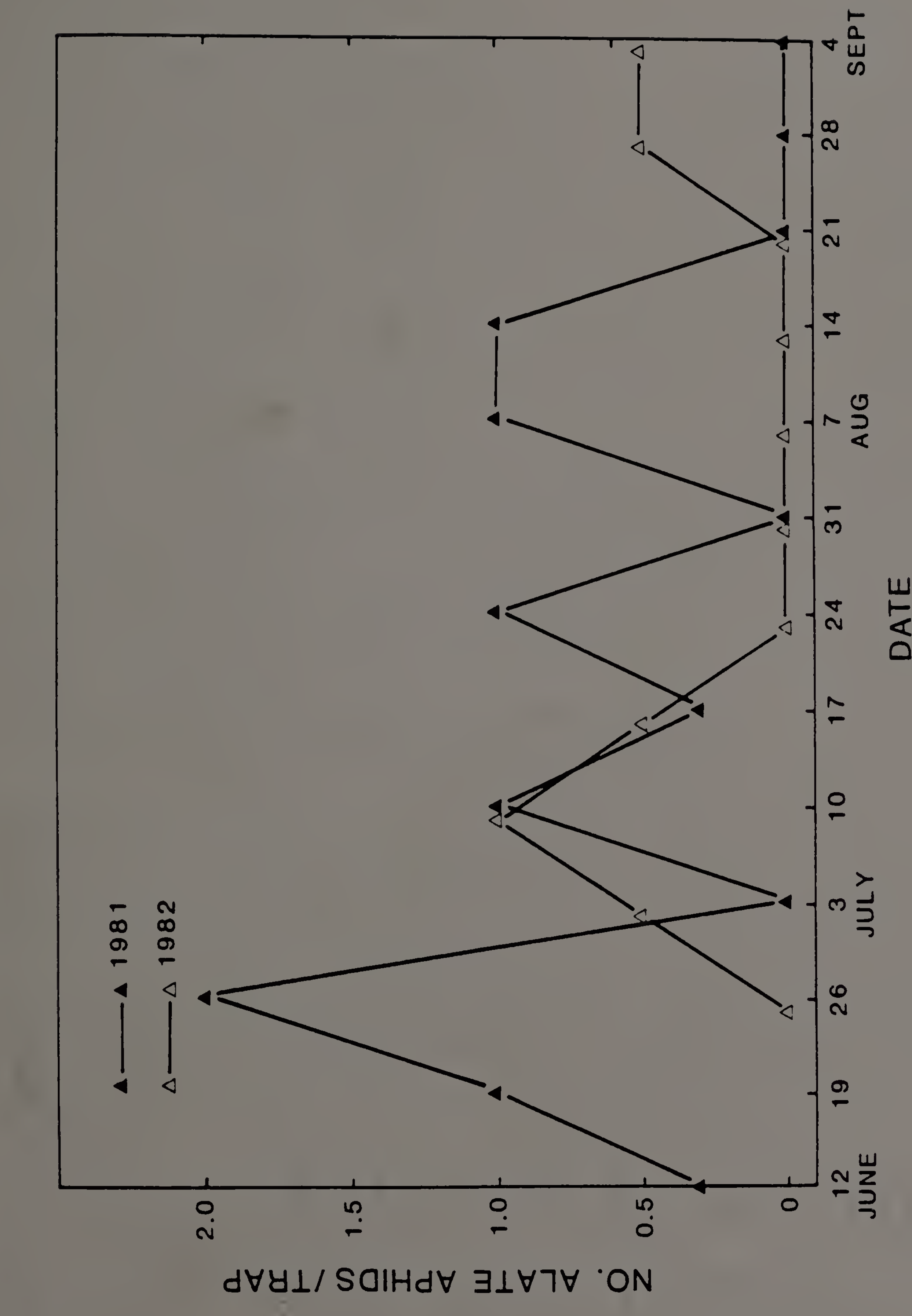
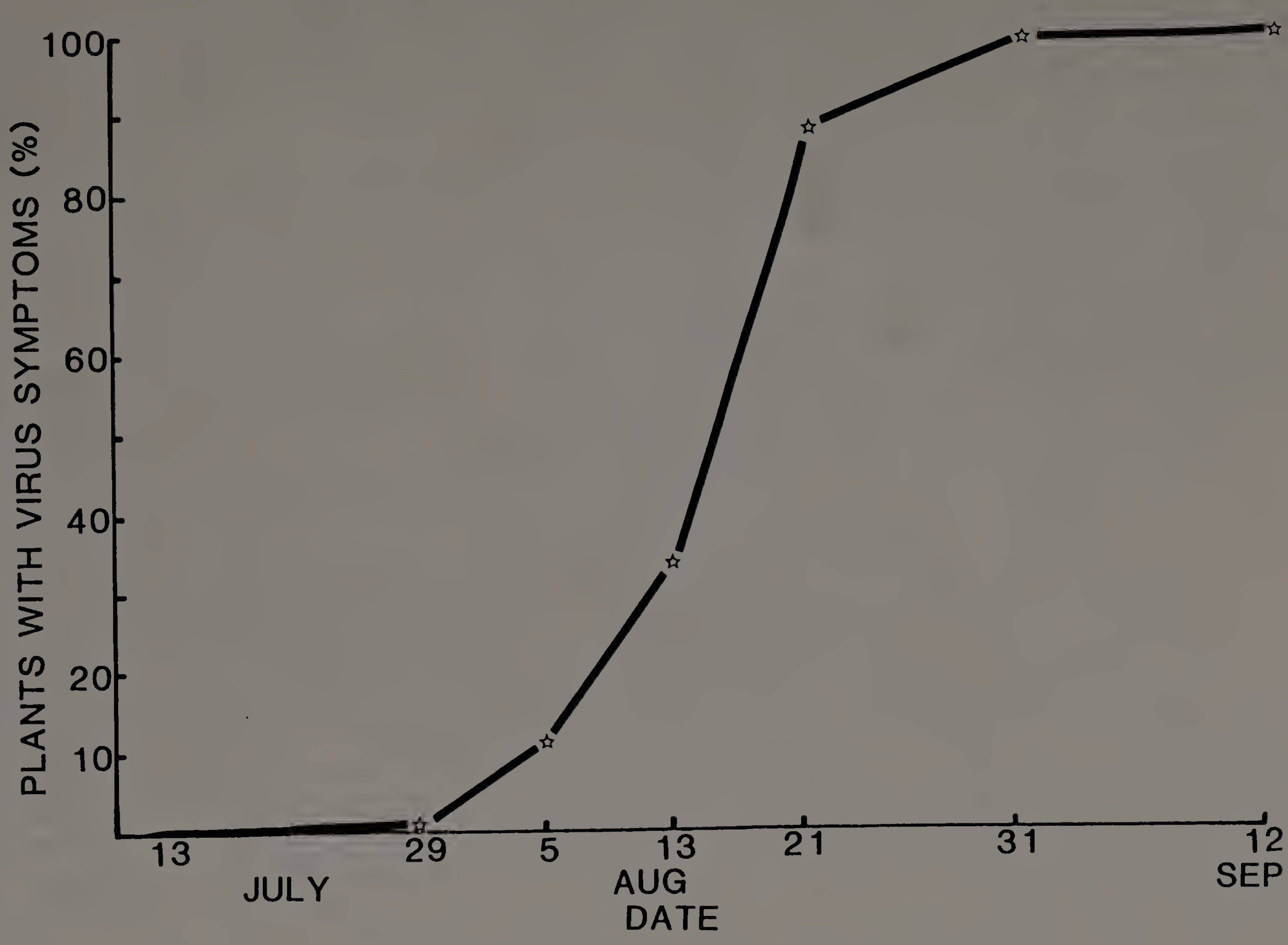

1981
1982
NO. ALATE APHIDS /TRAP
2.0
1.5
1.0
0.5
0
12
JUNE
19
26
3
JULY
10
17
24
31
7
AUG
14
21
28
4
SEPT
DATE

Figure 16. Percentage of green pepper plants (cultivar "Lady Bell") showing virus symptoms in 1982.


PLANTS WITH VIRUS SYMPTOMS (%)
100
80
60
40
20
10
13
29
5
13
21
31
12
JULY
AUG
SEP
DATE

in commercial pepper crops in this area towards the end of July. Based on virus spread and taking into account the incubation period of the virus (ca. 7 days in the field from inoculation to visible symptoms), I could separate flight phenology of aphids into two different phases:an early season phase extending from the beginning of crop establishment until the middle of July, during which there are no visible viral symptoms and the aphids trapped are mostly non colonizing, transient species; and a late season phase extending from the middle of July to the time of the last harvest in early September, during which the initial infection and rapid spread of virus occurred, and colonizing and transient species land on the crop. Assuming the yellow traps captured species that landed and probed pepper plants and knowing that non persistent viruses such as CMV can be transmitted by aphid probing, alates caught during the second and third week of July could be important early season vectors of pepper viruses.

In 1982, there were several aphid species active in early July, including _Aphis_ spp., _C_. _eleagni_, _H_. _atriplicis_, _U_. _pseudambrosiae_, _M_. _pallens_, and _R_. _maidis_. The rapid increase in viral infection from 34% to 89% from August 13 to August 21, coincided with the high number of alate aphids captured the first two weeks of August of 1982. This was the time when adult alates were produced in the pepper and potato fields, and when alates dispersed from and within these crops. Therefore, although non colonizing species could be responsible for the initial spread of viral infection in the crop, the very rapid spread of viruses in August seems to be due to the migratory phase of the alate adults of the colonizing species.

I hypothesize that the high population of aphids caught in the yellow pan traps was coming from adjacent areas as a result of trivial flights before the definite dispensing flight. As reduction in yield is more drastic with an earlier infection of the plant (Agrios et al. 1985), noncolonizing species that could transmit Persistent viruses by June or the beginning of July would cause a greater reduction in yield, due to the plants being inoculated during this critical period. Plants infected by mid August have only four or five more weeks to grow until the last harvest and, consequently, not enough time will have lapsed for the virus to cause serious losses. The problem is that yellow pan traps attract aphids that may not be representative of the aphid species actually landing on the crop. Also, it is important to properly identify all aphid species and their phenology if any conclusions are to be drawn about the relationship of their abundance and the epidemiology of a nonpersistent virus. Once the epidemiology of the virus is documented and the aphid species active during the early season phase are identified, the vector potential of each needs to be determined. It would also be interesting to determine whether the alates coming into the crop originate from winter hosts of the aphids or in other summer hosts, and whether the individuals leaving the area during the first two weeks of August stop within other crops in which virus transmission could be a problem. Information on these questions would help in designing appropriate control measures of important virus-vectoring aphid species in their area of origin.

