POPULATION STUDIES OF THE POTATO LEAFHOPPER, *EMPOASCA FABAE* (HARRIS), ON ALFALFA, *MEDICAGO SATIVA* L.

By

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To Leslie and Whitney Anne-

Thank you for your love and support.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

The potato leafhopper, Empoasca fabae (Harris), is a common pest of second and third growth alfalfa and new spring seedings in Virginia. Although this species has been extensively studied, little work has been done on developing sampling techniques and plans for assessment of leafhopper populations in alfalfa.

Sampling design studies are an integral part of any pest management program; and efficient sampling techniques are necessary to obtain information on pest abundance, population dynamics, and economic levels. For each situation, techniques that are efficient in sampling the specific insect pest are necessary. Whether the sampling method chosen is the sweep-net, D-Vac, direct field counts, shake cloth, Berlese extraction, or some other; it is necessary to consider the primary objectives of the sampling program, and determine if these objectives can be met effectively using a particular method. Only after objectives of the program have been established, the technique(s) selected, and preliminary evaluations completed, can intensive studies on a sampling plan begin. These studies should include determinations such as: (1) number of samples needed for a specific level of reliability (such as 10 or 20% coefficient of variability about the mean), (2) size of the sample unit, (3) and sampling interval. Studies of factors such as wind, temperature, humidity, time of day, etc. and their effect on sampling efficiency may also be useful.

The main purpose of the first section of this study is to report the development and evaluation of a sampling plan for each stage of

the potato leafhopper (egg, nymph, and adult). The objective of the sampling plan is to make density estimates for population studies of the potato leafhopper in alfalfa.

The second section is concerned primarily with studies of developmental thresholds and temperature summation for the egg and nymphal stages. I also investigated oviposition rate, mortality under laboratory conditions, and other factors which may help explain certain phenomena observed in field populations of the potato leafhopper.

The last section deals with studies of field populations based on laboratory studies and data collected in the field during the summers of 1976 and 1977.

II. LITERATURE REVIEW

The genus Empoasca is a complex of closely related species that can be accurately identified at the species level only by examination of male or female genitalia (DeLong 1931, Cunningham and Ross 1965). Until revision of this genus by DeLong (1931), the taxonomic status of the potato leafhopper was unclear. Therefore, reports on potato leafhopper bionomics before this time may not be accurate.

The inability of the potato leafhopper to overwinter in northern regions of the United States was reported by DeLong and Caldwell (1935). They hypothesized the possibility of a long-range migration from the Gulf states. However, it was not until the late 1950's and early 1960's that this migratory behavior was proven by high-altitude insect collection (Glick 1960), and the cooperative effort of several mid-western states (Medler 1957). Medler (1962) also reported conditions at the overwintering site that induced these long-range migrations. Other research focused on weather conditions associated with the dispersal and arrival of spring migrants in the northern United States (Decker 1959, Pienkowski and Medler 1964). Medler et al. (1966) reported on the reduced ability of males to survive these migrations resulting in a predominance of fertilized, egg-laying females in the spring population. Other research has concerned factors affecting local migrations and movements of the potato leafhopper within alfalfa fields (Dysart 1962), and between fields of alfalfa and soybeans (Poston and Pedigo 1975).

Effects of cold temperature on the survivorship of potato leafhoppers in laboratory and field studies were reported by Decker and Cunningham (1967, 1968), and Decker and Maddox (1967). These results supported earlier work on inability of the potato leafhopper to overwinter in northern areas of the United States. The possibility of a southerly migration in the Fall has not been investigated although Dingle (1972) reported this to be a common phenomenon among insects exhibiting a northern spring migration.

DeLong (1938) reported that relative humidity, altitude, and rainfall-evaporation ratio were important in survival and growth of potato leafhopper populations on beans. No correlation was found between temperature and population growth. He concluded that spring and early summer rainfall were important factors in determining distribution and abundance. The potato leafhooper was also attracted to plants having a high sugar concentration (DeLong 1965, Hibbs et al. 1964).

Relative humidity and temperature have been shown to be important mortality factors (DeLong 1965, Decker and Cunningham 1967). Eggs were laid in the plant tissue where 100% R.H. is maintained. Both nymphal and adult stages spent most of their time on the undersurfaces of leaves where 75-100% of the stomata are present and higher humidities are likely to be found. Humidity was also important in defining geographic boundaries of the potato leafhopper in the United States. Generally they are found east of the 100th meridian at lower altitudes where rather high relative humidities prevail.

Differential activity between males and ovipositing females has been reported by Decker et al. (1971) who measured their tendency to fly from a plant when disturbed. Carlson and Hibbs (1970) gave a thorough account of the ovipositional behavior which may account for the inactivity of female potato leafhoppers during oviposition. Pre and post-mating behavior exhibited by male and female potato leafhoppers have also been reported (Carlson 1967, Shaw et al. 1974).

Kieckhefer and Medler (1964) reported that a 16:8 (L:D) photoperiod and 75°F temperature were optimal for oviposition. However, O'Keeffe (1965) reported that photoperiod had no effect on oviposition. It may be that some other factor may also be important, or that photoperiod may influence mating. Reports on oviposition rates for the potato leafhopper range from 2.7 eggs/female/day (DeLong 1938) to 6 or more eggs/female/day (DeLong 1971). These differences in oviposition rates are due in part to the above environmental factors, and in part to both plant type and condition (Kieckhefer and Medler 1964).

The effect of temperature on development was studied by Kouskolekas and Decker (1966). They found that the temperature threshold for development was 11.4°C, that development rate increased between 15.6-28.3°C, but decreased above 31.1°C. The accumulated day-degrees necessary for development of the potato leafhopper from egg to adult was 258 using 11.4°C as a base.

The potato leafhopper feeds on over 100 plant species (Poos and Wheeler 1943), and is economically important on several crops including soybeans, potatoes, beans, peanuts, clover, and alfalfa. However,

Jenkins (1977) reported that potato leafhoppers did not significantly reduce peanut yields.

The nature of damage known as "tipburn", "hopperburn", or "alfalfa yellows" is caused by deposition of a proteinaceous sheath material in the phloem and xylem of the plant at the time of feeding (Poos and Wheeler 1934). This was thought to be the result of a type of viral disease that could be induced in the laboratory by injecting macerated potato leafhoppers into plant tissue (Eyer 1922), but other similar tests did not support this hypothesis (Fenton and Ressler 1922). The nature and description of injury caused by the potato leafhopper are extensively described in Smith and Poos (1931) and Hollebone et al. (1966).

Females have been shown to cause more injury than males possibly because oviposition creates higher energy needs resulting in more feeding (Newton et al. 1970). Due to feeding requirements for growth nymphs have also been reported to cause more damage than adults (Fenton and Hartzell 1923). Damage has also been related to tumor formation in certain alfalfa varieties resulting from some form of growth regulator-type substance (Barnes and Newton 1963). Generally, potato leafhopper damage reduces photosynthetic capabilities in the plant (Ladd and Rawlings 1965) causing decreases in yield, quality, and stand duration (Hower and Byers 1977, Kouskolekas and Decker 1968, Hartwig and Edwards 1970, Smith and Medler 1959, Poos and Johnson 1936).

Several approaches have been attempted to control the potato leafhopper on alfalfa. Early recommendations by Graber and Sprague (1933, 1935) and Jewett (1934) recommended delaying the first cutting of hay until the crop showed abundant bloom. This would destroy most of the eggs laid by the immigrant leafhoppers. Searls (1934, 1935) also studied the effect of cutting on potato leafhopper abundance and damage. Recommendations to delay cutting alfalfa were before the widespread occurrence of the alfalfa weevil, Hypera postica Gyllenhal, which is the primary pest of 1st growth alfalfa. Pienkowski and Medler (1962) recommended early cutting of the 2nd growth period thereby reducing time for nymphal development and feeding. The cultural practice of irrigation reduced the effect on potato leafhopper damage by decreasing plant stress (Wilson et al. 1955).

Economic threshold levels have been developed for the potato leafhopper on soybeans (Ogunlana and Pedigo 1974), and have contributed significantly to control recommendations for that crop. Similar qualitative and quantitative studies need to be done for the potato leafhopper on alfalfa. Poos (1942) suggested that 1 potato leafhopper per sweep would cause significant damage within 3 weeks. It is now considered necessary to apply insecticides when one potato leafhopper per 180° sweep using a standard 38.1 cm net is collected in alfalfa less than 25.4 cm tall (Edwards 1974, Blair 1975).

Even though several parasites, predators, and a pathogen have been cited as natural control agents (Fenton and Hartzell 1923), research in this area has been lacking. Thompson (1944) listed 2

parasites attacking potato leafhoppers, but these are generally thought of as unsuccessful agents in satisfactorily reducing populations of the potato leafhopper.

Host plant resistance has been the most researched area in potato leafhopper management to date. Davis and Wilson (1953) worked on varietal tolerance and contributed a method of scoring damage by the potato leafhopper to evaluate resistance. Newton and Barnes (1965) worked on assessing damage, and nymphal hatch and development as indicators of resistance. Kindler and Kehr (1970) found that plants selected for resistance in the greenhouse did not possess increased resistance in field tests. Kindler et al. (1973) also reported that resistance to yellowing did not necessarily indicate resistance to stunting which would affect yield and quality. Other workers have concentrated their efforts on developing resistance by selecting for seedling survival, and evaluating effects on those varieties in relation to susceptible strains after infestation (Webster et al. 1968a, 1968b; Sorenson and Horber 1974). This area of research is still active (Roof et al. 1976), and holds promise for the future as a management technique.

General guidelines on management practices which can alleviate damage by the potato leafhopper were outlined by the USDA (1963). Suggestions include growing hardy varieties, regulating time of cutting, planting border crops of grass between fields, and planting alfalfa as far as possible from other host crops.

III. DEVELOPMENT OF SAMPLING PLANS FOR THE POTATO LEAFHOPPER ON ALFALFA

The potato leafhopper, Empoasca fabae (Harris), is a primary pest of second and third growth alfalfa in Virginia. Predominantly adult females arrive in the spring from overwintering sites along the Gulf coast. This migration has been associated with movements of air masses (Decker 1959, Pienkowski and Medler 1964). The time of the major potato leafhopper migration and rate of population increase relative to the stage of alfalfa growth are two factors which contribute to economic damage of alfalfa by this pest (Kouskolekas and Decker 1968). To increase the understanding of dynamics of potato leafhopper populations on alfalfa, sampling plans for each metamorphic stage were developed.

Field Description: Two alfalfa fields (located on University property) in Montgomery County, Virginia were selected as sites for collecting data on the potato leafhopper. Field 1 was irregularly-shaped and planted in ca 30 acres of Weevlchek alfalfa. Field 2 was rectangular and contained ca 5 acres of Tempo alfalfa. No insecticides were applied for potato leafhopper control; however, treatment for the alfalfa weevil (0.28 kg/ha carbofuran) was applied to both fields in the Spring of 1976. Sheep grazed both fields during the winter. Neither grazing nor insecticide application was thought to have a significant effect on subsequent potato leafhopper populations.

A. SAMPLING AND DISTRIBUTION OF POTATO LEAFHOPPER EGGS IN ALFALFA STEMS:

a) Introduction:

Clearing or staining of plant tissue has been used to detect eggs of the potato leafhopper in other host plants (Curtis 1942, Carlson and Hibbs 1962). Curtis' staining method is complex and unsuitable for large amounts of plant material. Carlson and Hibbs used a lactophenol solution to clear potato leaves. Although more practical than Curtis' method, this method is unsatisfactory for use in alfalfa because the fibrous nature of the stems obscures the eggs.

In this section, a method for egg detection, data on abundance and distributional patterns, and the development of a sampling plan are discussed.

b) Materials and Methods:

Potato leafhopper eggs in two Montgomery County, Virginia alfalfa fields were sampled from June through Aug., 1976. Each field was sampled at least every 2 wk. (except immediately after cutting). On each sampling date, 100 stems were collected from each field by selecting single stems at 20-30 pace intervals. The sample unit consisted of the primary stem with its lateral branches. The average plant height was measured, and the growth stage of the field was estimated by visual observation.

I have found that simultaneous clearing and staining of alfalfa stems with lactophenol and acid fuchsin is an effective method for observing potato leafhopper eggs. This method was originally developed

for counting nematodes in plant tissue (Goodey 1937, Southey 1970). In the laboratory, stems were boiled in a solution of lactophenol-acid fuchsin for 15-20 min. and allowed to cool overnight. The lactophenol solution consisted of 1 part distilled water, 1 part phenol, 1 part lactic acid, and 2 parts glycerin (Carlson and Hibbs 1962). One g of acid fuchsin stain was added to 1 liter of this solution. Boiling cleared the stems which absorbed the acid fuchsin stain as the mixture cooled. Excess stain was removed by rinsing with warm water. The cleared and stained stems were pressed between 2 single thickness glass plates for examination. Eggs could be seen with the unaided eye when holding the prepared stems in front of a light. Since various other insects such as mirids oviposit inside alfalfa stems, proper identification of potato leafhopper eggs was made by observing them under a stereomicroscope at 60X magnification, using substage lighting. Leafhopper eggs were counted and their location in the stem recorded.

c) Results and Discussion:

i) Temporal Abundance of Eggs: The mean number of eggs per stem rapidly increased in both fields during the 2nd and 3rd alfalfa growth periods (Fig. 1). Measurement of adult abundance showed that egg numbers increased with alfalfa height during each growth period. This is due to the influx of adult leafhoppers into growing succulent alfalfa which is preferred for feeding and oviposition (Kieckhefer and Medler 1964). Accumulation of eggs also contributed to this increase since the time required for eggs to hatch was, in many cases, greater than the interval between sampling periods. There was no decrease