CHAPTER III

APHID VECTOR MANAGEMENT STRATEGIES FOR THE SPREAD OF PEPPER VIRUSES IN WESTERN MASSACHUSETTS

Introduction

Cucumber Mosaic Virus (CMV) causes serious losses on several vegetable crops, particularly cucurbits, spinach, tomato and pepper throughout the world and in the northeastern United States (Agrios et al. 1985, Komm and Agrios 1978). Several strains of CMV cause symptoms on pepper that vary from slight to severe mottling of leaves, with or without brown rings, various degrees of stunting of plants and fewer fruit which are usually smaller and may show distortion and occasionally uneven ripening, and are generally unmarketable (Agrios et al. 1985, Francki et al 1979, Simons 1957). Similar symptons on pepper plants are caused by tobacco etch virus (TEV) potato virus Y (PVY) and tobacco mosaic virus (TMV). All four viruses are often present in the same field, and could be present in the same pepper plant (Zitter 1980, Anderson and Corbett 1957). Several pepper viruses including CMV, PVY and TEV, are vectored in the nonpersistent manner by a number of aphid species including the green peach aphid, Myzus persicae (Sulzer) and the potato aphid, Macrosiphum euphorbiae (Thomas).

As insecticides applied to control aphid vectors do not prevent the transmission of nonpersistent viruses (Broadbent 1969), the need for a different approach has led to the successful use of reflective mulch and mineral oils in reducing spread of aphid transmitted plant viruses in various crops.

Bradley et al (1962) showed mineral oil to interfere with aphid transmission of PVY. Loebenstein et al. (1966), Zitter and Everett (1979), Wyman et al. (1979), reported successful use of mineral oil to reduce the spread of nonpersistent aphid transmitted viruses. Simons and Zitter (1980) reported almost total suppression of the spread of CMV on pepper, cucumber and squash, where M. persicae was the main vector. Smith et al. (1964) and Kring (1972) hypothesized that reflective mulch repelled aphids and decreased the spread of virus infection. This strategy has been successfully used on a number of crops, including summer squash, watermelon and lettuce by Toscano et al. (1969), Adlerz and Everett (1968), Wolfanger and Adlerz (1971), Smith et al. (1972), Nawrocka et al. (1975), Chalfant et al. (1977), and Wyman et al. (1979). Black and Rolston (1972) showed that aluminum mulched pepper plots had fewer aphids and a reduction of virus spread. The effectiveness of this strategy has not been proven sufficiently well, however, to become an acceptable practice for aphid and aphid transmitted virus control. This strategy may be effective only if the flight activity of the vectors is known.

Yellow pan traps traditionally have been used to determine flight activity and landing patterns of aphids on different crops (Adlerz and Everett 1968). However, Irwin (1980) concluded that yellow pan traps produce a skewed measure of aphid populations alighting on crops and that they are not appropriate for studying the epidemiology of viruses transmitted by aphids. He suggested the use of a trap that reflected the exact hue, saturation and intensity given by the leaves of the crop under study as the way to accurately measure the number of aphids alighting on the crop for epidemiological studies.

I tested the combined effect of reflective mulch and mineral oil on reducing virus, particularly CMV spread in peppers and determined the feasibility of using these two approaches to manage spread of nonpersistent viruses in Massachusetts. Aphid flight activity was monitored using foliage mimic traps that we designed after Irwin's (1980) ermine lime ceramic tile trap.

Materials and Methods

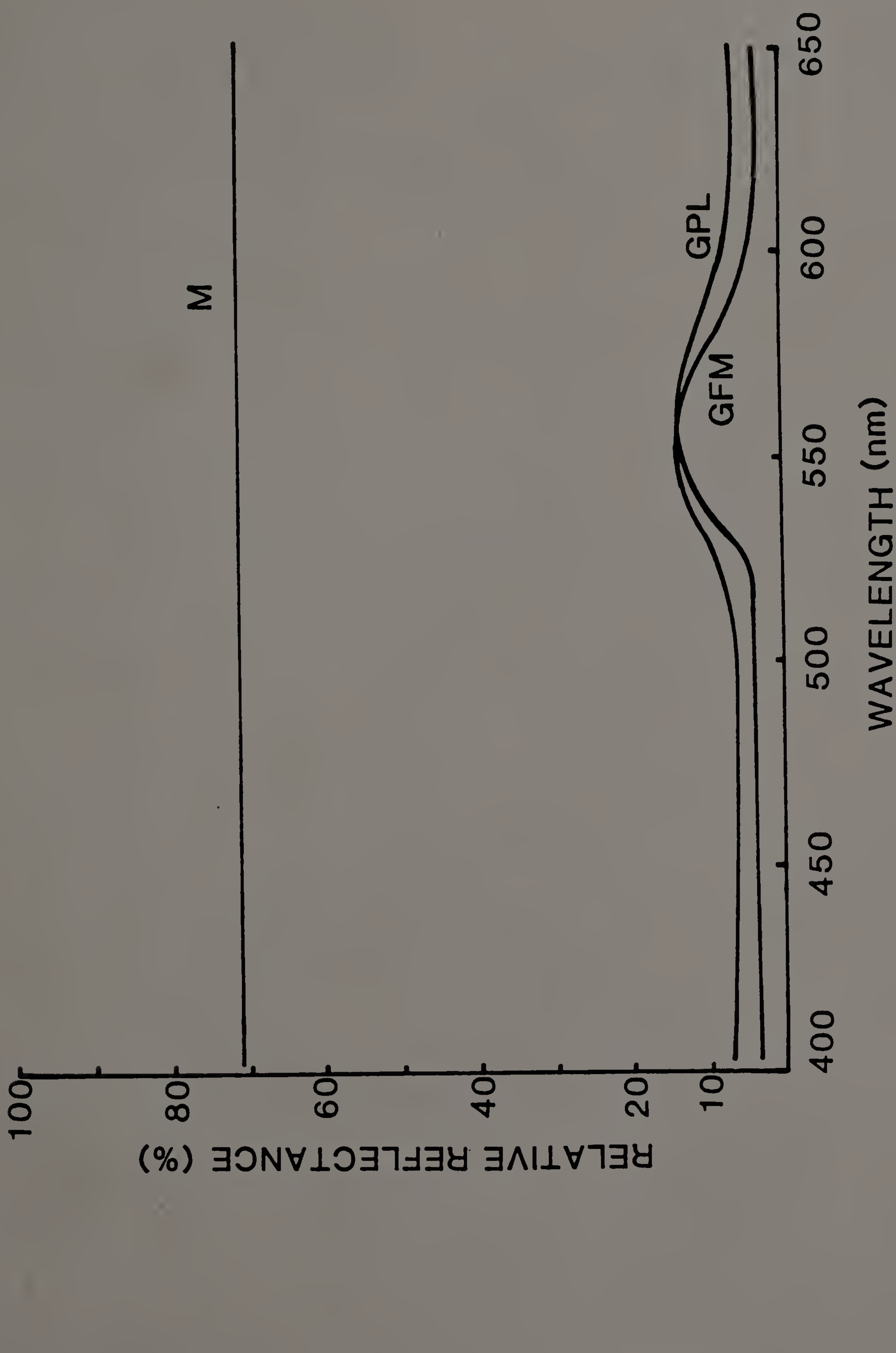
Experiments were conducted in 1981 and 1982 at the University of Massachusetts research farm in Sunderland, MA. Pepper, Capsicum annuum L., Cultivar "Lady Bell", seedlings were hand planted the first week of June in each year. Each plot consisted of six raised beds 10m long by 7.2m wide and treatments were arranged in a randomized complete block design. Plant spacing in 1981 was 60 cm between plants and 60 cm between rows in each bed and 1.2m between beds. In 1982, only one row of transplants weere placed in each bed at 45 cm between plants and 1.2m between beds. The four treatments were: reflective plastic mulch (0.76 m wide) with black backing (Polyagro Plastics, Bridgeport, PA); mineral oil (J.M. Stylet Oil Corp. 95% plus purity), applied as a 0.75% emulsion; reflective mulch plus mineral oil; and untreated control. Reflective plastic mulch was placed over the beds after the soil had been prepared for planting and 1000 kg/ha of $10N:10P_2O_5:10K_2O$ fertilizer had been broadcast and incorporated. An emulsion of mineral oil was applied weekly with a boom sprayer at 28 kg/cm^2 (400 psi), with #22 T-jet (Spray Systems) nozzles. Four plants were mechanically inoculated

(0.01 M buffer and Carborundum) in the middle of each plot in 1981. Only two plants per plot were inoculated in 1982.

Alate aphid populations landing in the crop were estimated using a green foliage mimic trap. An average measurement of the upper surface of green pepper spectral reflectance was determined with a Shimadzu UV-210 spectrophotometer (Bausch and Lomb, Inc.), using magnesium oxide as a reflectance standard. Several Liquitex acrylic pigments (Perm. Pigments Co., Cincinnati, OH) were tried and the closest reflectance to the leaves (ca. 14% at 550 nm) was achieved by mixing phthalocyanine green and cadmium orange in a proportion of 50:50 (Fig. 1). The pigments were applied to the bottom of 10 x 10 cm Petri dishes. The reflectance pattern was measured through the plexiglas Petri dish, as would be viewed by aphids in flight. The trap was filled with water and ethylene glycol (50:50 mixture). Four of these traps were placed in each plot beginning the last week of May, two weeks prior to the time alates of colonizing aphid species first began to arrive. The traps were placed on stakes at canopy height. Aphids were collected weekly and the most abundant species were identified, while species observed in low numbers were counted but not identified. Statistical analyses were based on the mean number of alate aphids per trap per plot. Apterous and alate aphid populations within the plots were recorded in 1981 by taking weekly counts of aphids on five middle leaves per plant on five plants from each of five beds for a total of 125 leaves per plot.

Plants were examined for virus infection and visible virus symptoms were recorded throughout the season. At least 36 plants per

Figure 17. Relative reflectance of plastic mulch (M), green pepper leaf (GPL) and green foliage mimic (GFM).


RELATIVE REFLECTANCE (%)
100
80
60
40
20
10
400
450
500
550
600
650
WAVELENGTH (nm)
M
GFM
GPL

plot were sampled in July, August and September to serologically verify incidence and spread of CMV, PVY and TEV in 1981, and of CMV and PVY in 1982. Fruit were harvested three times and the marketable and unmarketable fruit in the four center beds were recorded. Number of marketable fruit and total weight were also recorded.

Results and Discussion

Reflectance patterns of leaves and traps did not change throughout the growing season. Ideally, this foliage mimic trap eliminates the skewed measure of aphid populations alighting on the crop as produced by the yellow pan trap. Although it is tempting to state that this trap gives a precise assessment of the number of individuals alighting per unit area of crop foliage, it must be acknowledged that other factors, such as odor, besides the reflective properties of leaves could influence alighting preferences by aphids. Presently, the green foliage mimic trap provides the closest leafminer for aphids alighting within the green pepper canopy and should prove useful for aphid/virus studies.

Alate aphids began landing on the green mimic traps placed in the experimental field by the last week of June, while yellow pan traps placed within an adjacent, commercial green pepper field trapped the first alate aphids by the middle of June. Substantial qualitative and quantitative differences characterized the aphid landing rates in the two years of the experiment (Tables 1 and 2). Favorable environmental conditions in 1981 and higher density of plants caused the foliage to cover the reflective mulch earlier in the season than in 1982. Plants covered about 50% of the reflective mulch by early July in 1981. In 1982, wetter and cooler conditions

Table 1. Alate aphids captured in green mimic traps in green pepper, *Capsicum annuum*, at the University of Massachusetts Research Farm, Sunderland, MA, 1981.

Treatment	Mean number alate aphids/trap/week									
	3 Jul	10 Jul	17 Jul	24 Jul	31 Jul	7 Aug	14 Aug	21 Aug	28 Aug	4 Sept
	Total number of aphids									
Mulch	0.1 a[a]	0.8 a	3.4 a	5.1 a	10.6 a	11.0 a	19.0 a	10.1 a	9.6 a	13.3 a
Mulch and oil	0.1 a	1.0 a	2.8 a	4.8 a	10.0 a	10.1 a	22.8 a	12.4 a	7.1 a	11.4 a
Oil	0.8 b	1.3 a	3.4 a	6.4 a	11.3 a	12.5 a	29.5 a	16.1 a	8.5 a	11.8 a
Control	1.1 b	1.2 a	4.0 a	7.0 a	11.8 a	11.8 a	29.4 a	12.2 a	9.6 a	11.0 a
C.V.(%)	101	81	51	11	7	10	18	9	12	12
	Macrosiphum euphorbiae									
Mulch	0	0 a	0.3 a	0.5 a	1.1 a	3.8 a	5.8 a	2.6 a	3.4 a	3.8 a
Mulch and oil	0	0 a	0.3 a	0.5 a	1.8 a	4.3 a	6.4 a	2.6 a	2.2 a	2.9 a
Oil	0	0.1 a	0.3 a	1.5 b	2.4 a	6.3 a	13.5 a	3.3 a	2.6 a	4.3 a
Control	0	0 a	0.4 a	1.6 b	2.4 a	6.0 a	14.7 a	3.6 a	3.7 a	3.8 a
C.V.		5	14	19	16	25	29	28	19	19
	Myzus persicae									
Mulch	0	0 a	0.1 a	0.2 a	1.5 a	1.6 a	2.9 a	2.0 a	1.8 a	2.4 a
Mulch and oil	0	0 a	0 a	0.2 a	1.1 a	1.4 a	4.5 a	3.9 a	1.6 a	1.7 a
Oil	0	0.1 a	0.1 a	0.1 a	1.7 a	1.0 a	5.9 a	5.7 b	2.3 a	2.0 a
Control	0	0 a	0.3 b	0.2 a	1.0 a	1.1 a	3.6 a	2.7 a	2.1 a	1.7 a
C.V.		10	0.5	10	3	24	15	14	15	13
	Aphis nerii									
Mulch	0	0 a	1.8 a	1.8 a	2.4 a	1.8 a	4.8 a	3.6 a	3.4 a	3.8 a
Mulch and oil	0	0.1 a	1.9 a	1.6 a	2.3 a	1.6 a	6.3 a	4.3 a	2.2 a	2.9 a
Oil	0	0.1 a	1.9 a	1.9 a	2.7 a	2.3 a	6.9 a	4.3 a	2.6 a	4.3 a
Control	0	0 a	2.1 a	2.8 a	2.6 a	2.1 a	5.6 a	3.9 a	3.7 a	3.8 a
C.V.	0	8	15	21	10	11	19	14	20	18

[a]Mean values followed by the same letter are not significantly different at the 0.05 level of significance, (Duncan's multiple range test), (Sokal and Rohlf 1981).

Table 2. Alate aphids captured in green mimic traps in green pepper, <u>Capsicum annuum</u>, at the University of Massachusetts Research Farm, Sunderland, MA, 1982.

	Mean number alate aphids/trap/week								
Treatment	2 Jul	9 Jul	16 Jul	23 Jul	30 Jul	6 Aug	13 Aug	20 Aug	27 Aug
	Total number of aphids								
Mulch	0.2 a[a]	2.0 a	0.9 a	0.9 a	1.3 a	2.2 a	5.9 a	6.0 a	1.8 a
Mulch and oil	0.2 a	1.2 a	1.0 a	1.4 a	3.2 a	2.9 a	7.1 a	7.6 a	3.8 a
Oil	0.8 b	10.5 b	7.3 b	8.0 b	15.4 b	12.4 b	18.6 b	13.6 b	5.5 a
Control	1.1 b	10.0 b	6.4 b	7.4 b	14.0 b	13.0 b	20.3 b	14.4 b	4.0 a
C.V.	13	10	20	14	15	13	13	14	23
	Macrosiphum euphorbiae								
Mulch	0 a	0 a	0 a	0 a	0 a	0.1 a	0.5 a	0.7 a	0.6 a
Mulch and oil	0 a	0 a	0 a	0 a	0.1 a	0.2 a	0.4 a	1.3 a	0.6 a
Oil	0.1 a	0.1 a	0.2 a	0.3 b	1.5 b	2.8 b	8.3 b	5.1 b	1.4 a
Control	0 a	0.1 a	0.1 a	0.3 b	1.6 b	2.7 b	8.9 b	6.8 b	1.3 a
C.V.	6	12	11	12	17	16	12	22	22
	Myzus persicae								
Mulch	0	0	0 a	0 a	0 a	0.8 a	2.3 a	1.5 a	0.9 a
Mulch and oil	0	0	0 a	0 a	0.3 a	0.8 a	3.4 a	2.1 a	1.4 a
Oil	0	0	0.1 a	0.1 a	1.2 b	2.8 b	3.6 a	2.3 a	1.1 a
Control	0	0	0.1 a	0.1 a	0.6 b	3.7 b	3.6 a	2.6 a	0.2 b
C.V.			6	8	16	17	16	21	22

continued next page

Table 2. Continued

Treatment	Mean number alate aphids/trap/week								
	2 Jul	9 Jul	16 Jul	23 Jul	30 Jul	6 Aug	13 Aug	20 Aug	27 Aug
					Capitophorus eleagni				
Mulch	0 a	0.1 a	0.2 a	0 a	0.3 a	0.1 a	0.4 a	0.1 a	0.1 a
Mulch and oil	0 a	0.1 a	0.1 a	0 a	0.4 a	0.1 a	0.6 a	0 a	0 a
Oil	0.3 b	3.8 b	1.9 b	2.1 b	3.3 b	0.8 b	0.9 a	0.3 a	0.3 a
Control	0.4 b	3.7 b	1.5 b	2.1 b	3.4 b	1.1 b	1.1 a	0.2 a	0.2 a
C.V.	8	11	27	27	13	19	18	23	13
					Cavariella sp.				
Mulch	0.2 a	1.7 a	0.2 a	0.1 a	0 a	0	0	0	0
Mulch and oil	0.2 a	1.7 a	0.3 a	0.2 a	0 a	0	0	0	0
Oil	0.4 a	3.3 a	0.1 a	0.3 a	0.1 a	0	0	0	0
Control	0.5 a	2.5 a	0.1 a	0.4 a	0.1 a	0	0	0	0
C.V.	14	20	17	19	6				

[a]Mean values followed by the same letter are not significantly different at the 0.05 level of significance, Duncan's multiple range test (Sokal and Rohlf 1981).

prevailed which slowed down plant growth. It was not until the middle of August that 50% of the mulch was covered.

Except for the first count on July 3 there was no difference in the total number of aphids trapped in the different treatments in 1981 (Table 1). The most abundant aphid species in both years were the two colonizing species, the potato aphid and the green peach aphid; numbers of other species varied from year to year. *Aphis nerii* Fonscolomb, a relatively abundant species in 1981, was not trapped in 1982. *Capitophorus elaeagni* (Del Guercio) and *Cavariella* sp. were present in low numbers in 1982. The peak captures of total number of alate aphids as well as of *M. euphorbiae* and *M. persicae* was in mid-August for both years. This flight activity corresponded to the phase of alates produced by colonizers in the crop and adjacent crops. The number of dates per five leaves (Table 3) showed an increase of dates as the growing season progressed. It is possible that the alates counted during the initial weeks were aphids that had recently arrived to colonize the plants. The alate counts from mid-August to the end of the season included mostly newly formed alates produced within the pepper plants, as aphid populations at this time of year alates which probably disperse to the primary host plants.

There were no differences in the numbers of alate *M. euphorbiae* among the different treatments in 1981, except on July 24. However from July 31 to August 21 there was a trend toward lower numbers landing on the mulched treatments (Table 1). There was little difference in 1981 in the number of *M. persicae* captured among the different treatments. The high number of alate *M. persicae* trapped

Table 3. Mean number of alate aphids on green pepper *Capsicum annuum*, at the University of Massachusetts Research Farm, Sunderland, MA, 1981.