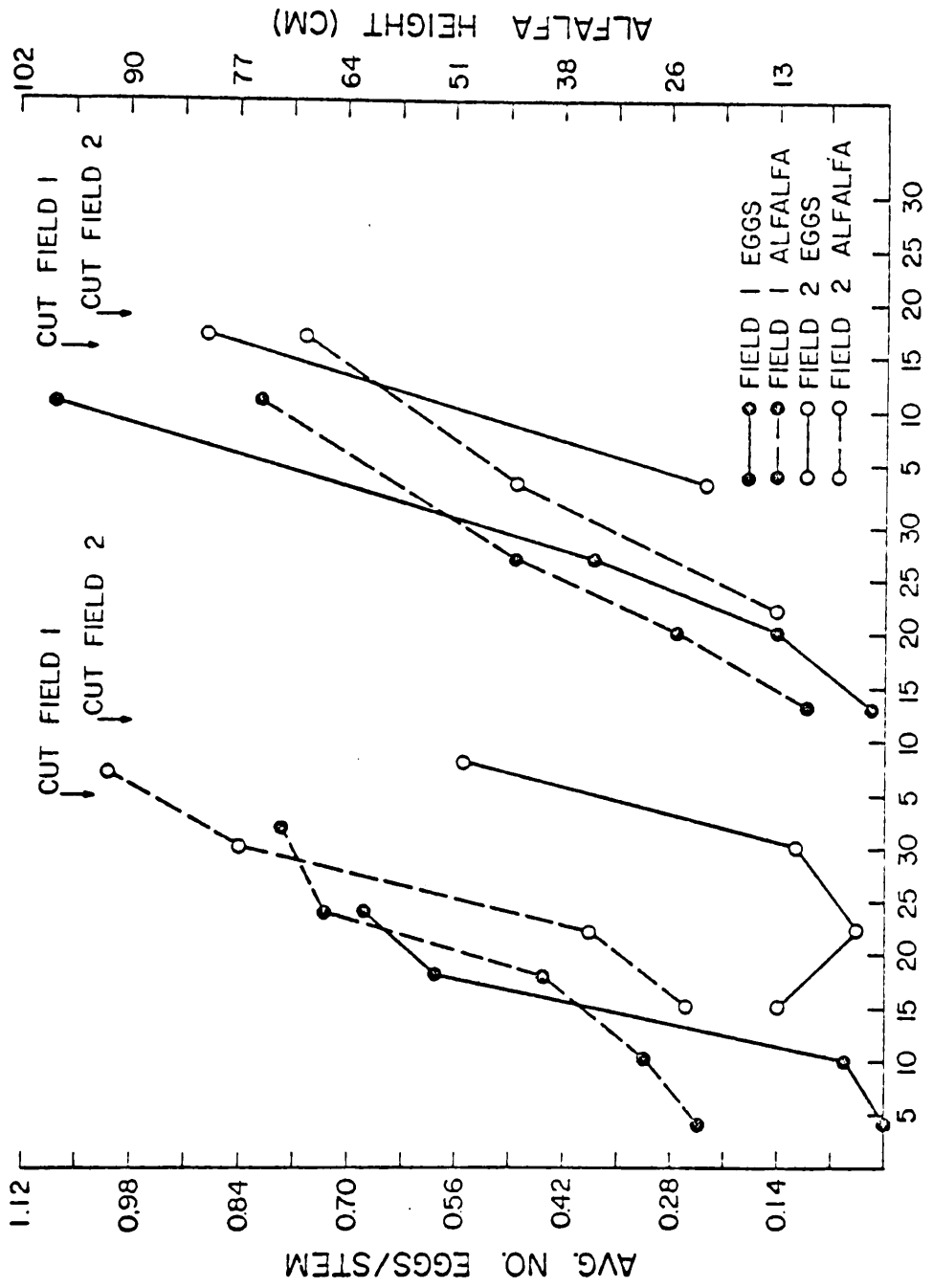

Fig. 1. Temporal abundance of E. fabae eggs during the 2nd and 3rd growth periods of alfalfa during summer, 1976, in 2 fields in Montgomery Co., Va.

in egg numbers in either field except from June 15-22 in Field 2. This decrease was probably due to sampling error.

ii) Distribution of Eggs: When the primary stems began to produce flowers and lignify, succulent lateral stems began to develop. A greater proportion of the leafhopper eggs were found in lateral stems as lignification of the primary stems continued (Table 1). This was due in part to the increase in the number and size of lateral stems as the plant developed. In Field 2 at the 90% bloom stage (July 7), 100% of the eggs were found in lateral stems. At this time the field was badly lodged, and tertiary lateral stems were present. About 52% of the eggs were found in secondary stems and 48% in tertiary stems. Results from Fields 1 and 2 generally support other reports of the oviposition preference of potato leafhopper for succulent plant tissue (Kieckhefer and Medler 1964, Miller and Hibbs 1963, Graber 1941)

The vertical distribution of eggs laid in primary stems is shown in Fig. 2. Egg distribution was concentrated in the upper 17 cm of the plant. No eggs were found below 27 cm, again supporting previous work on the ovipositional preference of potato leafhoppers for succulent tissue. The distribution of eggs in lateral stems showed almost a bell-shaped distribution (Fig. 3) from the youngest to oldest stems. Both figures represent pooled data of all eggs counted and do not compensate for plant growth from sample period to sample period. However, the general trend of egg deposition in more succulent tissue, as well as the absence of eggs in more lignified tissue, is evident.

Table 1. Allocation of E. fabae eggs in primary and lateral branches of alfalfa at different stages of plant development.

Date	Stage of Plant	Eggs in Primary Stem (%)	Eggs in Lateral Stem (%)
Field 1:			
10 June	Prebud	100	0
18 June	10% Bloom	55	45
24 June	50% Bloom	32	68
5 July	Field Cut	--	--
14 July	Vegetative	100	0
20 July	Vegetative	85	15
27 July	Prebud	70	30
12 Aug.	60% Bloom	30	70
Field 2:			
15 June	Prebud	100	0
22 June	10% Bloom	55	45
30 June	50% Bloom	18	82
7 July	90% Bloom (lodged)	--	100[1]
12 July	Field Cut	--	--
3 Aug.	Prebud	12	88
17 Aug.	60% Bloom	29	71

[1]52% in secondary lateral stems and 48% in tertiary lateral stems.

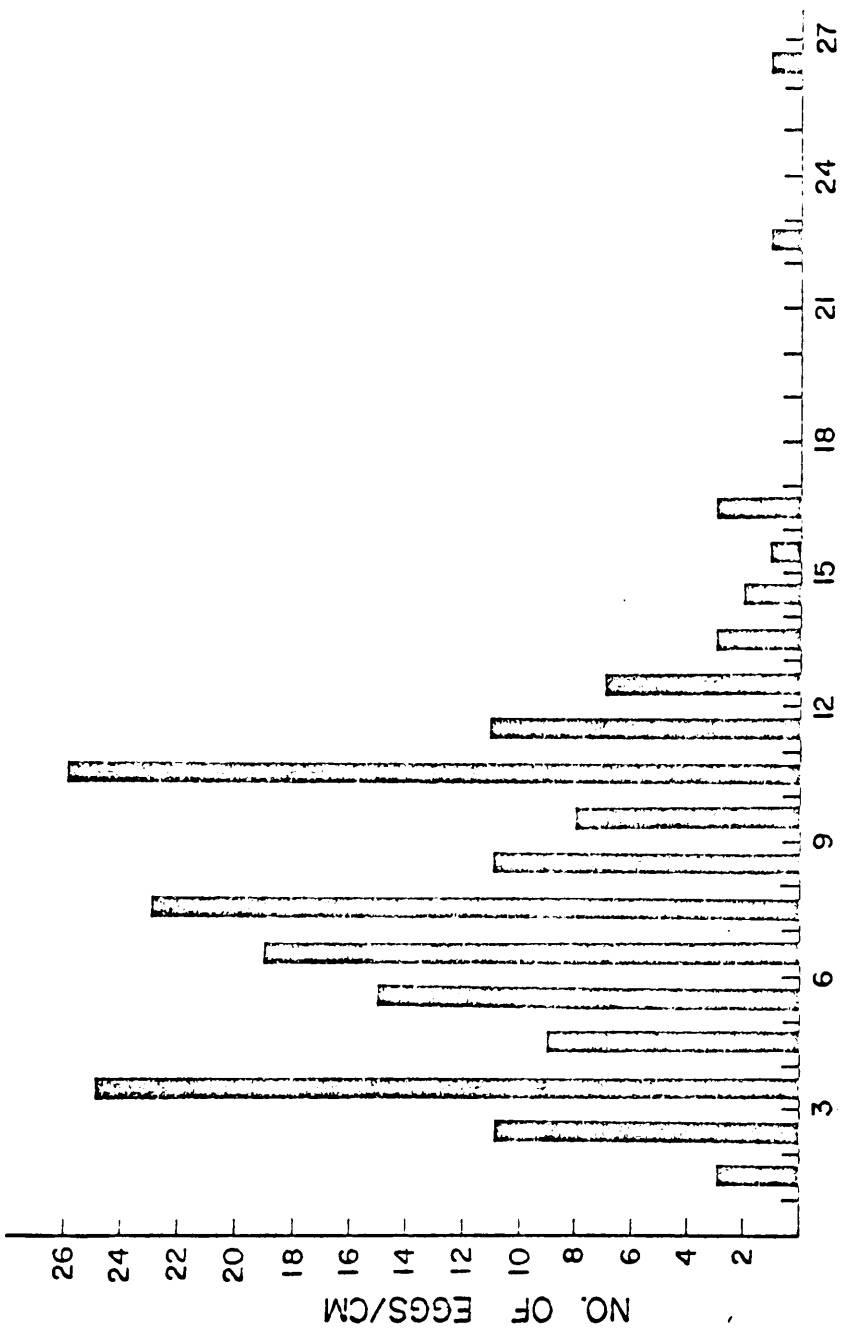

Fig. 2. Distribution of E. fabae eggs along the primary stems of alfalfa during June, July, and Aug. 1976.

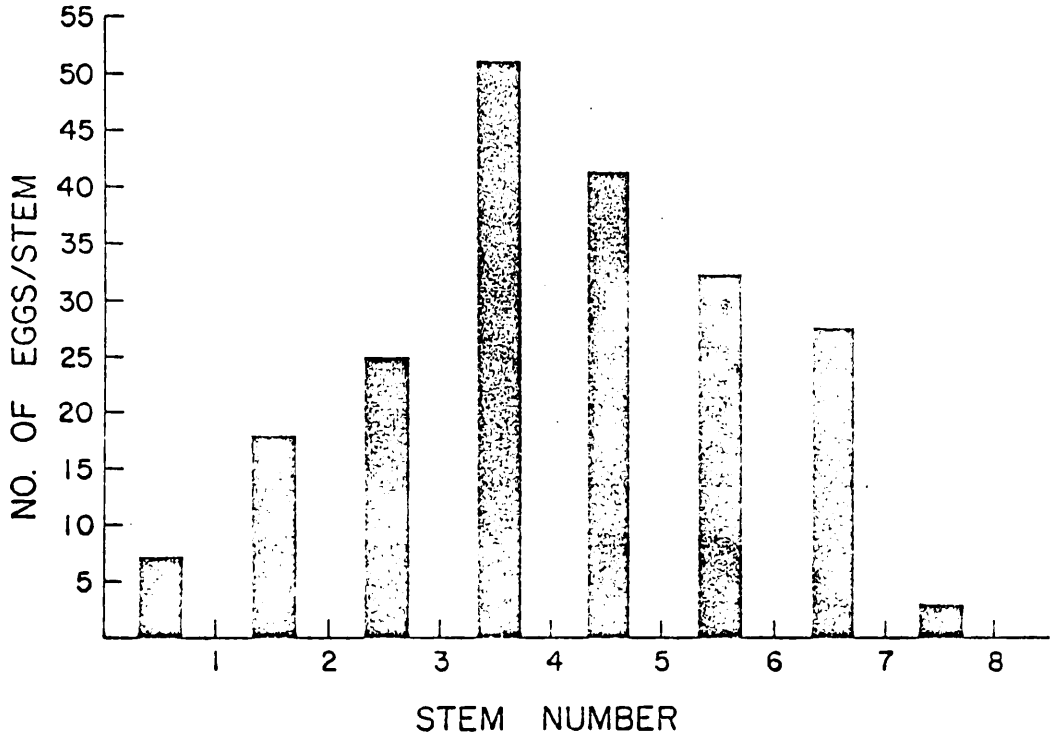

Fig. 3. Distribution of E. fabae eggs in the lateral stems of alfalfa. Stem 1 is the youngest stem and stem 8 is the oldest.

While a few eggs (3% of the total) were found in leaf petioles, no eggs were found in leaf midribs. This is in contrast to ovipositional behavior by potato leafhopper on potato (Miller and Hibbs 1963), and E. solana on cotton (Moffitt and Reynolds 1972). The smaller diameter of the alfalfa leaf midrib is a probable reason for the difference. This allows us to modify our sampling technique in the future by removing leaves before clearing and staining, eliminating much of the bulk and allowing more effective staining of the stem. In addition, there is no need to examine more than the top 20 cm of each stem.

Frequency distributions for eggs from each field and date were analyzed to determine their approximation to the negative binomial or Poisson distributions by goodness of fit. Sample dates which had low egg densities were not tested since they did not have enough frequency classes to make the test meaningful. These two distributions have been shown to be common for insect populations (Southwood 1966). Populations showing an aggregated distribution can be most easily analyzed as the negative binomial (Bliss 1958). Egg distributions for all dates tested fit the negative binomial better than the Poisson model except on Aug. 12, which fit the Poisson distribution (Table 2). On those dates when egg densities were not high enough to justify the χ^2 (chi-square) goodness of fit test, a test based on the 2nd moment (the variance) was conducted (Southwood 1966). All samples, except June 10 and Aug. 12, showed the negative binomial to be an acceptable model for the distribution of eggs.

Table 2. Goodness of fit of egg counts in stems to the negative binomial and Poisson distribution models with an estimation of optimum sample sizes using the coefficient of variation as the reliability criterion.

Date	$\bar{x}$ + S.E.	k	Goodness of Fit[a]		Optimum Sample Size		
			Neg. Binom.	Poisson	10% c.v.	20% c.v.	30% c.v.
10 June	.05 ± .06	.033	...	...	5,030	1,258	559
15 June	.14 ± .05	.162	...	...	1,331	333	148
18 June	.59 ± .18	.131	+	-	935	234	104
22 June	.03 ± .02	.046	...	...	7,333	1,833	815
24 June	.68 ± .21	.308	+	-	474	118	53
30 June	.11 ± .04	.170	...	...	1,534	384	170
7 July	.55 ± .12	.311	+	-	504	126	56
14 July	.02 ± .02	.020	...	...	15,000	3,750	1,667
20 July	.14 ± .05	.191	+	-	1,514	379	168
27 July	.38 ± .08	.717	+	-	448	112	50
3 Aug.	.24 ± .08	.176	+	-	1,147	287	127
12 Aug.	1.08 ± .22	1.550	-	+	157(92)[b]	39(23)	17(10)
17 Aug.	.88 ± .14	.727	+	-	263	66	29

[a] + = Distribution not significantly different from expected at 5% level.

- = Distribution significantly different from expected at 5% level.

... = Distribution not determined.

[b] Numbers in parentheses are sample estimates based on Poisson distribution.

Values of k (the dispersion parameter), calculated by the proportion of zeros method (method 2 of Southwood 1966), ranged from 0.020-1.55, indicating a contagious or aggregated distribution. Low values of k ($k \longrightarrow 0$) indicate convergence of the negative binomial to the logarithmic series if units containing no eggs are omitted (Bliss 1958).

iii) Estimation of Optimum Sample Size: As pointed out by Karandinos (1976), there are several methods to calculate the optimum sample size for a given distribution, depending on the way we choose to express reliability. In the present study, we chose the coefficient of variability and used the formulae given by Karandinos for the negative binomial and Poisson distributions. Optimum sample sizes were calculated for CV of 10, 20, and 30% (Table 2). Sample size varied inversely with mean ($\bar{x}$) and parameter k. In general, for the range of variability found in the present study (see SE's in Table 2), the mean number of eggs per stem can be estimated with a coefficient of variability of 30% by taking ca. 100 stems, if there are at least 0.3 eggs/stem on the average, or by taking ca. 150 stems if 0.1-0.3 eggs/stem are expected. For lower densities, a much larger sample is needed. Inspection of the data in Table 2 (shown graphically in Fig. 4) would produce similar guidelines for a CV of 20 or 10%.