	Mean number of alate aphids/5 leaves/plant					
Treatment	10 Jul	17 Jul	27 Jul	3 Aug	13 Aug	24 Aug
Mulch	0.3a[a]	2.3a	5.0 a	13.0 a	25.7a	3.2a
Mulch and oil	0 a	2.0a	7.5 a	10.5a	33.0a	2.5a
Oil	1.3b	2.3a	7.2 a	12.7a	33.5a	1.7a
Control	2.3b	2.3a	8.0 a	13.0a	26.2c	5.0a

[a]Mean values followed by the same letter are not significantly different at the 0.05 level of significance, Duncan's multiple range test (Sokal and Rohlf 1981).

on August 21 in 1981 in the oil treatment was probably due to the high population of apterous aphids (Table 4) in these plots and consequently the highest number of dispersing alates. Undoubtedly, some of these alates were captured in the traps before they flew from the area. A similar phenomenon occurred in the oil treatment plots on August 14 and 28, 1981.

A. nerii was a rather abundant species thorougout the whole season in 1981. Alates trapped were more numerous than M. euphorbiae and M. persicae until the end of July. However, there were no significant differences in the number of alates of this species landing among the treatments.

Total number of winged aphids trapped in 1982 revealed significant differences between number landing in mulched and unmulched plots. This was true from the first week in which aphids appeared until August 20. The number of M. euphorbiae was considerably lower in the mulched treatments in 1982, and very low numbers of alates were captured on mulch and mulch plus oil treatments compared to unmulched treatments from July 23 to August 20, 1982.

There were significant differences in the number of alate M. persicae captured in 1982 on July 30 and August 6 (Table 2), in mulched and unmulched treatments. Although the number of alates trapped was lower than in 1981, apterous populations consisted mostly of green peach aphid and the number of alates captured on August 13 and 20 was influenced by migrants produced within the treatment plots.

Table 4. Mean Number of apterous aphids on green pepper at the University of Massachusetts Research Farm, Sunderland, MA, 1981.

	Mean number of apterous aphids/5 leaves/plant					
Treatment	10 Jul	17 Jul	27 Jul	3 Aug	13 Aug	24 Aug
Mulch	4.5 a[a]	11.5 a	158.7 a	482.7 a	1235.7a	11.7 a
Mulch and Oil	18.2 b	18.2 ab	194.0 a	646.0 a	2508.2bc	23.5 a
Oil	26.0 b	36.5 b	239.0 a	701.7 a	3175.5 c	35.0 a
Control	22.2 b	20.5 ab	182.0 a	665.5 a	1774.2 ab	32.5 a
CV	30	27	12	17	16	42

[a]Mean values followed by the same letter are not significantly different at the 0.05 level of significance, Duncan's multiple range test (Sokal and Rohlf 1981).

Capitophorus elaeagni and *M. euphorbiae* were the species with the highest behavioral response to reflective mulch in 1982 as there were lower numbers of this aphid in the mulched, than the unmulched treatments until August 13, by which time the foliage had covered the reflective mulch. *C. elaeagni* was at least partially responsible for the significant differences between mulched and unmulched treatments found in the total number of alate aphids captured on July 2, a time at which the number of *M. persicae* and *M. euphorbiae* were almost nil.

There were no significant differences between treatments for *Cavariella* sp. captured throughout their flight activity period. Peak number of alates occurred on July 9. The data from 1981 and 1982 show that reflective mulch was therefore not effective in repelling equally all aphid species. *Cavariella* sp. and *A. nerii* do not seem to be very responsive to the repelling effect of the mulch, while *C. elaeagni* had a tendency to respond to a higher degree to mulch. If this relationship were consistent, it would be important to determine the degree of responsiveness to reflective mulch of the colonizing and transient species transmitting nonpersistent viruses in order to decide on how the reflective mulch could be used to decrease virus infection by impeding landing rates and probing. Trapping data for 1981 and 1982 show that *M. euphorbiae* and *M. persicae* colonization was very synchronous from year to year, beginning between July 8 and 10.

These data support the hypothesis that transient species landing and probing plants early in the season serve as primary vectors for the spread of nonpersistent viruses. Species like *Cavariella* sp. and *C. eleagni* could be responsible for the primary spread of CMV and other nonpersistent viruses. Colonizing species coming in later in the season might be the main population responsible for the secondary spread of viruses.

The effect of reflective mulch on landing rates decreased as the mulch became covered by green pepper foliage. Favorable environmental conditions, a good fertilization program and densely planted plants could produce rapid growth that could quickly nullify the effectiveness of the mulching system. Critical flight activity periods of transient alates arriving on the crop, and their vector potential, and time taken for the crop to cover the mulch need to be taken into account to effectively utilize reflective mulch for preventing early season spread of nonpersistent viruses. The results on virus occurrence, identity, and spread within the pepper plots are presented in detail in another paper (AG.N.A. et al. unpublished) and only a brief summary is given here. The percentage of virus infection is summarized in Figures 2 and 3. In 1981, with ca 2% of plants inoculated initially with CMV, the rate of infection measured visually through assessment of viral symptoms increased very slowly. Only by the third week of September was there a drastic increase in the number of infected plants, with a maximum of 50% in the control.

The mulch plus oil treatment showed the lowest level of infection followed by the mulch treatment. In 1982, with ca. 1% of plants inoculated initially with CMV, the rate of viral infection measured visually reached 100% by August 21. The mulched treatments had low infection rates until August 5 (1.5-2.3%) compared to 15.6-23% for non-mulched treatments. In 1981 the level of inoculation was twice that of 1982 and there were higher numbers of alate colonizers

Figure 18. Percentage green pepper plants, Capsicum annum L., showing virus symptoms for mulch (M), mulch plus oil (M&O), oil (O) and untreated control (C) treatments at the University of Massachusetts Research Farm, Sunderland, MA, 1981.

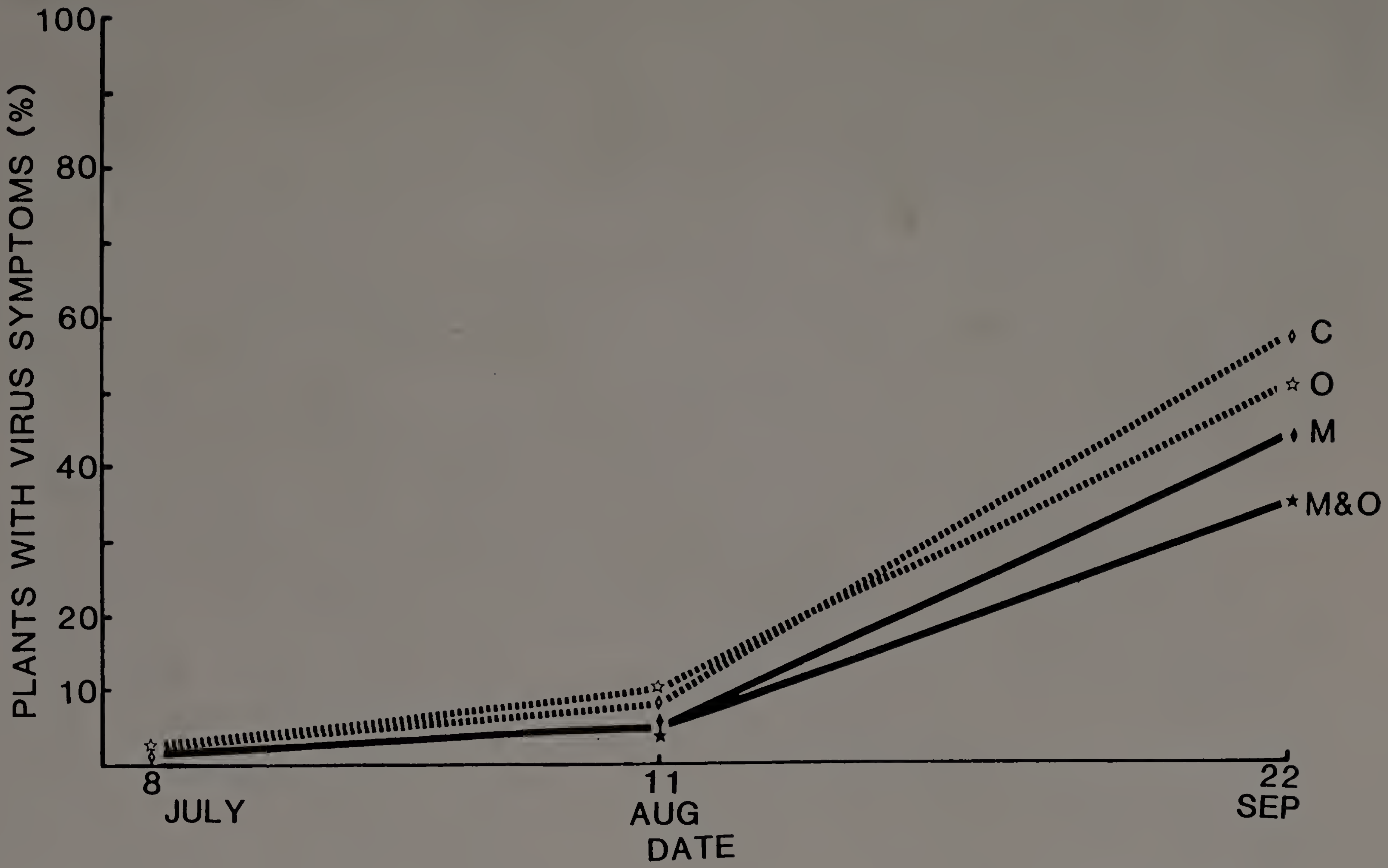
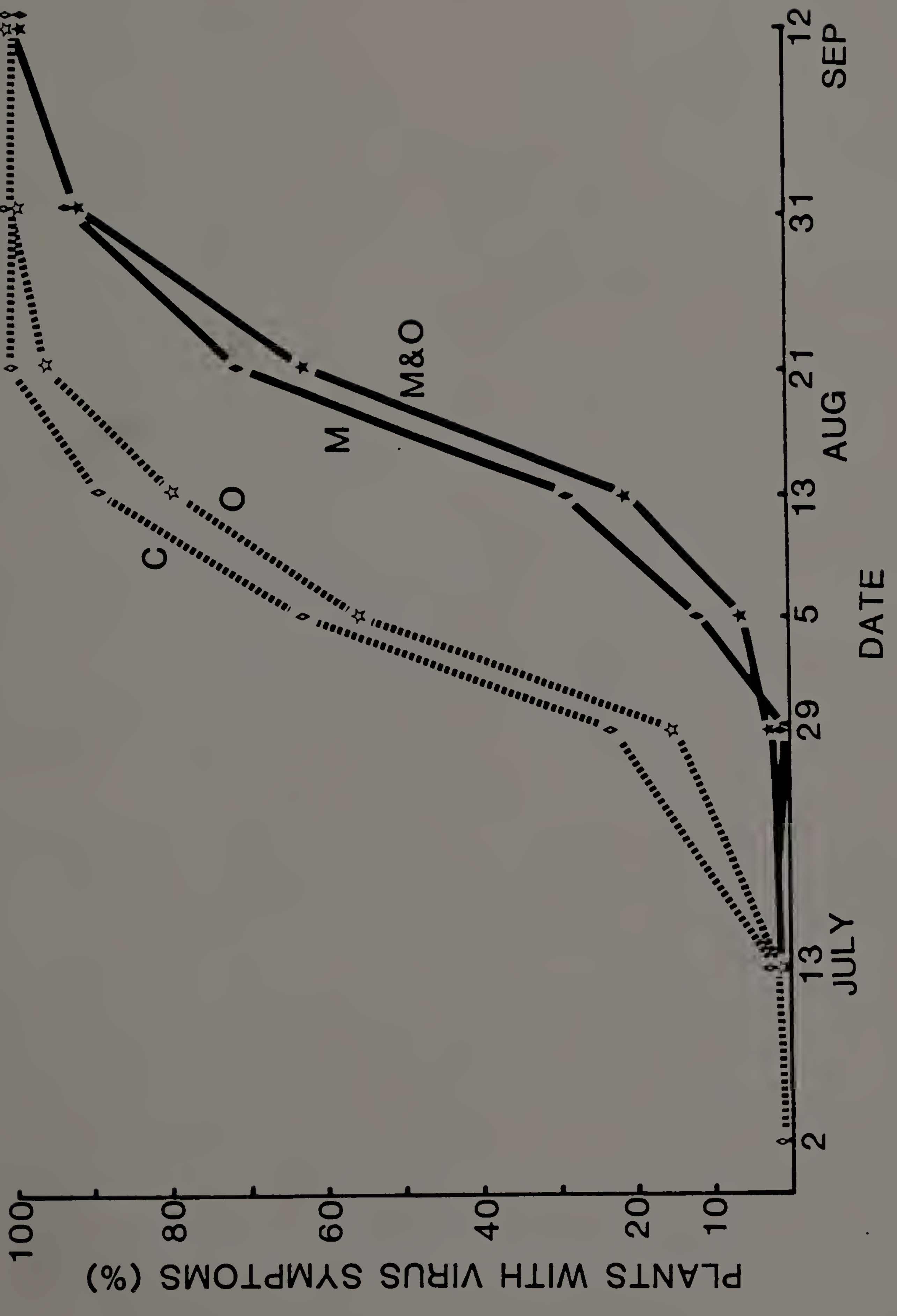