B. LABORATORY AND FIELD EVALUATION OF SAMPLING TECHNIQUES FOR THE NYMPH STAGE OF THE POTATO LEAFHOPPER ON ALFALFA:

a) Introduction:

Potato leafhopper nymphs are usually found on the undersurface

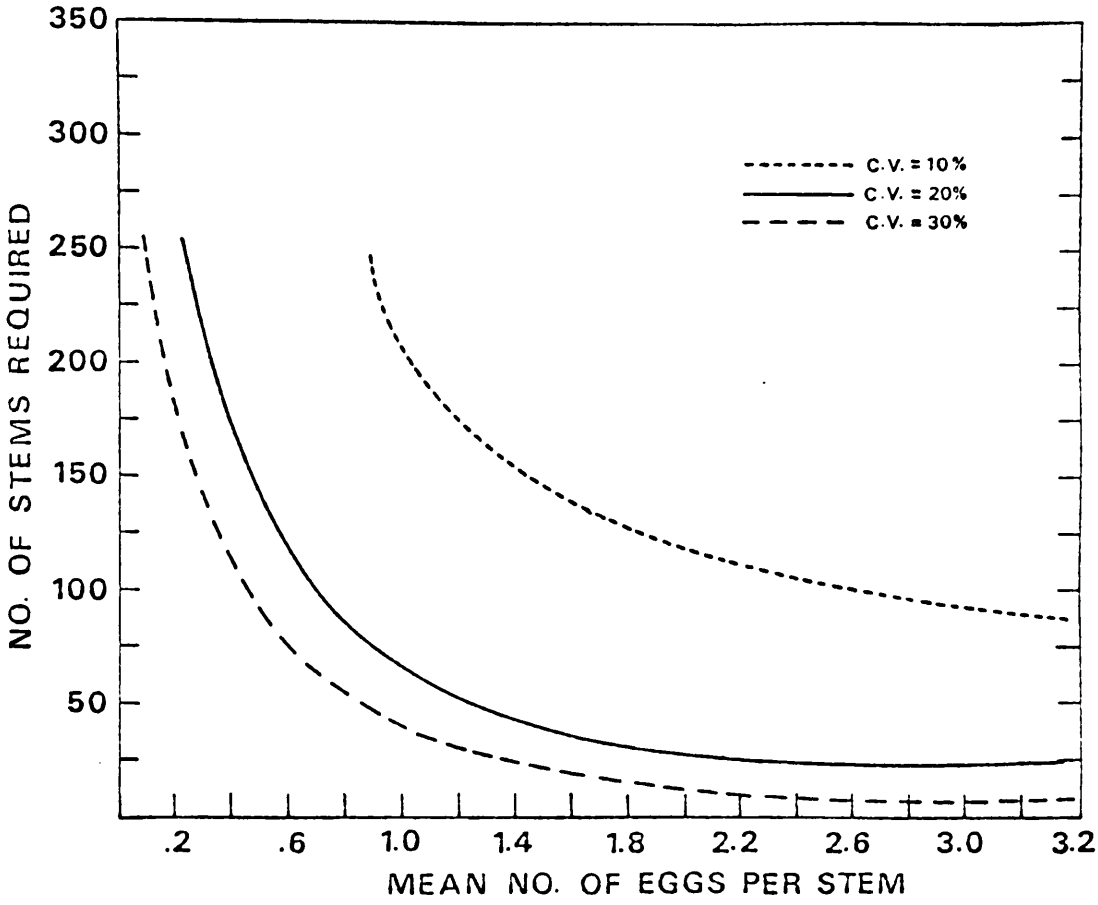

Fig. 4. Sample size estimates for eggs of the potato leafhopper at levels of 10, 20, and 30% C. V. about the mean.

of leaves throughout their development (DeLong 1965). Jarvis and Kehr (1966) placed plants in paper bags and extracted nymphs by fumigation. I felt that an efficient nymphal sampling method could be developed based on the same principle. The sample unit should be easy to collect in the field, should provide a density estimate, and should allow rapid examination of the samples. A small sample unit would be desirable for distributional analysis of the nymphal stage which is an important step in the development of a sampling plan.

This section reports the results of laboratory evaluation of extraction techniques, and field comparison with other sampling methods for the nymphal stages of the potato leafhopper.

b) Materials and Methods:

One quart ice cream containers were selected for use in evaluating extraction methods. Stems (30 cm long) containing known numbers of nymphs were placed in cartons, and extracted by several different means. Methods used were: heat-drying by placing cartons containing stems ca .5 m from 250 watt infra-red lamps, a pyrethrum aerosol spray applied inside the container before closing, and squares (ca 1.2 cm^2) of dichlorvos resin glued to the inside of the cartons. Pyrethrum was applied using both a short (light application) spray time ($<$ 1 sec), and a long (heavy application) spray time ($>$ 3 sec).

All methods were evaluated by placing 1 nymph infested stem in each carton for 24 hr. and replicated 10 times. In addition, the dichlorvos square method was tested using 1, 3, and 5 stems at 24 hr.; and 1 stem at 1, 3, and 24 hr. After the exposure period, nymphs

were collected in the lids by shaking the cartons in an upside-down position. Nymphs recovered in this manner were counted, and percent recovery determined.

In field evaluations of 6 different sampling methods, 25 stakes were set at ca 30 m intervals in an alfalfa field. At each stake alfalfa density was measured as no. of stems per 0.092 m^2 to estimate stand density in the field. The following types of samples selected for comparison were taken within 7 m of each stake:

Dichlorvos-Carton Method: The sample unit selected was a 3-stem bouquet. The unit was collected by excising 3 stems near the base of an alfalfa plant, and placing them in 1 qt. ice cream cartons containing dichlorvos squares. Four samples were collected near each stake and returned to the laboratory for extraction and counting. After 24 hr. nymphs were collected in the lid as described above. The stems were shaken as they were removed from the container, placed in white enamel pans, and searched thoroughly. The additional nymphs were added to those collected in the carton lids.

Observation Method: Before placing the 3-stem bouquet in the carton, the number of nymphs detected by direct observation was recorded.

Pan-shake Method: A 0.062 m^2 area (ca 42 x 15 cm) of alfalfa was shaken into a white enamel pan (42 x 23 cm). The number of nymphs were counted and removed. Four samples were collected near each stake.

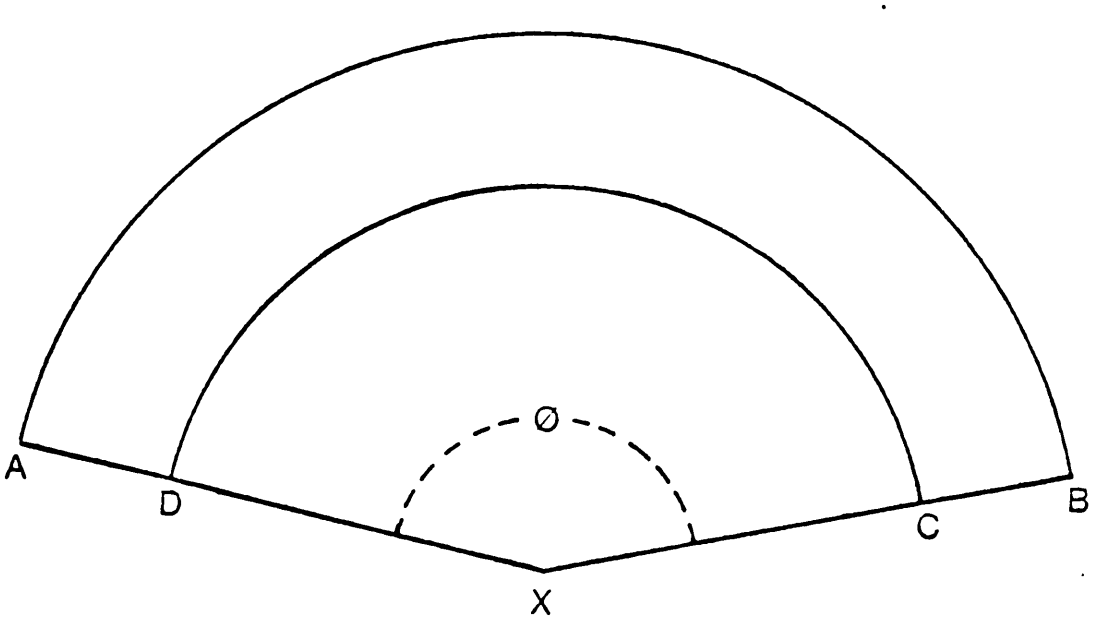

Fig. 5. The sector ABCD covered using a 180° sweep of a standard 15" sweep net. Where: AX = 1.92m; DX = 1.57 m; and Ø = 160°.

Sweep Method: A standard 15" sweep net was used to collect one set of 25 - 180° sweeps near each stake. The samples were placed in paper bags and returned to the laboratory for counting.

D-Vac ® Suction Method: One set of 25 (0.092 m^2) sucks was collected near each stake using a backpack D-Vac insect collector (Dietrick 1961). The samples were put in paper bags and returned to the laboratory for counting.

Drop Trap Method: A plexiglass box (ca 0.26 m^2) similar to the one used by Smith et al. (1976) was dropped near each stake. The D-Vac insect collector with a hose attachment (diam 10 cm) was used to suction arthropods out of the enclosed area. Samples were placed in paper bags and returned to the laboratory for counting.

All field methods were evaluated as no. of nymphs/m^2. The following conversions were used based on a mean no. of 610 alfalfa stems/m^2:

No. of nymphs/carton x 203

No. of nymphs/observation x 203

No. of nymphs/pan-shake x 16

No. of nymphs/drop trap sample x 4

No. of nymphs/D-Vac sample x .43 (based on 25 sucks/sample)

No. of nymphs/sweep net sample x .10 (based on 25 sweeps/sample)

The estimate for sweep net density is based on our approximation of the no. of alfalfa stems effectively swept. The area covered by the sweep net (Fig. 5) can be calculated as $\frac{1}{2} \varnothing (AX + DX) (AX - DX)$ (Hodgman et al. 1953) where $\varnothing$ is the angle in radians (based on 160°), and AX and DX are the distances from the individual sweeping to the

outer and inner margin of the sweep net. Based on these calculations, we estimated that 1.7 m^2 or 1037 stems were being covered, but only ca 238 stems (23%) were effectively swept through each sweep. Based on this estimation, ca 5950 stems were effectively swept in 25 sweeps. Thus, the no. of nymphs collected in 25 sweeps x 0.10 (610/5950 = 0.1) approximates the no. of nymphs/m^2.

c) Results and Discussion:

To be useful in population studies, sampling techniques should meet the 6 criteria listed by Morris (1955). The technique should be equally accessible to all units in the system, the sample unit should not be influenced by plant growth or damage, the proportion of the population using the sample unit should not vary, the unit should be small enough for variance evaluation, it should lend itself to density determination, and should be easily taken without significant damage to the population. Use of the dichlorvos-carton technique in sampling for potato leafhopper nymphs on alfalfa stems satisfactorily met these requirements. Also, laboratory evaluation indicated that nymphs were efficiently recovered from alfalfa stems (Table 3).

The use of a dichlorvos square in the ice cream carton was most efficient for extracting nymphs in laboratory tests of the carton method when analyzed by a single classification analysis of variance. The light application of pyrethrum and heat-drying were not significantly different from the dichlorvos square ($P < 0.05$). A heavy application of pyrethrum was less efficient in recovering nymphs because they tended to stick to the alfalfa stems. The dichlorvos

Table 3. Laboratory evaluation of extraction techniques for potato leafhopper nymphs on alfalfa.

Extraction Method	No. Alfalfa Stems	Time of Exposure (hr)	% Recovered ($x \pm$ s.e.)[1]
Heat-Drying	1	24	$86^{abc} \pm 5$
Pyrethrum (Heavy Application)	1	24	$63^{c} \pm 7$
Pyrethrum (Light Application)	1	24	$94^{ab} \pm 2$
Dichlorvos	1	1	$94^{ab} \pm 4$
Dichlorvos	1	3	$98^{a} \pm 2$
Dichlorvos	1	24	$97^{ab} \pm 2$
Dichlorvos	3	24	$91^{ab} \pm 4$
Dichlorvos	5	24	$78^{bc} \pm 9$

[1]Means followed by the same letter are not significantly different ($P < 0.05$) according to the least significant range test.

square was selected for further use, beacuse of its efficiency and practical application in field situations.

Using 30 cm lengths of alfalfa, there was no significant difference in the recovery of nymphs exposed for a 1, 3, or 24 hr. time period, and when collecting nymphs from 1 or 3 stems per carton. However, the number of nymphs collected from 5 stems after 24 hr. was significantly less than the number collected from 1 stem after 3 hr. This was thought to be due to the increased amount of plant material when using 5 stems/carton. In later field work, a 24 hr. period using 3 stems per carton was used. The 24 hr. period was chosen simply for convenience since samples collected 1 day could be counted the next.

In field sampling, I was concerned that the efficiency of the dichlorvos-carton technique would be reduced when alfalfa reached heights above 30 cm. When counting samples containing alfalfa 30 cm or higher the stems were shaken as they were removed from the carton, and placed in enamel pans. Although nymphs were recovered from the bottom of the cartons after removal of the stems, no nymphs were ever found when the alfalfa in the pans was checked.

Table 4 compares the effectiveness of the dichlorvos-carton technique to other sampling methods in the field. The analysis of variance was conducted on data transformed to log $(x + 1)$ to stabilize the variance (Frazee 1977). On each date the dichlorvos-carton method indicated the highest nymphal densities, and recovered significantly more nymphs than any other method of August 1. Direct

Table 4. Field Evaluation of Sampling Techniques for the Nymphal Stages of the Potato Leafhopper.

Sample Type	No. of nymphs/m^2 ($\bar{x} \pm$ s.e.)[1] 28 Jul	1 Aug	21 Aug
Dichlorvos-Carton	$105.7^{a} \pm 18.12$	$149.0^{a} \pm 21.14$	$30.2^{a} \pm 8.28$
Panshake	$74.8^{a} \pm 7.38$	$57.6^{b} \pm 4.58$	$16.6^{ab} \pm 2.24$
Observation	$44.3^{b} \pm 11.29$	$12.1^{c} \pm 4.80$	$2.0^{c} \pm 2.01$
D-Vac Suction	$8.3^{b} \pm 1.26$	$10.6^{c} \pm 1.28$	$2.2^{bc} \pm 0.49$
Drop Trap	$9.5^{b} \pm 2.06$	$9.0^{c} \pm 2.95$	$0.7^{c} \pm 0.40$
Sweep Net	$1.0^{b} \pm 0.19$	$0.5^{c} \pm 0.08$	$0.2^{c} \pm 0.04$

[1]Means followed by the same letter are not significantly different ($P < 0.05$) according to the least significant range test.

observation, D-Vac, sweep net, and drop trap methods were least efficient, while the panshake method was next to the dichlorvos-carton method in efficiency. The estimated no. of stems swept may be low due to our approximation that only 23% of the area covered is effectively swept. However, increasing this estimate would further decrease the estimated no. of nymphs collected per m^2.

Although the sweep net has been useful in sampling for adult populations it is quite inefficient in estimating nymphal densities. Reasons for the reduced efficiency of the sweep net method as well as the D-Vac and drop trap methods include: nymphs remaining on alfalfa, nymphs becoming entangled in the net, and nymphs lost in transportation to the laboratory.

The dichlorvos-carton method comprises a compact sampling unit. This method is as efficient for early as for later instars. Nymphs on stems placed in the carton are not lost in transportation. Nymphs are recovered in a small area (the lid) which can be rapidly examined. With other methods the early instars, especially 1st and 2nd, are easily overlooked and not counted. Besides being relatively efficient for estimating nymphal populations and easily applied to field use, the sample unit using a 3-stem bouquet is small enough to delineate spatial distribution of the nymphs.

The dichlorvos-carton method is not useful when sampling wet alfalfa since the nymphs tend to stick to leaves and stems. Also, it is applicable only in assessing populations for dynamics or threshold studies, or for other purposes where an accurate density estimate is

desired. This method would have little use in a sampling program where rapid decision making is needed. Where a rapid decision is required a sequential sampling technique where the panshake method would be useful might be utilized.

C. A SAMPLING PLAN DEVELOPED FOR DENSITY ESTIMATES OF POTATO LEAFHOPPER NYMPHS ON ALFALFA:

a) Introduction:

Little work has been reported on the development of usable sampling techniques for making density determinations of nymphs. Simonet and Pienkowski (1977) developed a sampling plan for potato leafhopper eggs. Jarvis and Kehr (1966) reported a method for evaluating nymphal populations in determining alfalfa resistance to the potato leafhopper. In the previous section (Section B), I described an efficient sampling procedure for assessment of nymphal populations using quart ice cream cartons containing 1.2 cm^2 pieces of dichlorvos, and compared this method with several others.

The increasing value of alfalfa as a forage crop, the higher cost of prophylactic insecticide use, and environmental concern over pesticide abuse make sound management practices necessary. Detailed field population studies for the potato leafhopper will be required to determine economic thresholds. In order to accomplish this a sampling plan for each developmental stage is needed. This section describes a sampling plan using the dichlorvos-carton technique for the assessment of nymphal population densities. This is a basic step toward effective potato leafhopper management decisions on alfalfa grown for hay.

b) Materials and Methods:

i) Sample Unit: The basic sample unit was a 3-stem alfalfa bouquet. This unit was stable through time, and could be related to actual density estimates since alfalfa stem density was sampled. These criteria and others which should be considered in selection of a sample unit (Morris 1955) were satisfactorily met using the 3-stem bouquet. Each individual unit was small enough to enable delineation of spatial distribution. The method used to separate the nymphs from the herbage was efficient. The dichlorvos-carton technique (Section B) recovered above 90% of the potato leafhopper nymphs.

ii) Sampling Procedure: Each field was divided into 4 plots. On each sample date, 5 samples were collected from 4 randomly selected areas in each plot for a total of 80 samples per field in 1976. In 1977, 5 samples were collected from 5 areas in each plot for a total of 100 samples per field. The sample was taken by carefully excising 3 stems from the base of the alfalfa plant with scissors. Nymphs collected in this manner remained on the stem while it was placed in the carton. Cartons containing stems were returned to the laboratory. A rubber-band placed longitudinally around each carton ensured that lids did not come off in transit. After 24 hr., nymphs were collected in the lid of the container by shaking the cartons vigorougly 5-7 times. Lids were removed, and stems were shaken while being removed from the cartons which were held in an upright position. Any additional nymphs collected were added to the nymphs already in the lids. Nymphs were counted and separated by instar using a stereomicroscope. Instars

were separated based on measurements from laboratory reared nymphs as follows ($\bar{x} \pm$ s.e.); 1st instar = 0.29 $\pm$ 0.013 mm; 2nd instar = 0.40 $\pm$ 0.017 mm; 3rd instar = 0.50 $\pm$ 0.017 mm; 4th instar - 0.61 $\pm$ 0.014 mm; and 5th instar = 0.76 $\pm$ 0.012 mm. This method of determining instars is valid only for living or freshly dead specimens since the head capsule shrinks as the nymph dries. The nymphs collected after 24 hr. in the dichlorvos-cartons were suitable for measurement.

Samples were collected throughout the summer months beginning after the arrival of spring immigrants in May or June, and continuing until first frost or last harvest in the fall (ca mid-September). The sampling interval varied throughout the summer, but samples were collected at least every 2 wk. except immediately after harvest in 1976. In 1977, samples were collected during the post-harvest period at about 3 day intervals until field growth was 9-12 cm.

c) Results and Discussion:

i) Spatial Distribution: Natural distributions of insects have generally been described as following an aggregated pattern corresponding to the negative binomial model. Several authors have discussed the statistics of this distribution pattern (Bliss and Fisher 1953, Anscombe 1949, Fisher 1941). This distribution has been reported in sampling studies of several insects including: the diamond-back moth (Harcourt 1960), imported cabbageworm (Harcourt 1961), clover root curculio (Ng et al. 1977), and Colorado potato beetle (Latheef and Harcourt 1973).

Analysis of our data by the χ^2 (chi-square) goodness of fit test showed the distribution of potato leafhopper nymphs fit that expected by the negative binomial model in most cases at $P > 0.05$ (Table 5). Although only 19 out of 37 samples had enough frequency classes to be analyzed by goodness of fit, those analyzed generally fit the negative binomial pattern better than the more random Poisson distribution. Each nymphal instar was distributed in an aggregated pattern. No major differences in distribution between instars were noted. This was expected since potato leafhopper nymphs exhibit similar behavior patterns at each instar, and rarely leave the alfalfa plant unless dislodged.

The dispersion parameter (k) is used in indicating degree of clumping. Aggregations with small k values tend toward the logarithmic series as k approaches 0, and tend toward randomness as k values increase (Southwood 1966). Values of k were calculated for potato leafhopper nymphs by method 1 of Anscombe (1950) as $k = \bar{x}^2/(s^2-\bar{x})$; k = dispersion parameter, $\bar{x}$ = sample mean, and s^2 = sample variance. Although Southwood (1966) pointed out that, in certain cases, this method may not be as precise as methods 2 and 3 of Anscombe (1950); the equation lends itself readily to computation, and is sufficiently accurate for most field population studies. The range of k values (Table 6) indicates a clumped distribution for the 5 nymphal instars. Low values of k correspond to samples taken during low densities of nymphs occurring from post harvest through early regrowth.

Table 5. The fit of potato leafhopper nymphal distributions to the negative binomial and Poisson models by goodness of fit.

Instar	No. Samples Tested	No. fitting[1] Neg. Binomial	No. fitting[1] Poisson	No. not[2] fitting either model
First	12	9	0	3
Second	7	5	1	1
Third	2	1	0	1
Fourth	3	2	0	1
Fifth	1	1	0	0
Total Nymphs	19	17	0	2

[1]Not significantly different from expected at $P > 0.05$.

[2]Significantly different from expected at $P < 0.05$.

Table 6. Range of means and k values, common k (k_c), and Taylor's b value for potato leafhopper nymphs.

Instar	$\bar{x}$ Range[1]	k Range[1]	k_c	b
First	0.02-1.12	0.02-1.78	0.29	1.41
Second	0.02-1.25	0.02-3.16	0.11	1.44
Third	0.02-1.14	0.06-1.78	0.11	1.44
Fourth	0.02-0.78	0.05-3.80	0.08	1.45
Fifth	0.02-0.27	0.08-0.45	0.21	1.44
Total Nymphs	0.04-4.56	0.05-4.31	0.14	1.33

[1]Values $\leqslant$ 0 are not included.

The common k (k_c) (Bliss and Owen 1958), and Taylor's b value (Taylor 1961) were calculated over several sample periods or intervals, and indicate an innate tendency of aggregation in a population. Both parameters show similar distributions for the 5 nymphal instars when considered separately and when grouped (Table 6). In the case of Taylor's b, values above 1.0 indicate a clumped distribution.

ii) Estimation of Optimum Sample Size: Optimum sample sizes were computed based on the negative binomial distribution using the coefficient of variation (c.v.) as a reliability parameter. The formula $(1/\bar{x} + 1/k)/D^2$ was used to estimate sample size; where $\bar{x}$ and k are as before, and D = the desired precision (in this case 10, 20, or 30% c.v.). This method has been evaluated (Southwood 1966, Karandinos 1976) as one method of estimating sample size. It is true that since we are estimating sample size using the inverse of $\bar{x}$ and k, our sampling requirements should decrease as densities increase, or if we maintain the same sample size, our reliability in accurately estimating population density should increase. This same pattern will follow based on k values since k is computed using $\bar{x}$ and s^2. For example, in 1977, density estimates for total instars (based on sample sizes of 100 3-stem bouquets per field) were accurate within 30% c.v. for populations > 0.3 nymphs per sample, within 20% c.v. for populations > 0.6 nymphs per sample, and within 10% c.v. for levels above 2.2 nymphs per sample (Fig. 6). Guidelines can also be followed for individual instars in Figs. 7-11. However, these guidelines varied depending on s^2, which would affect k. This was

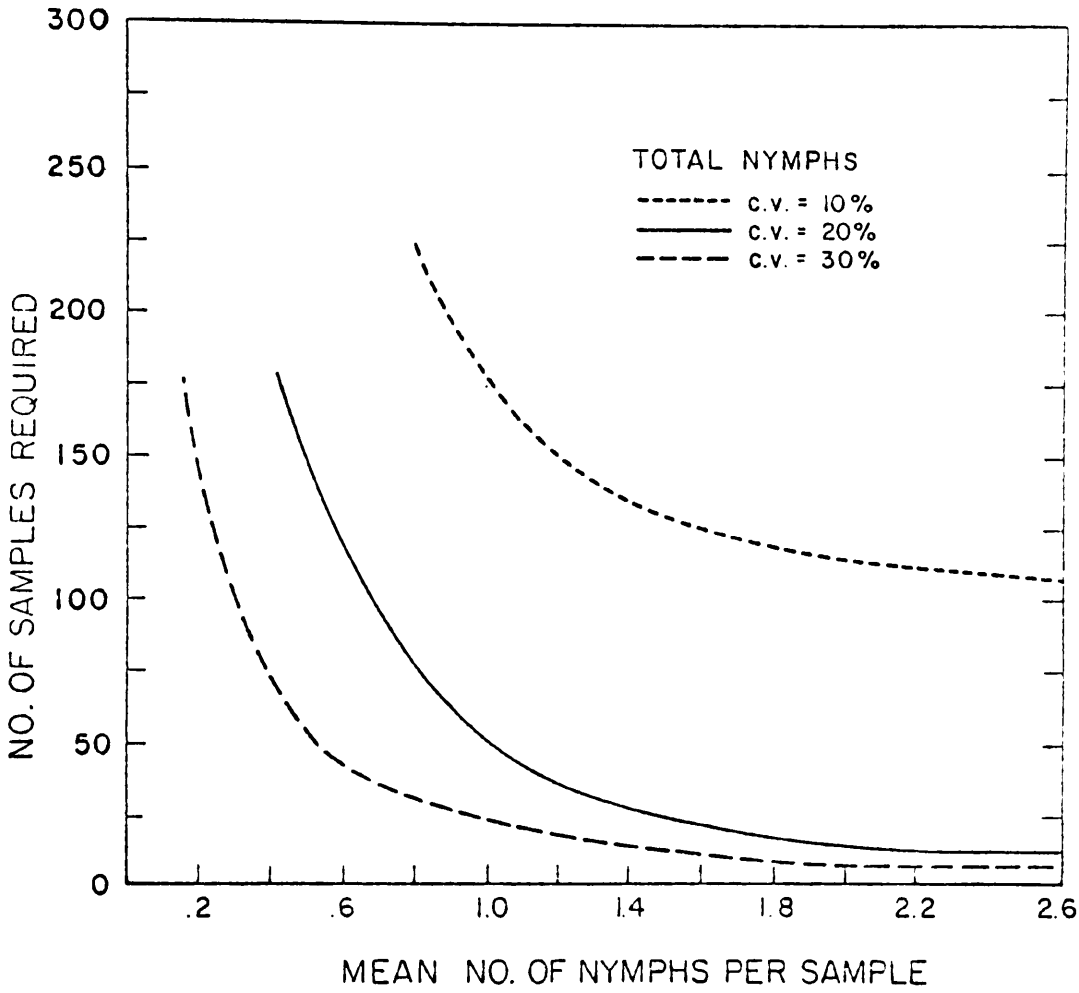

Fig. 6. Estimation of optimum sample sizes for the total number of potato leafhopper nymphs on alfalfa using a 3-stem bouquet as the sample unit.

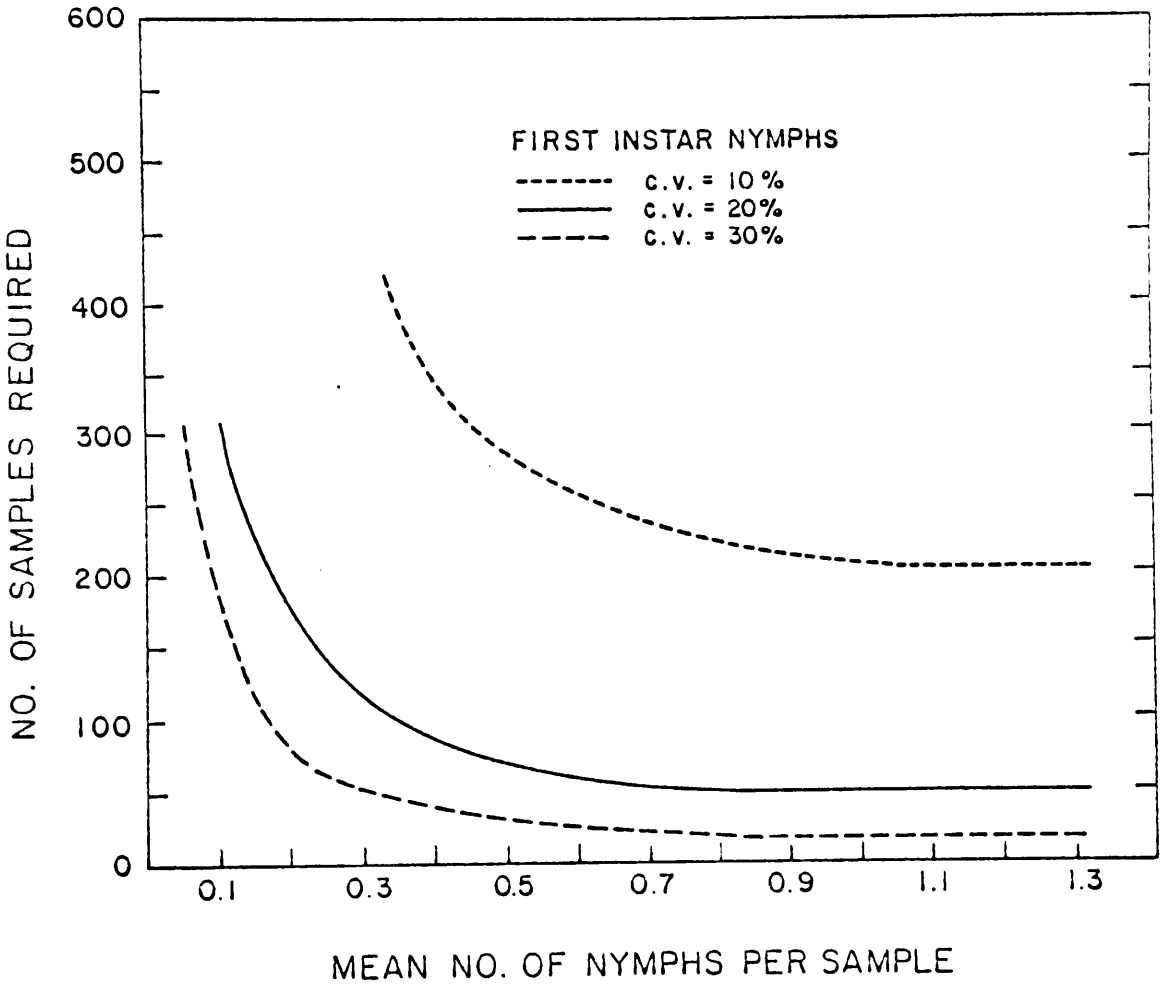

Fig. 7. Estimation of optimum sample sizes for 1st instar potato leafhopper nymphs on alfalfa using a 3-stem bouquet as the sample unit.