PLANTS WITH VIRUS SYMPTOMS (%)
100
80
60
40
20
10
8
JULY
11
AUG
DATE
22
SEP
C
O
M
M&O

Figure 19. Percentage green pepper plants, _Capsicum_ _annuum_ L. showing virus symptoms for mulch (M), mulch plus oil (M&O), oil (O) and untreated control (C) treatments at the University of Massachusetts Research Farm, Sunderland, MA, 1982.



PLANTS WITH VIRUS SYMPTOMS (%)
100
80
60
40
20
10
2
13
JULY
29
5
13
AUG
21
31
12
SEP
DATE
C
O
M
M&O

in 1981. Yet the spread of viruses was much greater in 1982. The spread of viruses in 1982 was first observed on July 13, ca. 10 days earlier than alate activity by the colonizing species M. persicae and M. euphorbiae. Viral symptoms occur 7-10 days after inoculation, which means the initial spread occurred around July 3. The early season spread of viruses can only be attributed to the non colonizing, transient species of Cavariella and Capitophorus.

The rapid increase in infection rates during the first 3 weeks of August is correlated with the presence of high numbers of aphids trapped, which corresponds to the period of dispersal of newly produced alates. If this is the case, it would be advisable to spray an aphicide prior to the production of alates in early August, hence reducing the number of alates and their subsequent vectoring of viruses. It is necessary to clarify whether the winged morphs from the same field go through a series of trivial flights with probing behavior on the plants within the field or if alates from other adjacent fields act as transient aphids, spreading the nonpersistent viruses by probing.

Looking at the mean number of unmarketable fruits due to viral symptoms (Table 5) there were no significant differences among the treatments in 1981. During 1982 the data showed significant differences for this parameter, with the two mulched treatments having the lowest number of unmarketable fruits. The difference in marketable fruit for the two years is probably due to the fact that in 1982 there was a higher percentage of infected plants earlier in the season. Infections after the middle of August showed no

Table 5. Mean number of unmarketable green pepper fruit due to virus symptoms and total yields of marketable fruit per hectare.

Treatment	Mean Number of Unmarketable Fruit/Plot		Total Yield int/ha	
	1981	1982	1981	1982
Mulch	44.0 a[a]	26.7 a	9.5 a	11.3 a
Mulch plus Oil	34.2 a	18.0 a	8.6 a	11.7 a
Oil	30.2 a	59.5 b	7.5 a	5.9 b
Control	40.7 a	79.2 b	8.4 a	4.1 b

[a]Mean values followed by the same letter are not significantly different at the 0.05 level of significance, Duncan's multiple range test (Sokal and Rohlf 1981).

reduction in yield based on an inoculation study at a nearby site (Agrios et al. 1985).

There was no difference in yields between treatments in 1981 (Table 5). The data for 1982 clearly show that the mulch treatments had higher yields than the unmulched treatments (Table 5). These data suggest that the oil treatment had a negligible effect on yield and consequently its use based on these studies can not be justified.

Wyman et al. (1979) have stated that the effect of mulch treatments in increasing yields results from the action of several factors. Repellency of alate aphids, reduction in virus spread, higher soil temperatures, water conservation and weed control all tend to increase yield. How much of the yield increase was due to the mulch reducing alate landing rates and subsequent decrease on virus infection is not known. Experiments with reflective mulch and a neutral mulch need to be conducted to answer this question. Although the first two harvests in 1981 produced no differences in yield, the first two pickings in 1982 showed a significant difference between the mulched and unmulched treatments. With only two pickings, the yields for the control and oil treatments in 1981 were considerably higher than the corresponding total yields in 1982! This lack of differences between mulched and unmulched treatments in 1981 might be attributed to the very low rate of virus infection shown throughout the entire season, and (or) the delay in virus spread until after the critical period.

M. euphorbiae and *M. persicae* were the only two species found as colonizers of pepper plants in the area. More than 95% of the nymphs present throughout the 1981 season were green peach aphid nymphs (Table 4). On July 10, July 17, and August 13 the number of apterous aphids was significantly different for the treatments. After August 13 there was a sharp decline in apterous populations which coincided with the formation of alates and the dispersing phase of *M. persicae*. In 1982 the apterous population was also mostly *M. persicae*; however, populations were very low and apterous aphids were rarely detected when plants were examined. Alate *M. persicae* trapped in mid-August could have originated in adjacent potato or cucurbit fields.

At the time of aphid migration in 1981, the mulch and control treatments had the lowest apterous populations, while the oil and mulch plus oil treatments had the highest. During the entire season, there was a clear tendency for the two oil treatments to have the highest apterous populations. A similar phenomenon had been reported by Ferro et al (1980) working with *Rhopalosiphum maidis* on corn in the same area. This could have been due to fewer predators feeding on aphids in the oil treatments.

The high rate of reproduction of *M. persicae* in oil treatments again supports the idea of applying an aphicide before alate migration when oil treatments are used. Lowering migrating populations at a regional level could decrease nonpersistent virus transmission to other crops. This is especially valid for areas where late season crops are grown, e.g. potato seed production areas in Maine.

CHAPTER IV

FOLIAGE MIMIC TRAPS FOR MONITORING ALATE APHIDS LANDING IN GREEN PEPPER

Introduction

Green pepper, Capsicum annuum L., is an important vegetable crop grown in western Massachusetts. Yields and quality of fruit are reduced by plant viruses, transmitted in the nonpersistent manner. Such viruses include potato virus (PVY) and tobacco etch virus (TEV) and cucumber mosaic virus (CMV). CMV is vectored by several species of aphids two of which commonly colonize pepper in this area, the green peach aphid, Myzus persicae (Sulzer) and the potato aphid, Macrosiphum euphorbiae (Thomas). Because nonpersistent viruses are introduced into plants within a few seconds by colonizing and transient alate aphids insecticides have proven to be ineffective in preventing the spread of such viruses. I have shown that reflective mulch reduces the initial spread of nonpersistent viruses, and based on trap catches in field trials the reduction appears to be due to fewer alates landing in the mulched crop. In this study, I examined the importance of background on the number of aphids trapped by yellow pan traps (Moericke traps) and by green foliage mimic traps to better quantify the role of reflective mulch. It would appear that there should be some relationship between the number of alates landing in a crop (absolute estimate), the initial levels of virus inoculum in the field, and the epidemiology of the virus, especially the time of virus spread. Agrios et al. (1985) have shown that severity of foliar and fruit symptoms decreased as the date of inoculation of pepper plants was delayed, demonstrating the importance of the initial virus spread.