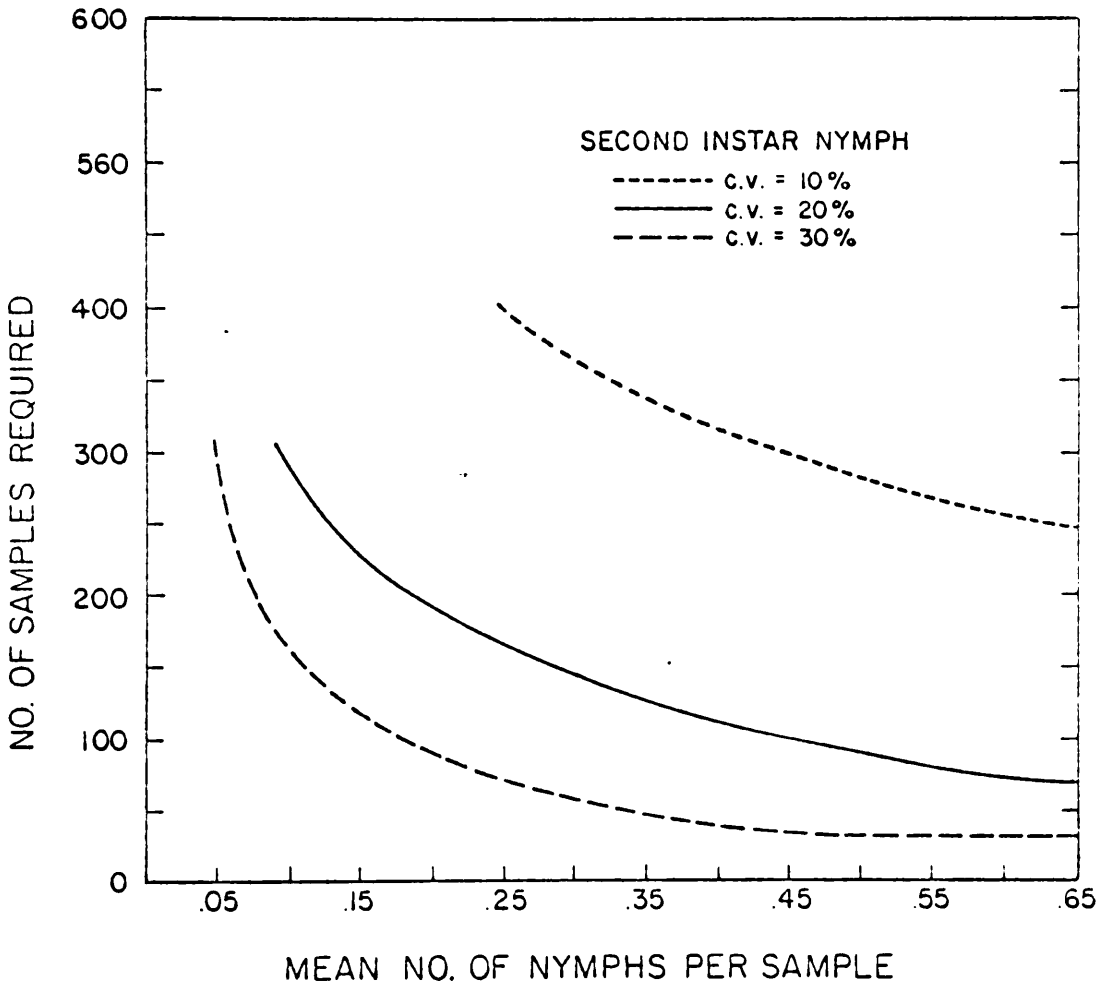

Fig. 8. Estimation of optimum sample sizes for 2nd instar potato leafhopper nymphs on alfalfa using a 3-stem bouquet as the sample unit.

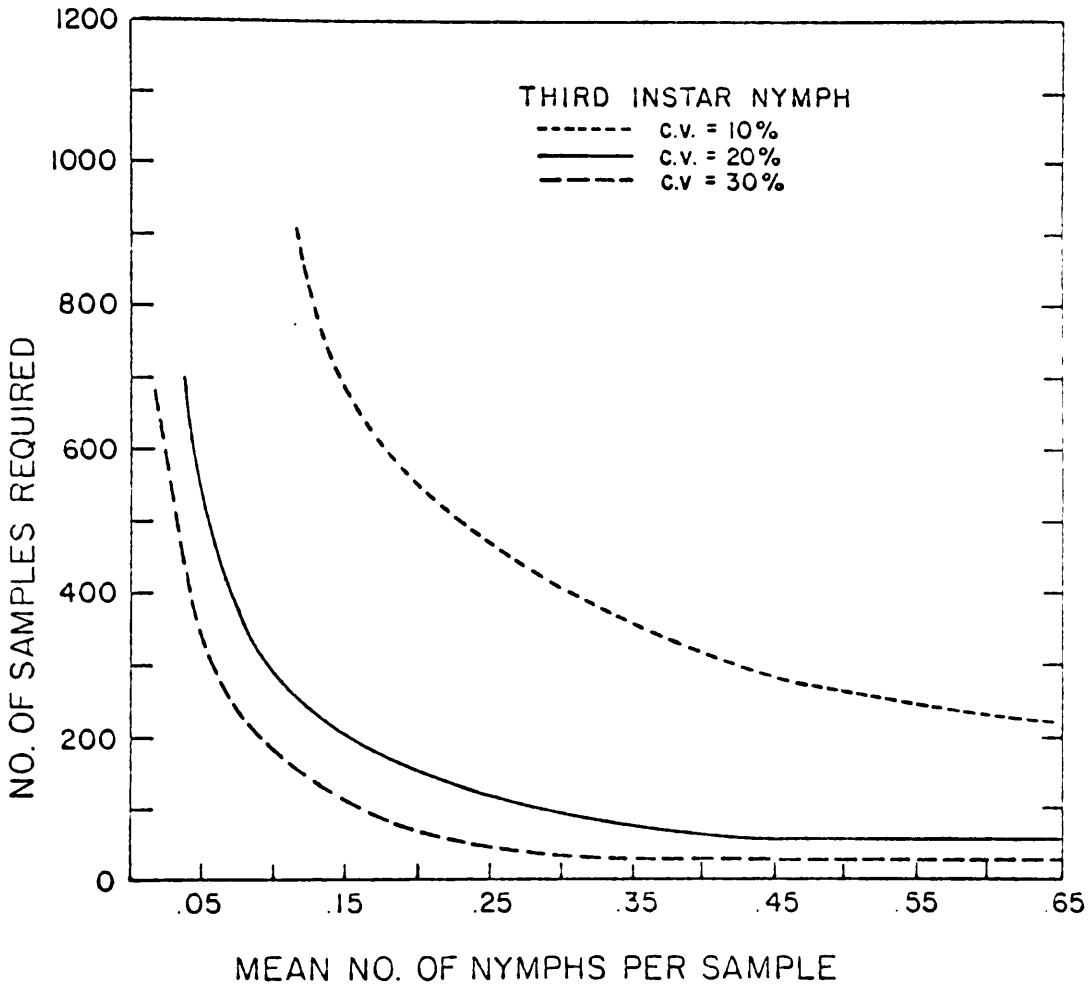

Fig. 9. Estimation of optimum sample sizes for 3rd instar potato leafhopper nymphs on alfalfa using a 3-stem bouquet as the sample unit.

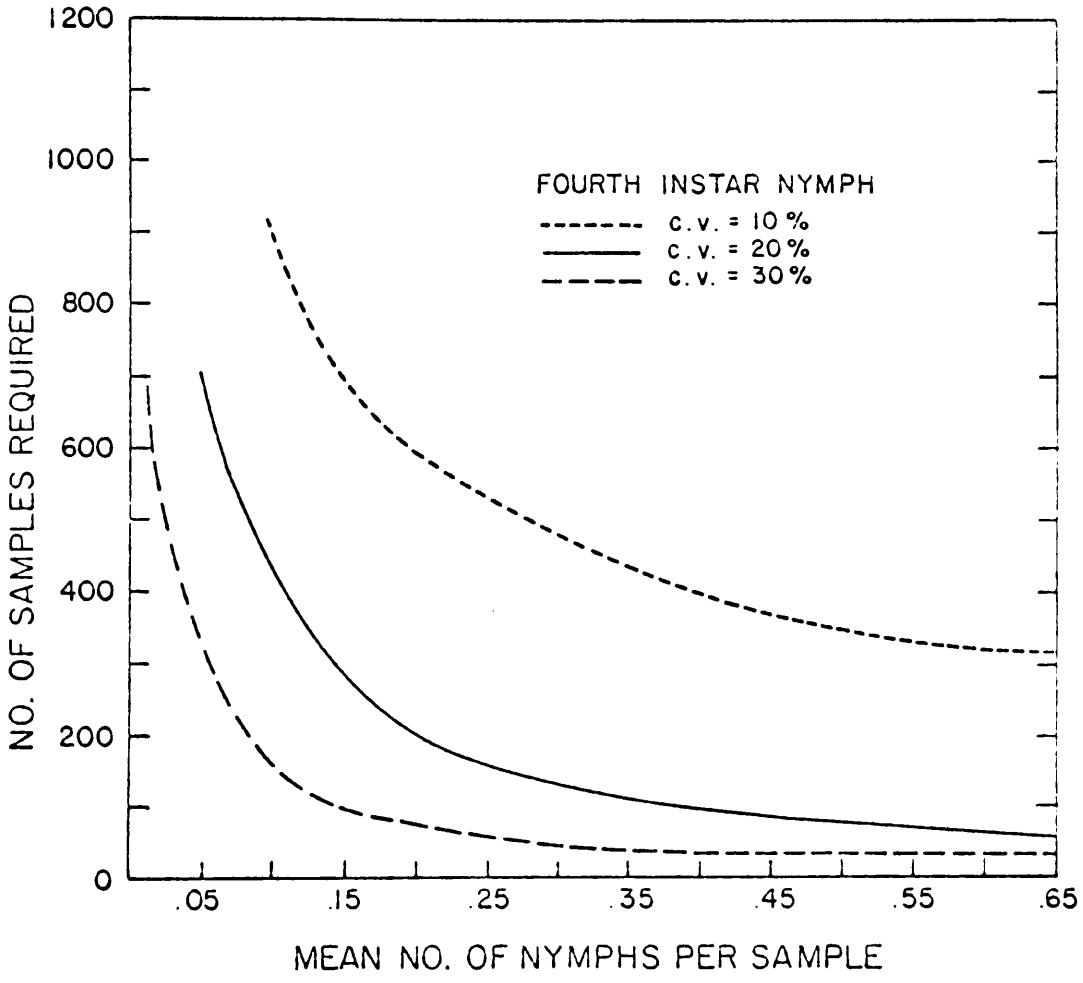

Fig. 10. Estimation of optimum sample sizes for 4th instar potato leafhopper nymphs using a 3-stem bouquet as the sample unit.

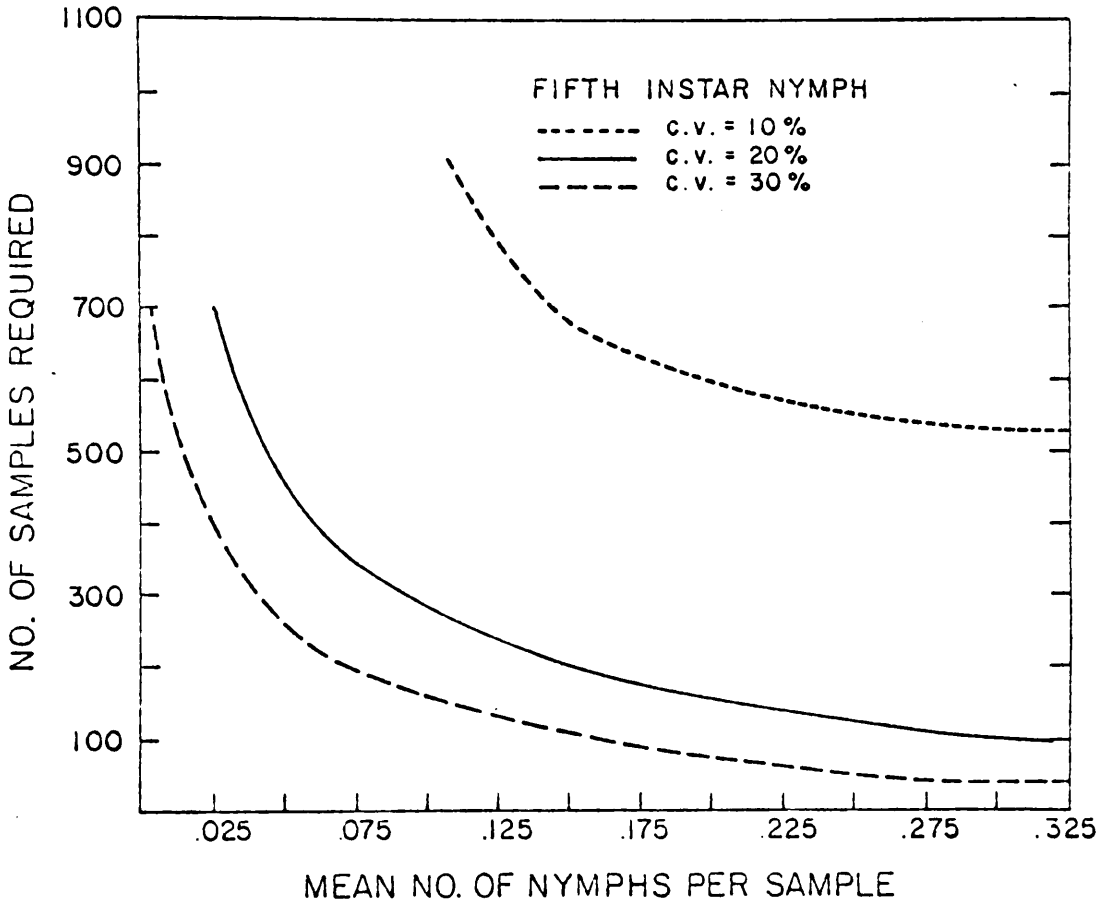

Fig. 11. Estimation of optimum sample sizes for 5th instar potato leafhopper nymphs on alfalfa using a 3-stem bouquet as the sample unit.

demonstrated on Aug. 26, 1977 in Field 2. The number of nymphs per sample was 4.56; however, k was low (0.067) resulting in a larger than expected sample size (10% c.v. = 1513, 20% c.v. = 378, and 30% c.v. = 168 samples). The reason for this was partly due to overlap in sampling between new growth alfalfa which had a low nymphal density, and lodged uncut alfalfa from the previous harvest which harbored a high population density (148 nymphs were collected in one sample). This resulted in a high variance which affected sample size. Overlap between harvests or generations need to be considered in sampling and determining sample sizes, especially in crops such as alfalfa which are periodically harvested. Ideally, these unharvested or incompletely harvested areas will be minimal, but if encountered in a random sampling procedure, they should be noted and sampled.

iii) Transformation of Data: In sampling programs where the sample site is divided into subareas the analysis of variance is useful in determining what amount of variation in the sample is due to these divisions. The distributional pattern of potato leafhopper nymphs indicates a heterogeneous sample variance. That is, the variance varies with the mean as shown by high r^2 values when plotting the log variance against the log mean (Table 7 values for untransformed data). Before the analysis of variance can be completed, the variance should be made independent of the mean by transforming the data. Several transformations have been pointed out that under most circumstances will adequately stabilize the variance (Southwood 1966). I tested the following transformations on the nymphal data; log (x + 1),

Table 7. Variance-mean relationship (r^2) of untransformed and transformed data for potato leafhopper nymphs on alfalfa.

Instar	Untrans.	Log(x+1)	Log(x+k_c)	Log(x+k_c/2)	$x^{1-b/2}$
First	0.816	0.393	0.315	0.274	0.222
Second	0.794	0.370	0.341	0.362	0.293
Third	0.837	0.500	0.514	0.543	0.463
Fourth	0.836	0.464	0.475	0.505	0.420
Fifth	0.865	0.642	0.624	0.640	0.642
Total Nymphs	0.795	0.279	0.056	0.041	0.102

log $(x + k_c)$, log $(x + k_c/2)$, and $x^{1 - b/2}$. The latter 2 transformations have been suggested by Anscombe (1948) and Taylor (1961) respectively.

Transforming the data by any of the 4 methods adequately stabilized the variance (Table 7) for 1st and 2nd instars, and total nymphs. Variance of 3rd, 4th, and 5th instars was not sufficiently stabilized by transforming the data. This may be due to low densities of these older instars during much of the alfalfa growth period. Southwood (1966) stated that at very low densities no transformation may adequately stabilize the variance.

Since distribution patterns between instars had been shown to be quite similar, I felt that the 5 instars could be grouped into 1 level for the analysis of variance as in the previous computation of sample size. Taylor's (1961) power law using $x^{.34}$ was selected to transform the data for the analysis of variance (x = total nymphs counted in each sample). Results showed that in 37 sample periods during 1976 and 1977 there was a significant difference ($P < 0.05$) between areas within plots only 7 times, and between plots within fields only 8 times. For this reason it was determined that random sampling for potato leafhopper nymphs throughout the field was an adequate sampling method.

iv) Comments on a Sampling Plan: The described procedure involves collection and counting of 100 samples. This requires ca 4 man-hr. Based on population levels of potato leafhopper nymphs found during 1976 and 1977, this sample size will sufficiently estimate population

levels within 20% c.v. during most of the alfalfa growth period. Precision of 10% c.v. or less cannot be achieved based on this number of samples using a 3-stem bouquet as the sample unit. Results of inter-plot and inter-area variances indicate that samples can be taken randomly throughout the field without delineating subgroupings within the field.

The technique and plan described here is effective in assessing population dynamics of the potato leafhopper nymph. This is regarded as a first step in the development of economic thresholds and sampling techniques through which sequential or other grower/scout oriented sampling plans can be developed.

D. EVALUATION OF SAMPLING TECHNIQUES AND DEVELOPMENT OF A SAMPLING PLAN FOR POTATO LEAFHOPPER ADULTS ON ALFALFA:

a) Introduction:

Sampling the adult potato leafhopper has been considered important in making management decisions. Early work considered relative estimates of population densities. Poos (1942) first suggested that a level of 1 potato leafhopper per sweep using 5 collections of 20 sweeps would indicate an infestation that would cause economic injury to alfalfa within 3 weeks. This has since been modified to 1 adult leafhopper per sweep collected (using a 180° sweep with a 38 cm diameter sweep net) in new seeded alfalfa (Blair 1975) or alfalfa that is less than 25 cm high (Edwards 1974). More recent work has centered on methods of estimating population density using a sweep net (Pruess et al. 1977, Cherry et al. 1977). However, little work has

been done on development of a sampling plan for evaluating population levels of potato leafhopper adults on alfalfa.

Sampling methods and plans have been reported for both the egg (Simonet and Pienkowski 1977) and nymph stage (Section B and C). This section deals with evaluation of sampling techniques, and development of a sampling plan to study adult potato leafhopper populations on alfalfa.

b) Materials and Methods:

i) Sampling Technique Evaluation: The D-Vac ® backpack suction insect collector (Dietrick 1961) was selected for use in sampling for potato leafhopper adults in alfalfa. In order to compare this method with other sampling techniques 25 stakes were placed in an alfalfa field at ca 30 m intervals. Samples with the D-Vac and 3 other techniques selected for evaluation were taken within ca 7 m of each stake, on 3 separate occasions. The techniques evaluated were: (1) The D-Vac backpack insect collector - 1 sample of 25 0.092m^2 sucks was collected near each stake. (2) The 15" sweep net - 1 sample of 25 180° sweeps was collected near each stake. (3) A trash can emergence trap described by Cherry et al. (1977) - 20 gal. aluminum trash cans (0.74m^2 at the base) painted flat black on the interior was dropped inverted over alfalfa, 2 samples were taken near each stake. Leafhoppers emerging through a hole cut in the top were collected in a ½ pint jar lined with Tac Trap ® screwed into lid rims fastened over the opening. (4) A plexiglass drop-trap similar to that described by Smith et al. (1976) - 1 sample was collected near each stake by

dropping the $0.26m^2$ trap over alfalfa. A 10 cm diameter hose attached to the D-Vac was used to carefully suction all insects out of the enclosed area. The samples were taken in areas near each stake that had not been previously sampled that day.

The 4 techniques were evaluated based on number of potato leafhoppers collected/m^2. To obtain m^2 estimates the number of adults collected in 25 D-Vac sucks was multiplied by 0.43; the number collected with the drop trap was multiplied by 3.85; the number collected in the emergence trap was multiplied by 1.67. The number collected in 25 sweeps was converted to nos./m^2 by the conversion equation $M = 2.7 (1.498)^W (T)^{-1.135}$ (Cherry et al. 1977), where M is the conversion factor, W is wind speed (m/sec) and T is temperature (°C). M was originally determined for conversion of 50 pendulum sweeps to m^2 estimates. Based on the estimate of the ratio of adults collected in pendulum and 180° sweeps as .48:1 (Cherry et al. 1977), we estimated that nos./m^2 using 180° sweeps caught approximately twice as many adults. Thus M x the number of adults collected in 25 180° sweeps would approximate the no. of adults/m^2.

ii) Sampling Procedure for Population Studies: Based on the comparative efficiency in collecting adult potato leafhoppers using the D-Vac shown by these field evaluations, and other reports of relatively high efficiency using this method (Pruess et al. 1977, Southwood 1966), we considered this technique to be relatively accurate in sampling potato leafhopper adults, although it was not efficient in sampling for the nymphal stage (Section B).

For adult population studies 2 alfalfa fields were selected, and sampled at least every 2 weeks. The sampling method consisted of placing the D-Vac hose opening (0.092 m^2) over the alfalfa at ca .5m intervals for ca 2 sec. Ten sucks comprised a sample unit. This unit satisfied the critera proposed by Morris (1955). Samples collected in this manner were placed in 25# paper bags and brought back to the laboratory for sorting and counting. In 1976, 100 samples and in 1977, 60 samples were collected in each field on each sampling date.

c) Results and Discussion:

i) Sampling Technique Evaluation: Results (Table 8) indicate that the D-Vac and drop trap methods collected the highest numbers of adults, sweep net samples were significantly less on 2 dates ($P < 0.05$), and the emergence trap collected the least adults on each date. Cherry et al. (1977) reported that the emergence trap collected 80% of the actual density of adult leafhoppers. The reduced number collected by our emergence trap was probably due to the time that the trap was left in place. We set the trap down for a period of 3-5 minutes, whereas, Cherry et al. (1977) left their traps in place for 15 minutes.

ii) Distribution Pattern: Because of the large area of the sample unit collected, I was not able to determine the true distribution of adults as had been done for both the egg and nymphal stages (Sections A and C). However, distribution patterns shown by adults

Table 8. Evaluation of sampling techniques for adult potato leafhoppers on alfalfa.

Sample Type	No. Adults/M^2 ($\bar{x} \pm$ s.e.)[1]		
	28 Jul	1 Aug	31 Aug
Drop Trap	16.3^a ± 3.06	20.6^b ± 2.84	5.1^a ± 0.99
D-VAC Suction	14.1^a ± 1.03	29.5^a ± 2.48	4.8^a ± 0.67
Sweep Net	10.6^a ± 1.01	10.3^c ± 0.98	1.1^b ± 0.10
Emergence Trap	1.8^b ± 0.28	1.5^d ± 0.26	0.5^c ± 0.16

[1]Means followed by the same letter are not significantly different ($P < 0.05$) according to the least significant difference test.

in the sample unit, although not relating to the true pattern of distribution in the field, were adequate for statistical treatment.

I tested the observed distribution by a χ^2 (chi-square) goodness of fit test to those expected for both the negative binomial (aggregated) and the Poisson (random) distribution models. Analysis showed that out of 32 samples which could be tested (from a total of 41) 23 adequately fit the negative binomial model ($P > 0.05$). Nine of these also fit the Poisson model. Where both models fit adequately the expected distribution shown by the negative binomial always gave a better fit to the observed distribution than did the Poisson. Nine samples fit neither model. Based on this data, the negative binomial was concluded to be a satisfactory model for the distribution pattern of adult potato leafhoppers shown by the sample unit used.

Other distribution indices which can likewise be used to evaluate distribution trends in organisms were also calculated (Table 9). Morisita's I_d (1962, 1964) which is relatively free of influence from sample unit size may give a true picture of distribution. In this case, values greater than 1 indicate aggregation. The other 2 indices, Taylor's (1961) b value and the common k (k_c) (Bliss and Owens 1958), also indicate that the distribution pattern of adult leafhoppers tended to be aggregated based on these samples. However, I do not feel that the true distribution pattern of the adult potato leafhopper can be accurately evaluated using composite samples collected in different areas (sample = total of 10 sucks), and these results should not be interpreted as doing such. The distribution

Table 9. Distribution indices calculated for adult potato leafhoppers on alfalfa.

Group	k_c	Taylor's b	I_d
Male	1.681	1.188	7.386
Female	3.612	1.250	4.111
Total	2.900	1.289	4.190

patterns shown in the $0.92m^2$ (10 x 0.092) areas do show aggregation, and further evaluations are based on this distribution pattern.

iii) Estimation of Optimum Sample Size: Sample size estimates can be calculated in a variety of ways. Karandinos (1976) and Southwood (1966) pointed out several methods and commented on each. Based on the negative binomial distribution shown by these sample units, sample size was most easily calculated by 3 parameters: the mean ($\bar{x}$), the index of dispersion (k) (Bliss and Fisher 1953), and a reliability parameter. In this study, the coefficient of variation (c.v.) was selected as the reliability parameter, and sample size estimates were calculated for 10, 20, 30% c.v. Figure 12 shows the estimate of sample size as a function of adult potato leafhopper density. The large sample unit is advantageous since variance between samples was decreased thus decreasing the number of samples necessary. For example, to estimate the population density when the expected density is 10 potato leafhopper adults per sample, only 8 samples are needed for a c.v. of 30%, 16 samples for a c.v. of 20% and 42 samples to be within 10% c.v. of the mean.

iv) Transformation of Data: When dealing with discrete data as is shown in studies of populations it is often necessary to test for the variance-mean realationship. If a relationship is shown (by regression analysis of the log variance plotted as a function of log mean) then the variance must be stabilized by transforming the data before analysis by parametric statistical treatment. In this data, the variance was shown to be dependent on the mean (Table 10)

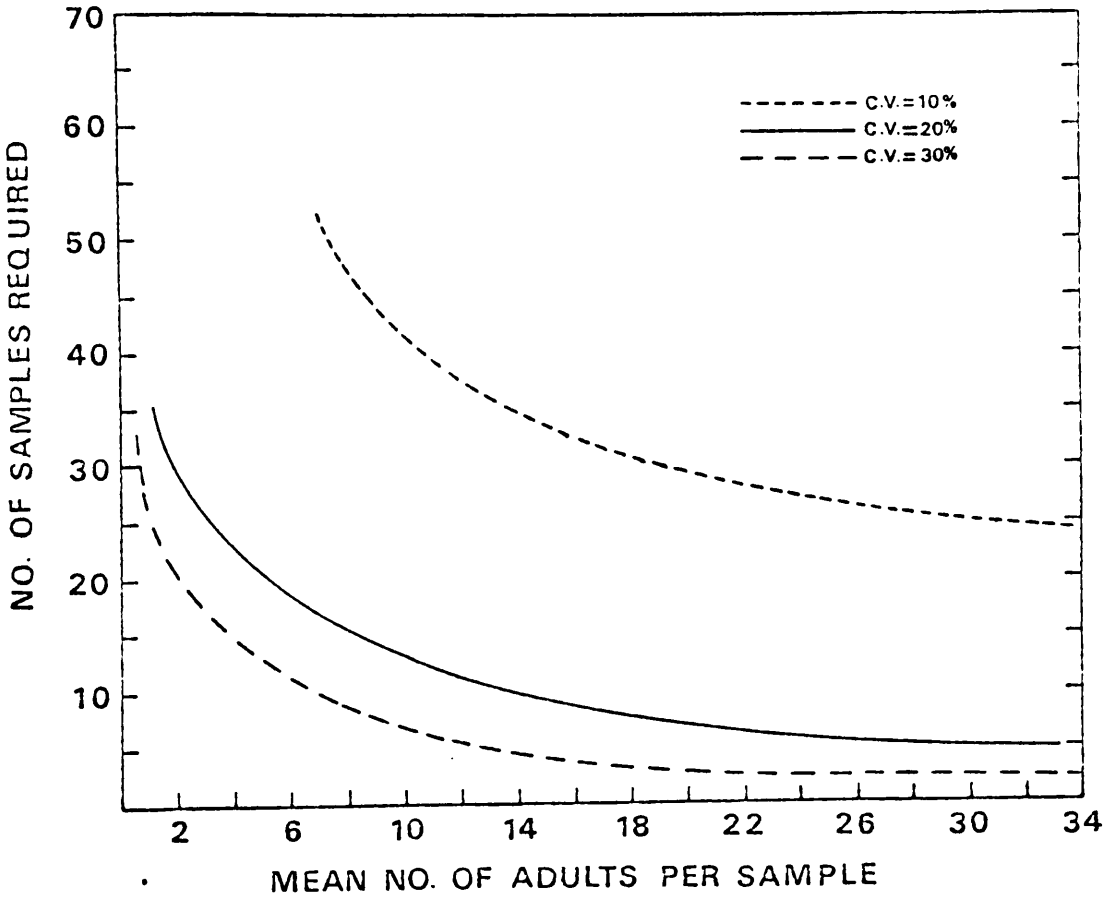

Fig. 12. Estimation of optimum sample sizes for adult potato leafhoppers on alfalfa based on a sample unit size of 10 ($0.092m^2$) D-Vac sucks.