Since Moericke (1951) found that yellow hue strongly attracts many species of aphids, yellow pan traps have been widely used to estimate the abundance of alate aphid populations landing on agricultural crops. As these traps act as "super mimics" and may trap aphid species that do not normally land within a particular crop, it is necessary to have traps that monitor those aphid species which normally alight within a crop canopy. This becomes extremely important when trying to study the epidemiology of nonpersistent plant viruses of which aphids are the primary vector. Irwin (1980) proposed that yellow pan traps were not appropriate for epidemiological studies of nonpersistent viruses as they tend to overestimate aphid populations or capture non-alighting species. For epidemiological studies, an accurate aphid monitoring system should measure the number of individuals that alight per unit area of crop foliage. Irwin (1980) designed a ceramic tile trap with reflectance characteristics in the visual spectrum that better mimic the plant canopy. However, these traps are expensive and it is difficult to control the spectral characteristics from one lot to the next. Based on Irwin's idea, we designed a mimic trap by using acrylic pigments that more closely mimic the reflectance characteristics of green pepper foliage and we present field data regarding the performance of this trap.

There are many factors affecting trap efficiency and specificity, such as trap size (Costa and Lewis 1967) and background (Moericke 1955). Surrounding bare soil and vegetation have been shown to influence the number of aphids captured in yellow pan traps (Smith 1969, Heathcote et al. 1969 and Kring 1972). A new green foliage mimic trap which clearly approximate the hue and percentage reflectance of green pepper foliage was designed to sample alates that would be naturally alighting on the crop canopy. Green and yellow traps were evaluated to examine how three different sizes and backgrounds affected the number of aphids trapped per unit area.

Materials and Methods

All experiments were carried out at the University of Massachusetts Research Farm, Sunderland, MA in 1983.

Trap Comparisons. Three trap types were compared. Green foliage traps were made by applying a 50:50 mixture of phthalocyanine green and cadmium orange Liquitex (Perm. Pigments Co. Cincinnati, OH) acrylic pigments to the undersurface of the bottom of a plastic tray (11.5 x 11.5 x 3.5 cm, sandwich box). Yellow traps were made by painting the tray bottom with Federal safety yellow (Rustoleum™). The ermine lime trap was made by placing a ceramic tile (11.3 x 11.3 cm, SE 11, H & R Johnson, Stoke-on-Trent, England) in the bottom of the tray. Traps were filled with a 50:50 mixture of ethylene glycol and distilled water to capture and preserve alate aphids between collections.

One each of the three trap types was placed on stakes within a $60 m^2$ green pepper plot. The experimental design was a randomized complete block with five replicates, and traps were re-randomized weekly from 24 June to 12 August 1983. The traps were placed within the plots at a height even with the top of the plant canopy to avoid, as much as possible, any bias due to trap height relative to plant architecture and background. The data are presented for number of alates trapped per week. The data were transformed using the square root of X + 0.05 (Sokal and Rohlf 1981) and treatment means were compared using Duncan's multiple range test (P=0.05).

A Shimadzu U-V 210 spectrophotometer (Bausch and Lomb) was used to measure the spectral reflectance of the different surfaces. Reflective measurements are given as percentage of reflectance compared to a magnesium oxide standard.

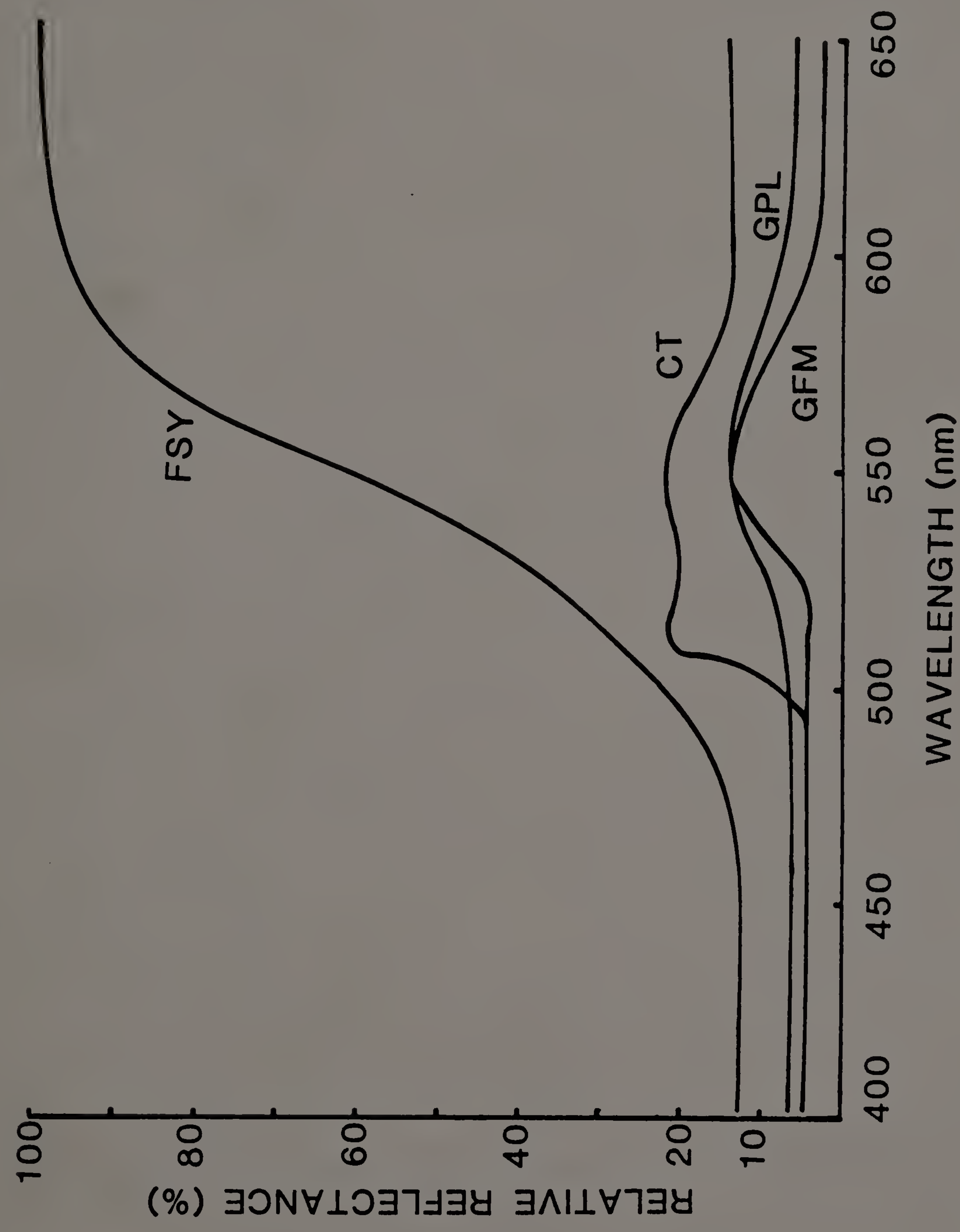
Trap Size. Square wooden traps 156, 625 and 1444 cm^2 were painted Federal Safety Yellow or green (same as foliage mimic traps described above) to compare trap efficiency by placing them on a fallow area (soil background). The upper trap surface was coated with a thin layer of Tanglefoot™ (The Tanglefoot Company, Grand Rapids, MI) to entangle the aphids. The traps were cleaned and recoated with Tanglefoot as necessary. The three trap sizes of the same color were placed 2m apart in a line and the other colored traps were placed 5 m away. The number of aphids captured over 24 hours was recorded and at this time the traps were rotated to a different location. This experiment was repeated 15 times from 12 June to 25 August 1983. Catches for rainy and very cloudy days were not included in the analyses, and were exclusive of the 15 recorded days.

Trap Background. The undersides of sandwich boxes were painted federal safety yellow or green (green foliage mimic trap), and filled with the glycol:water mixture. One of each color type was placed in the center of a round wooden platform (50 cm diam.) set 50 cm above the ground. The platforms were covered with green (same as green foliage mimic), soil from the test field or reflective mulch (Polyagro Plastics, Bridgeport, PA). As the green platform was painted with the same acrylics as the foliage mimic trap, there was no contrast between the trap and its background. The soil-covered platform had a background similar to when traps were placed over fallow areas. The reflective mulch background mimicked the situation early in the growing season, where small green pepper plants would be placed in the center of the reflective mulch. The experiment was set up in a fallow area. Each trap/background combination was a separate treatment. The platforms were rotated every 24 hours and the number of aphids was recorded at this time. Each 24 hour count was treated as a replicate, and there were 20 trial days from 24 June to 22 August 1983. Rainy and cloudy days were excluded from the analyses.