Table 10. Variance-mean relationship (r^2) of untransformed and transformed data for potato leafhopper adults on alfalfa.

Class	Untransformed	$LOG_{10}(x + 1)$	$X^{(1-b/2)}$	$LOG_{10}(x + k_c)$	$LOG_{10}(x + k_{c/2})$
Male	0.924	0.679	0.645	0.809	0.627
Female	0.882	0.186	0.065	0.643	0.424
Total Adults	0.885	0.117	0.032	0.574	0.281

and several transformations were attempted to stablize the variance. The transformations attempted were: Log $(x + 1)$, $x^{1-b/2}$ (Taylor 1961, 1965), Log $(x + k_c)$ (Anscombe 1948), and Log $(x + k_c/2)$. After transformation these data were again analyzed by regression analysis to determine the variance-mean relationship (Table 10).

All transformations adequately stabilized the variance when using counts of females and total adult counts. However, the variance-mean relationship for male counts were not adequately stabilized by any method. Southwood (1966) stated that no transformation may be adequate at low population levels. A low male population early in the season caused by predominantly female immigrating populations (Medler et al. 1966) may have been the reason male counts could not be adequately transformed.

v) Comments on the Sampling Plan: The large sample unit used, 10(0.092 m^2) sucks/sample, did not allow us to adequately estimate the true adult potato leafhopper distribution in alfalfa. However, the method is efficient and the large sample unit size reduces the variance between samples necessitating fewer samples for a given level of precision. This may result in a reduced cost of sampling. Based on a 60 10-suck sample size we were able to estimate the population within a 10-20% error during most of the season.

Although this method is good for use in population studies, the D-Vac has little value for making management decisions in grower or scout oriented situations. This method or the sweep net method, which can give a density estimate when using the conversion equation

(Cherry et al. 1977), could be used to evaluate a relative method which may be more acceptable for use by growers or scouts in making pest management decisions.

IV. LABORATORY STUDIES OF THE POTATO LEAFHOPPER

A. STUDIES ON THE BIOLOGY OF THE POTATO LEAFHOPPER:

a) Introduction:

There have been numerous studies concerned with the biology of the potato leafhopper (Kieckhefer and Medler 1964; Kouskolekas and Decker 1966; DeLong 1938, 1971; Medler et al. 1966). However, many aspects of this pest still need to be considered.

Part of my research on the potato leafhopper has been oriented toward certain biological aspects of their biology which could be related to field observations. This study was conducted in 2 phases: (1) nymphal and adult morphometrics, sex ratio of adults emerging from eggs laid by single females throughout the oviposition period, and effect of temperature on nymphal survival; and (2) thermal requirements for oviposition and development of the potato leafhopper. The findings of the first phase are reported in this section.

b) Materials and Methods:

Eggs were obtained from adult female leafhoppers placed in cages made from 50 dram vials, and containing excised broad bean stems in a 3% sucrose solution. Nymphs that emerged from these stems were reared on single broad bean leaves placed in 50 x 12 mm petri dishes. Leaves were replaced as needed. Nymphs were reared at 12.8°, 18.3°, 23.9°, 29.4°, and 35°C with a 16 L:8 D photoperiod. Head capsule measurements were made daily on each nymph using an ocular micrometer. In order to be consistent, the distance between the outer edge of the compound

eyes was always measured. The instar was also recorded by noting when the nymph molted. After reaching the adult stage, head capsule width, wing length, whole length, and body length were measured, and the sex was recorded. Whenever a nymph died, the stage at death was noted, and a new first instar nymph replaced the dead nymph until 10 replicates reached the adult stage at each temperature.

In a second group of experiments, nymphs were collected from several females throughout the oviposition period and reared to the adult stage. The sex of each adult that emerged was recorded for each day of oviposition throughout the period.

c) Results and Discussion:

i) Nymphal Measurements: The only method described for determining nymphal instars of the potato leafhopper was given by Fenton and Hartzell (1923). They described nymphs by instar based on body length, wing pad length, and eye color. However, no information has been published on head capsule width which has been a standard method for determining instars for many other insects, especially Lepidoptera and Coleoptera.

Head capsule measurements for potato leafhopper nymphs were ($\bar{x} \pm$ s.e.): first instar - 0.29 $\pm$ 0.013 mm; second instar - 0.40 $\pm$ 0.017 mm; third instar - 0.50 $\pm$ 0.017 mm; fourth instar - 0.61 $\pm$ 0.014 mm; and fifth instar - 0.76 $\pm$ 0.012 mm. These measurements were accurate for determining stages of potato leafhopper nymphs, and no differences within instars was noted between nymphs reared at the 5 temperatures ($P < 0.05$). However, after death the nymph dries, and

the head capsule collapses since it is not as sclerotized as in some other immatures such as larval Lepidoptera. This means that instar determination can be made using head capsule widths from living nymphs, freshly dead nymphs (ca within 1-2 days after death depending on humidity), or properly preserved nymphs. These same limitations would also hold for Fenton and Hartzell's (1923) instar descriptions.

ii) Adult Measurements: Head capsule, whole length, body length, and wing length measurements are shown in Table 11 for male and female leafhoppers reared at constant temperatures ranging from 12.8 - 35°C. A nested analysis of variance indicated significant differences between sex for head capsule and body length measurements, significant differences between adults reared at different temperatures for wing length measurements, and a significant difference between both sex and temperature for whole length measurements.

No significant relationship was noted between temperatures and changes in whole, body, or wing lengths. However, there does seem to be a trend toward decreasing size with increasing temperatures which could be due to faster developmental rates at higher temperatures (Kouskolekas and Decker 1966). Further investigation using more replications may clarify this point, and show a more significant relationship between temperatures and size of potato leafhopper adults.

iii) Sex Ratio: Adults reared from eggs laid by females throughout their oviposition period were sexed to determine if any sex ratio pattern could be described. Numbers of emerging males and females in 5 day oviposition intervals are shown in Fig. 13. These results

Table 11. Measurements of adult potato leafhoppers reared at different temperatures ($\bar{x} \pm$ s.e.)[1].

Temperature	Sex	Head Capsule[2]	Whole Length[3]	Body Length[2]	Wing Length[4]
12.8	M	0.76±0.110	3.43±0.116	2.83±0.157	2.77±0.117
	F	0.79±0.110	------	3.06±0.144	------
18.3	M	0.76±0.021	3.41±0.122	2.79±0.132	2.86±0.082
	F	0.79±0.029	3.66±0.064	2.99±0.105	2.94±0.087
23.9	M	0.76±0.031	3.29±0.160	2.63±0.212	2.69±0.098
	F	0.80±0.022	3.48±0.147	3.10±0.171	2.73±0.105
29.4	M	0.75±0.018	3.25±0.029	2.74±0.281	2.65±0.051
	F	0.79±0.028	3.32±0.187	2.85±0.201	2.64±0.162
35	M	0.76±0.000	3.08±0.180	2.70±0.072	2.47±0.108
	F	0.78±0.038	3.34±0.171	2.91±0.185	2.68±0.128

[1]Measurements (mm) are of 2-8 adults/sex at each temperature.

[2]Significant difference between sex ($P < 0.05$).

[3]Significant difference between sex and temperature ($P < 0.05$).

[4]Significant difference between temperature ($P < 0.05$).

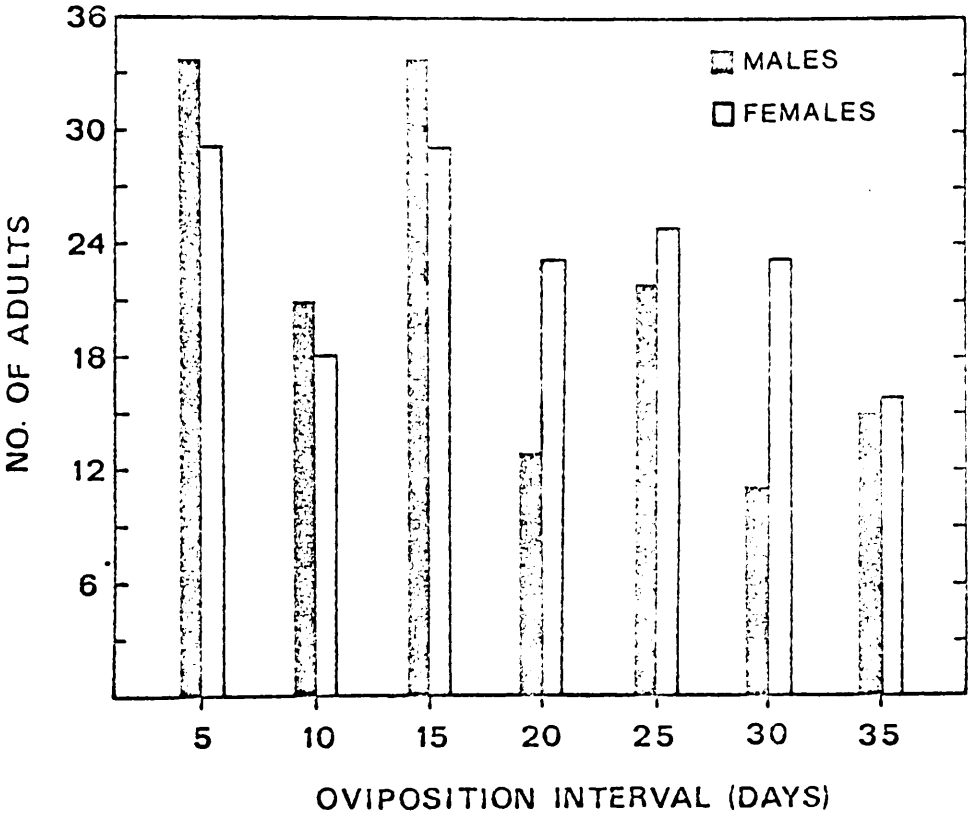

Fig. 13. Numbers of male and female potato leafhoppers emerging from eggs laid during the oviposition period.

indicated only that the male-female ratio favored males early in the oviposition period and favored females later. This agrees closely with results shown by Decker et al. (1971) who found 10% more males emerging early in the oviposition period, and a higher proportion of females later.

iv) Effect of Temperature on Nymphal Survival: DeLong (1938) reported that under field conditions the inability of nymphs to free their legs during eclosion was a major mortality factor. Although this was observed in laboratory studies, it was not quantified.

Mortality under laboratory conditions was higher at low (12.8°C) and high (29.4 and 35°C) temperatures (Table 12). First and fifth instar nymphs had the highest mortality. A no. 2 camel's hair brush was used to carefully transfer first instar nymphs. In spite of precaution mortality at this stage was considered to be largely due to handling.

Usually nymphal mortality would occur during molting. The increased mortality during the fifth instar is probably due to the major changes that the nymph is undergoing in development to the adult. In most cases, mortality during the fifth instar occurred just after the nymph had begun to molt or prior to completion of a molt.

Several general predators have been implicated as natural enemies of the potato leafhopper (Fenton 1918, Fenton and Hartzell 1923, Thompson 1944). Some of these, including Nabis sp. (Hemiptera: Nabidae), Geocoris sp. (Hemiptera: Lygaeidae), and Chrysopa sp. (Neuroptera: Chrysopidae) I observed feeding on potato leafhopper nymphs under

Table 12. Mortality of potato leafhopper nymphs reared at different temperatures.

Temperature(°C)	No. Reps.	Percent Mortality					
		First Instar	Second Instar	Third Instar	Fourth Instar	Fifth Instar	Total
12.8	16	6	13	0	6	6	31
18.3	11	9	0	0	0	0	9
23.9	13	15	0	8	0	0	23
29.4	23	17	0	4	4	17	43
35	42	33	7	7	12	21	81
Mean Mortality(%)		21	5	5	7	13	50

laboratory conditions. However, I consider the primary population regulating factors for the potato leafhopper to be weather (especially temperature), and harvest schedule. The latter has been reported (Pienkowski and Medler 1962) as a major factor reducing levels of potato leafhopper abundance in alfalfa.

B. THERMAL REQUIREMENTS FOR OVIPOSITION AND DEVELOPMENT OF THE POTATO LEAFHOPPER:

a) Introduction:

To complement my field studies, laboratory studies on growth and development under different temperature regimes were conducted. Others have considered temperature as a factor in population growth of the potato leafhopper (Kieckhefer and Medler 1964, Kouskolekas and Decker 1966).

This section reports the results of experiments to determine the effect of temperature on oviposition, development, and related areas which could be used to help interpret field observations and data.

b) Materials and Methods:

i) Oviposition Studies: In order to evaluate oviposition, single virgin females were placed with 2 males in cages made of 50 dram vials containing excised broad bean stems placed in a 3% sucrose solution. Experiments were conducted in environmental chambers at 12.8, 18.3, 23.9, 29.4, 32.3, and 35°C with a 16 L:8D photopheriod. Females were allowed to oviposit for a 24 hr. period after which fresh stems were provided. Stems which had been exposed to females for 24 hr.

were placed at a standard temperature (23.9°C). Hatching nymphs were counted and used as an indication of the no. of eggs laid. The experiments were continued until the female died or ceased oviposition.

ii) Developmental Studies: Developmental rates for the egg stage were studied at temperatures of 12.8, 18.3, 23.9, 29.4, 32.2, and 35°C. Broad bean stems which had been exposed to ovipositing females for 24 hr. period were placed in chambers at the above temperatures. Time of hatch was recorded.

Single newly hatched first instar nymphs were placed in 50 x 12 mm friction top petri dishes containing single broad bean leaves. These were placed at temperatures of 7.8°C, 12.8, 18.3, 23.9, 29.4, and 35°C. Times of development through each instar to the adult stage was recorded.

c) Results and Discussion:

i) Oviposition: Results from oviposition tests for 18.3, 23.9, and 29.4°C are shown in Table 13. Oviposition did not occur at 12.8, 32.2, and 35°C, and is not included in Table 13. These results agree with those of Kieckhefer and Medler (1964) who failed to obtain nymphs at 15.6 and 32.2°C. There was no significant difference ($P < 0.05$) in oviposition rate between the temperatures tested. Females laid eggs over a longer period at 23.9°C. Also, more total eggs/female were laid at 23.9°C. The maximum number of eggs laid in a 24 hr. period by a single female was 21 at 23.9°C. Maximum numbers of eggs at 18.3 and 29.4°C for a single day was 16.