Results and Discussion

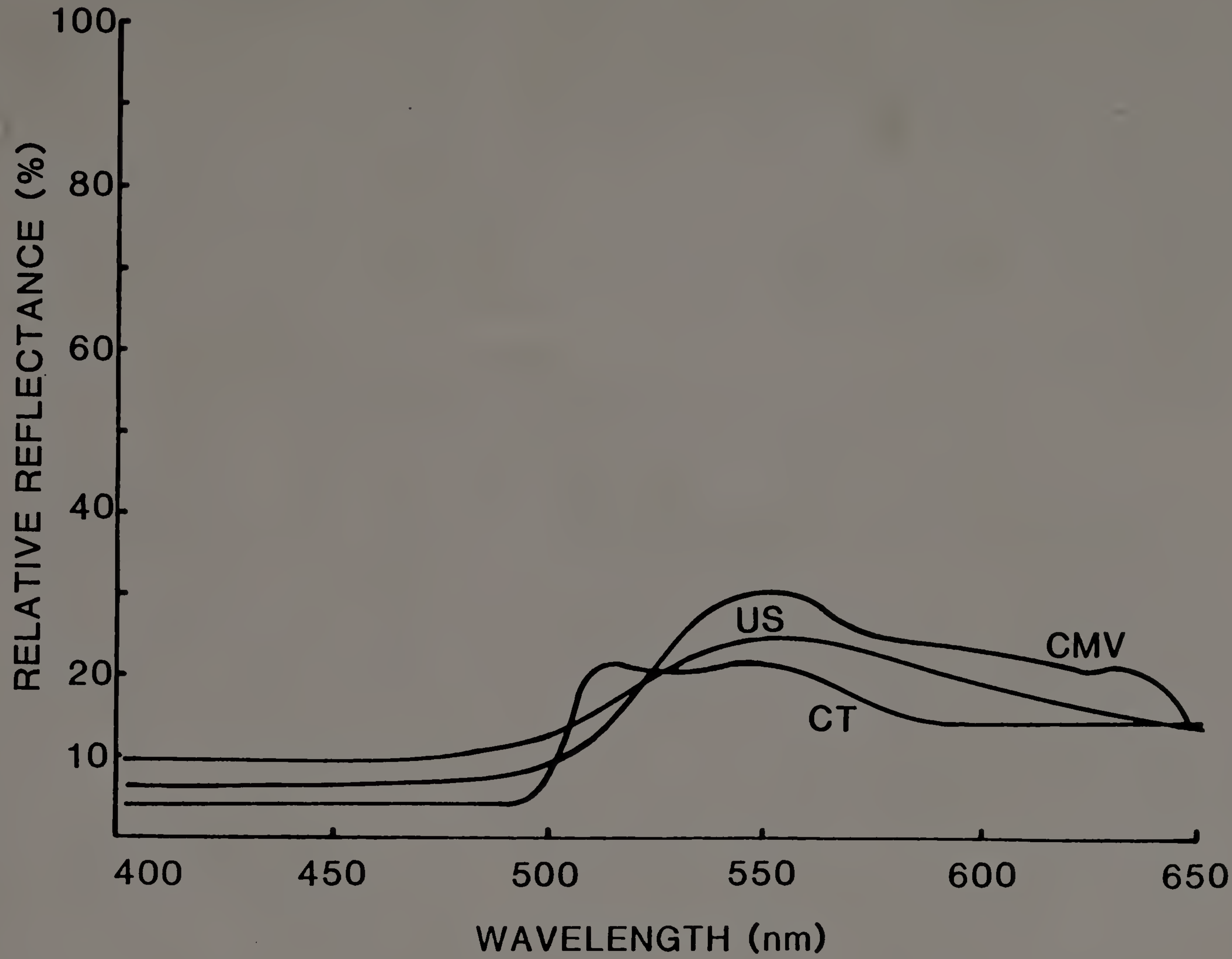
Trap Comparisons. The spectral characteristics for the yellow trap, green foliage mimic trap and the ermine lime ceramic tile trap were very different from each other. Only the foliage mimic trap closely resembled green pepper foliage (Fig. 20). Peak reflectance for the foliage mimic was 14% at 550 nm, exactly the same as the green pepper foliage but the mimic pigment was more saturated. The ceramic tile reflectance was consistently higher with a peak reflectance of 22%. Peak reflectance of light was from ca. 500-570 nm. The ceramic tile trap had a relative reflectance pattern closer to a virus-infected, heavily mottled pepper leaf, which had a peak reflectance of 31% at 550 nm (Fig. 21). The underside of a healthy green pepper leaf had a similar reflective pattern to the mottled

Figure 20. Relative reflectance of Federal safety yellow trap (FSY), ermine lime ceramic tile (CT), green foliage mimic trap (GFM) and green pepper leaf (GPL).



RELATIVE REFLECTANCE (%)
100
80
60
40
20
10
400
450
500
550
600
650
WAVELENGTH (nm)
FSY
CT
GPL
GFM

Figure 21. Relative reflectance of cucumber mosaic virus (CMV) infected green pepper leaf, under surface of a healthy green pepper leaf (US) and ermine lime ceramic tile trap (CT).


100
80
60
40
20
10
RELATIVE REFLECTANCE (%)
US
CMV
CT
400
450
500
550
600
650
WAVELENGTH (nm)

leaf (Fig. 21). The federal safety yellow trap had almost 100% reflectance from 550 to 650 nm.

There was no significant difference in the number of aphids captured by the different traps when aphid populations were low (Tables 6, 7 & 8). As the number of aphids captured increased (15 & 22 July), the federal safety yellow and the ceramic tile traps caught similar numbers, and both traps caught more than the foliage mimic trap. When the highest landing rates occurred (weeks ending 5 & 12 August), there was a significant difference between all traps for M. euphorbiae; however, the trap differences for M. persicae and miscellaneous aphids was variable.

All three traps caught their first alate M. persicae and M. euphorbiae the week ending 8 July, and their first miscellaneous aphids 24 June. This shows that any of the traps could be used to detect the first alates arriving in a green pepper plot. The first miscellaneous aphid species were captured the week ending 24 June. The federal safety yellow trap caught significantly more aphids than the other traps at this time.

Since all trap types detected the arrival of the different species of aphids at the same time, the only advantage in using the yellow or ceramic tile traps is in the number of aphids trapped. From an epidemiological stand-point, an absolute estimate of alighting alates is more important than abundance so that spread of viruses in the field can be better correlated with number of aphids landing per unit area per time interval, and for this purpose the green foliage mimic trap should provide a better estimate.

Table 6. Number of alate *M. persicae* captured on Federal safety yellow, ermine lime ceramic tile and green foliage mimic traps, 1983.

	Mean number of aphids/trap/week							
Trap Type	24 June	1 Jul	8 Jul	15 Jul	22 Jul	29 Jul	5 Aug	12 Aug
Yellow	0	0	0 a[a]	0.2a	0.4a	1.8a	15.0a	15.2a
Ceramic tile	0	0	0.4a	0 a	0.4a	1.4a	6.8b	4.2b
Green foliage	0	0	0.2a	0 a	0 a	0.8a	3.2c	4.8b
C.V.			28	18	26	24	14	14

[a]Means presented are untransformed. For statistical purposes data were transformed using x+0.5 and compared using Duncan's multiple range test at the 0.05 level of significance (Sokal and Rohlf 1981).

Table 7. Number of alate *M. euphorbiae* captured on Federal safety yellow, ermine lime ceramic tile and green foliage mimic traps, 1983.

	Mean number of aphids/trap/week							
Trap Type	24 June	1 Jul	8 Jul	15 Jul	22 Jul	29 Jul	5 Aug	12 Aug
Yellow	0	0	0.2a[a]	2.2ab	3.8a	15.0a	201.0a	181.0a
Ceramic tile	0	0	0.4a	3.8a	3.6a	9.0a	30.0b	63.0b
Green	0	0	0.2a	1.0b	1.2b	1.6b	3.8c	5.2c
C.V.			29	30	25	24	22	13

[a]Means presented are untransformed. For statistical purposes data were transformed using x+0.5 and compared using Duncan's multiple range test at the 0.05 level of significance (Sokal and Rohlf 1981).

Table 8. Number of alate miscellaneous aphids captured on Federal safety yellow, ermine lime ceramic tile and green foliage mimic traps.

	Mean number of aphids/trap/week							
Trap Type	24 June	1 Jul	8 Jul	15 Jul	22 Jul	29 Jul	5 Aug	12 Aug
Yellow	3.8a[a]	0.4a	6.8a	55.4a	19.2a	11.2a	35.0a	25.6a
Ceramic tile	1.0b	0.6a	3.4b	42.6b	14.6a	4.0b	20.6a	19.6a
Green foliage	0.8b	0 a	0.2c	3.2c	4.8b	6.2ab	22.0a	8.4b
C.V.	36	32	30	11	16	22	23	17

[a]Means presented are untransformed. For statistical purposes data were transformed using x+0.5 and compared using Duncan's multiple range test at the 0.05 level of significance (Sokal and Rohlf 1981).

Trap Size. Trap size influenced the number of aphids trapped (Table 9). The larger the trap the more alates were caught. This relationship held true for yellow and green traps. Yellow traps captured much higher numbers of alates for all corresponding sizes than the green foliage mimic trap. Proportions of aphids trapped by the green mimic when compared to the yellow trap were 14.6%, 12.1% and 10.8% for the 156 cm^2, 625 cm^2 and 1444 cm^2 trap respectively, and were always significantly different. If trap efficiency is measured by the number of alates caught per unit surface area, the smallest size trap was most efficient. Most of the aphids were captured along the edges of the traps for all trap sizes. This observation seems to indicate that the aphids are orienting to the contrast between the edge of the trap and soil background. Since the smallest trap had a greater periphery to surface area ratio (0.32) compared to the other traps, (625 cm^2=0.16, 1444 cm^2=0.1), this could partially explain why on a per cm^2 basis fewer alates were trapped as the size of the trap increased.

Trap Background. Yellow traps captured much higher numbers of *M. persicae*, *M. euphorbiae* and miscellaneous aphids than green foliage mimic traps when traps were placed over reflective mulch, soil or green backgrounds (Tables 10 & 11). The mulch background always resulted in significantly fewer alates captured than other backgrounds. When green foliage traps were placed over reflective mulch, no alates were trapped during the entire season. If it is assumed that the foliage mimic trap acts as a foliage model, since no aphids were trapped when this trap was placed over reflective mulch, it suggests that if the amount of reflective surface area to foliage

Table 9. Mean number of aphids landing on different sizes of sticky wooden traps over a soil background, for 15 trapping days from 12 June to 22 August 1983.

	Yellow trap		Green foliage mimic trap	
Trap area cm^2	No. Aphids per trap	No. Aphids/ cm^2	No. of Aphids/trap	No. of Aphids/cm^2
156	93.3a	0.59	13.6a	0.08
625	253.4b	0.40	30.8b	0.04
1444	461.3c	0.32	50.1c	0.03

a Means presented are untransformed; however, for statistical purposes data were transformed using X+0.5 and compared using a Duncan's multiple range test at the 0.05 level of significance (Sokal and Rohlf 1981).

Table 10. Number of alate aphids landing on green foliage mimic traps over mulch or green soil backgrounds for 20 trapping days from 24 June to 22 August 1983.

Background	Mean number of aphids/trap/day		
	M. persicae	*M. euphorbiae*	Other
Mulch	0 a[a]	0 a	0 a
Green Foliage mimic	1.1 b	0.1 ab	1.4 b
Soil	1.4 b	0.2 b	4.3 c

[a] Means presented are untransformed; however, for statistical purposes data were transformed using X+0.5 and compared using a Duncan's multiple range test at the 0.05 level of significance (Sokal and Rohlf 1981).

Table 11. Mean number of alate aphids landing on Federal safety yellow traps over mulch, green and soil backgrounds for 20 trapping days from 24 June to 22 August 1983.

	Mean number of aphids/trap/day		
Background	*M. persicae*	*M. euphorbiae*	Other
Mulch	0.1 a[a]	0 a	0.7 a
Green foliage mimic	13.4 b	6.2 b	16.8 b
Soil	16.5 b	13.4 c	31.5 c

[a]Means presented are untransformed; however, for statistical purposes data were transformed using X+0.5 and compared using a Duncan's multiple range test at the 0.05 level of significance (Sokal and Rohlf 1981).

remained high enough throughout the season, aphid colonization of foliage would be nil. This effect appears to be independent of aphid population densities on adjacent crops and weeds. Even when the super mimic (yellow trap) was placed over the reflective mulch, less than one alate/day was trapped.

Green foliage mimic traps placed over the soil background caught the same number of *M. persicae* and *M. euphorbiae* as when placed over the green foliage mimic background. Yellow traps placed over the soil background consistently had higher numbers of alate *M. euphorbiae* and miscellaneous aphids than the same traps over green foliage mimic background. These results agree with findings by Smith (1969) and Heathcote et al. (1969) in which aphids settled preferentially on plants surrounded by bare soil rather than on those surrounded by other plants when yellow traps were used.

Significantly more miscellaneous aphids were trapped by both trap types when placed over bare soil. Virtually none were captured in traps placed over the mulch. The differences presented for the soil and green backgrounds seem to indicate that within the miscellaneous aphids there were individuals whose stimulus to land was given mainly by the contrast between yellow and green foliage traps over the soil, but not over green background.

Trap type and placement within the cropping system is extremely important when studying the relationship between alate aphids alighting in a crop and spread of nonpersistent viruses. This can only be accomplished by obtaining a more precise estimate of alate landing rates. Any trap that is architecturally or spectrally different from plant foliage could produce a biased estimate of landing rates. The green foliage mimic trap when placed within the crop canopy should provide a more accurate estimate of alate landing rates. The green foliage mimic trap is inexpensive and by mixing different pigments it is possible to more closely mimic the spectral characteristics of any given plant foliage.

CHAPTER V

CONCLUSIONS

Yellow pan traps provided a very practical sampling method for qualitative and quantitative analysis of alate aphids species landing in a green pepper crop. Two different aphid complexes were characterized based on flight phenology of aphids captured in yellow pan traps during the two years of the experiment. There was an early season population in which alighting alates belonged mostly to transient species and a late season complex of mostly colonizing species. During the late season phase, I found a peak capture in the first two weeks of August. These results showed a two week time lag when compared to previous data obtained for several aphid species in New York (Gonzalez and Rawlins 1968).

I hypothesized that primary spread of nonpersistent viruses of green pepper at my research site was by transient species of aphids. Secondary spread was mainly by colonizing species. The complexity of the factors affecting primary and secondary spread of nonpersistent viruses by transient and colonizing species is great. Source and amount of inoculum, species and numbers of alate aphids landing and probing on the plants, weather conditions, distance from the source of inoculum relative to dispersal behavior of alate aphids and behavior of the host selection process by aphids are the main factors related to nonpersistent virus transmission. However, it appears that the reason for the primary spread of infection in 1982 was due to the presence of two noncolonizing aphids (*Capitophorus elaeagni* and *Cavariella* sp.) early in the season.

Irwin and Goodman (1981) found the transmission of the nonpersistent mosaic soybean virus to be associated with transient species and to be transmitted over very short distances, 95% of all infections were within 17 m of the source. However, Zeyen at al. (1978) demonstrated long distance dispersal by aphids could also be important in the spread of nonpersistent virus infections. The use of regional meteorological data to study long-range movement of insects (Hutchins et al. 1988) could help to understand long distance aphid dispersal and its relation to the spread of nonpersistent viruses.

It is essential to know if colonizing alate aphids being produced within the crop are dispersing to other late summer host plants or to winter host plants and how far they can disperse. Dixon (1986) related urge and distance of dispersal to reproductive investment. He proposed that aphids with higher number of ovarioles are short-distance dispersers and that those with lower number of ovarioles are long-distance dispersers. Determining the number of ovarioles of virginoparae for different clones of colonizing species could answer questions about distance of dispersal in the field.

It has been shown that aphids probe on hosts and nonhost plants and fly for variable time in flight chambers (Kennedy and Booth 1963, Wiktelius 1982). However, there is only superficial knowledge of the behavior of nonmigratory aphids and the host selection process (Klingauf 1987). Much research is needed, especially in field situations, on these topics to understand the epidemiological process of nonpersistent virus transmission. Marking aphids in the field could shed some light on some of these questions.

I proposed that the newly designed green foliage mimic trap might give better estimates for epidemiological studies on number of alate aphids alighting on some vegetable crops. In general, factors that affect the host selection process by visual cues might have a similar effect on any artificial trapping system based on color traps. Unfortunally, knowledge of the process by which insects visually detect plants is meager and background composition is poorly understood (Prokopy and Owens 1983). Awareness of the importance of background composition and optimal trap design would allow me to suggest further studies to determine how precise the trap is in evaluating number of alates alighting in vegetable crops.

The efficiency of the green foliage mimic trap and the yellow pan trap was found to decrease as the size of the trap increased. Similar results were obtained by Costa and Lewis (1967) working with yellow pan traps. However, the data presented so far have not shown an optimal size for traps based on visual cues. A series of color traps of different sizes, from very small to very large (for example, from 20 cm^2 to 1 m^2), would allow mathematical determination of optimal trap size.

Failure of reflective surfaces to repel aphids has been attributed to, among other factors, the presence of too many vectors in the area (Kring 1972). My data showed that this is not necessarily true. Green foliage mimic traps and yellow traps placed over reflective mulch captured none or very few alate aphids throughout the entire growing season, independent of alate population densities. It was apparent that as long as enough reflective surface was exposed, most alate aphids were repelled regardless of alate densities.

High costs of weekly sprays of mineral oil and the small decrease in the number of nonpersistent viruses infected plants for the oil treatments made the oil strategy of little practical use for management of nonpersistent viruses in vegetables in Massachusetts. These results agree with what has been found in field trials in New York (Nawrocka et al. 1975) and California (Toscano et al. 1979), but disagree with results obtained in Florida (Simons and Zitter 1980) and Israel (Loebenstein 1966). Nonpersistent virus transmission and its inhibition by oils in the field are such a complex process that no reasonable explanation to the different results found can be drawn based on the literature published on this topic.

Plots treated with mineral oil had higher apterous populations than those not sprayed with oil. A similar phenomenon was reported previously by Ferro et al. (1980) in Massachusetts. Whether mineral oil is affecting natural enemies of aphids or the fecundity of colonizing species still remains unanswered. It would be of interest to determine if there is also a higher rate of increase for apterous populations of aphids in those areas, such as Florida, where mineral oils are commercially used. If apterous populations increase with oil use, a well timed aphicide spray would lower the number of alates dispersing from infected plants late in the growing season. A wide regional basis approach for nonpersistent virus management should prove very rewarding.

Mulch plots resulted in a delay in nonpersistent virus infection. However, by the end of the growing season the number of infected plants was the same for all treatments. Failure of the mulch to reduce virus spread could be due to the reflective surface being covered by the plants before virus spread occurs (Kring 1972). Favorable weather conditions and higher plant density contributed to a rapid coverage (mid-July) of the mulch in 1981. Lower temperatures, heavy rains in the area and lower plant density influenced slow plant growth and later coverage (mid-August) of the mulch by the plant canopy in 1982. Consequently, there was a higher efficiency of the mulch to repel aphids and delay virus infection in 1982.

For the 1981 experiment, there was a higher number of CMV inoculated plants (4 per plot), higher numbers of alates landing in all treatments and a less efficient mulch due to plant coverage. These factors could only suggest a higher rate of nonpersistent virus transmission for 1981. However, the 1982 data showed a higher level of infection by nonpersistent viruses compared to 1981 data. This phenomenon could be the result of high temperatures in early August of 1981 (Barnett 1986), which could have inactivated the viruses in the pepper plants and made the virus particles less available for transmission. However, it appears that the primary reason for the high levels of virus infection in 1982 is the early season spread (prior to 29 July) by the noncolonizing species Capitophorus eleagni and Cavariella sp., which were not present in 1981. In 1981 the colonizing species did not become abundant until the week ending 31 July when ca. 5% of the plants were infected, while in 1982 the colonizing species became abundant the week ending 30 July and at this time 14-20% of the non-mulched plants were infected. The magnitude and rate of virus spread is dependent on initial inoculum levels, and these levels were 3 to 4 times greater in 1982 than in 1981.

Zalom and Cranshaw (1981) found that reflective mulch caused higher aphid fecundity, greater plant growth and lower initial parasitism in potted plants. My data on apterous populations for 1981 showed no difference in the number of alates trapped for the colonizing species M. persicae for pepper plants planted into reflective mulch, reflective mulch plus oil, oil alone or control. However, the number of apterous aphids varied among the treatments. The lowest number of apterae was in the mulch treatment (1236, 13 Aug.) which is different from Zalom and Cranshaw's study. The highest population was in the oil alone treatment (3176, 13 Aug.) and was slightly less in the mulch plus oil treatment (2508, 13 Aug.). These data indicate that although there was no treatment effect on alates, there was on the apterous populations. As the oil treatment had the highest population, it could be the oil affected the natural enemies or aphid fecundity. Lower alate landing rates, of course, would also show a similar trend toward lower apterous populations. Before these strategies are recommended for use by growers we should develop a better understanding of the secondary effect of mulch and oil on apterous populations.

The results from the mulch treatments to reduce nonpersistent virus spread in the field agree with findings by other researchers (Nawrocka et al. 1975, Wyman et al. 1979 and others). The mulch treatment had a tendency to show higher yields. This could be the result of other factors such as higher moisture and temperature around the plant root system and lower weed competition. Further studies on evaluation of these factors and their influence on yield, contamination of soil by mulch debris, delay of virus infection during the growing season and lower rate of virus infection are necessary to justify the additional cost associated with using reflective mulches in vegetables in the Notheast.

Nonpersistent virus transmission by aphid vectors may be so complex and variable that any treatment to decrease virus infection in vegetables would be difficult to evaluate. Only through a series of field trials is it possible to elucidate these complex interactions.

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