Fig. 14 shows the no. of eggs/female/day throughout the oviposition period. At 18.3°C the female reached a peak in oviposition 10-25 days

Table 13. Oviposition periods and rates of oviposition for the potato leafhopper.

Temp. (°C)	Reps.	Mean Preovip. Period (Days)	No. Eggs/Day ($\bar{x} \pm$ s.e.)[1]	Max. No. Eggs/Day	Mean Ovip.[2] Period (Days)	Mean No. Total Eggs/Female
18.5	5	5.5	6.6 ± 0.33	16	19[a]	125
23.9	9	5.3	6.7 ± 0.27	21	36[bc]	241
29.4	4	9	7.3 ± 0.48	16	29[ab]	212

[1]Means not significantly different ($P < 0.05$).

[2]Means followed by the same letter are not significantly different ($P < 0.05$) by the least significant range test.

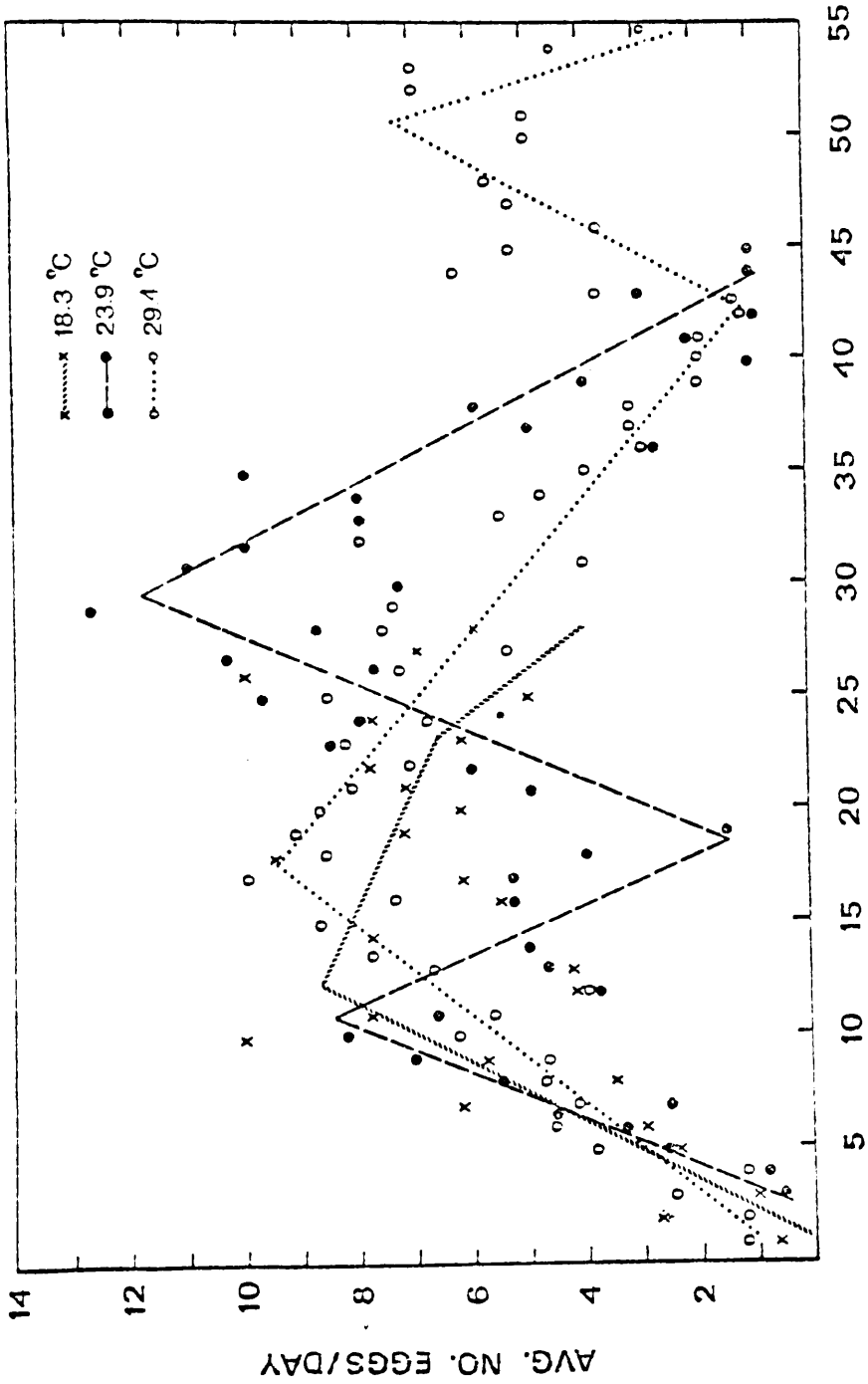

Fig. 14. Daily oviposition rates for the potato leafhopper throughout the oviposition period.

after emergence. No second peak was observed at this temperature. However, at both 23.9°C and 29.4°C there were 2 distinct oviposition peaks possibly reflecting a second mating. At 23.9°C, the first peak was reached at about 10 days after emergence, a second peak occurred between 25-35 days. At 29.4°C, the first peak occurred from 15-32 days after emergence, and the other occurred from 44-52 days after emergence.

The biological implications of this ovipositional behavior are not entirely clear. It is suspected that the biphasic activity exhibited indicates a reduction in oviposition rate followed by renewed activity after the female receives a new spermatophore during a second mating. Adults were observed to mate during this period of reduced oviposition, and second matings have been observed by other workers (Carlson 1967). It also appears that within the temperature limits (upper and lower thresholds) the oviposition rate is relatively constant. Only the period of oviposition changes.

ii) Development: Developmental thresholds and temperature summation for the potato leafhopper have been reported by Kouskolekas and Decker (1966). However, their °Day development was calculated for the entire period from egg to adult. In order to relate field samples for eggs, nymphs, and adults, separate developmental curves for the egg and nymph stage were needed.

Developmental rates as a function of temperature are shown in Figs. 15 and 16 for eggs and nymphs respectively. Developmental thresholds were somewhat lower than 11.4°C reported by Kouskolekas

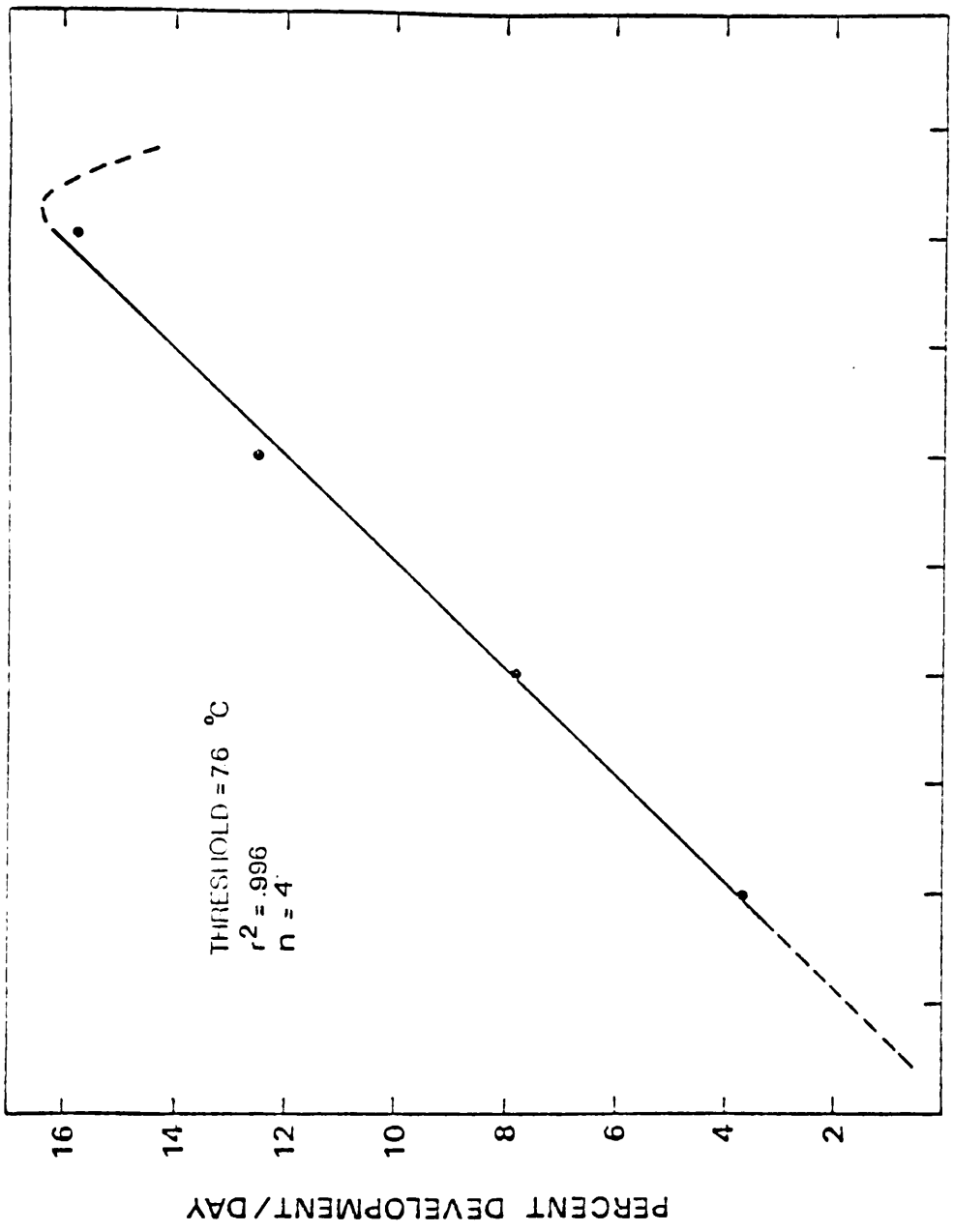

Fig. 15. Temperature threshold and development rate for hatch of potato leafhopper eggs.

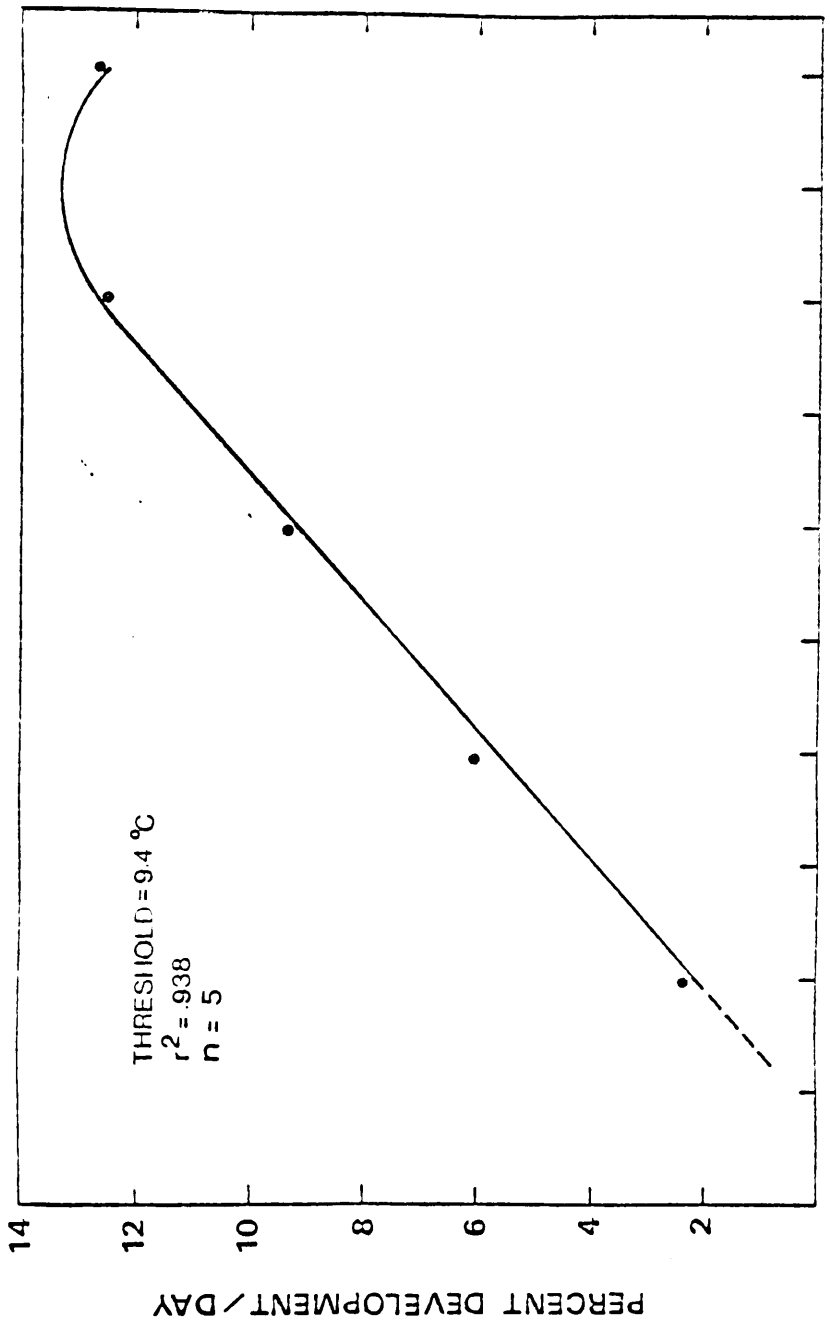

Fig. 16. Temperature threshold and development rate for potato leafhopper nymphs.

and Decker (1966). For the egg stage the threshold was 7.6°C, and for nymphal development it was 9.4°C. Egg development reached an upper threshold between 29 and 32°C. No eggs hatched at 32°C. Nymphal development continued at 35°C, but mortality was high and development was no faster than at 29°C. Thresholds and development rates were similar for both the egg and nymph stage and agree with results of Kouskolekas and Decker (1966). They are presented separately only for more accurate determination of development between stages in field studies.

Developmental times (°Days) for both stages are shown in Table 14. The mean total °Days necessary to develop from egg to adult was estimated to be 289. This agrees rather closely with the results of Kouskolekas and Decker (1966). However, as they have pointed out, the potato leafhopper cannot be readily studied apart from its host plant, and plant-insect interactions that may be taking place (especially in the egg stage) are not discernible.

Table 14. Development times (°Days) for eggs and nymphs of the potato leafhopper.

Temperature (°C)	Egg °Days[1]	Nymph °Days[2]	Total °Days
12.8	140	147	287
18.3	136	148	284
23.9	130	158	258
29.4	138	160	298
Mean	136	153	289

[1]Egg Development Threshold = 7.6°C.

[2]Nymph Development Threshold = 9.4°C.

V. POPULATION DYNAMICS OF THE POTATO LEAFHOPPER ON ALFALFA

A. FACTORS ASSOCIATED WITH OVIPOSITION BY THE POTATO LEAFHOPPER ON ALFALFA:

a) Introduction:

Preference for specific oviposition sites has been indicated for the potato leafhopper on alfalfa (DeLong 1971, Kieckhefer and Medler 1964, Simonet and Pienkowski 1977). Patterns in egg deposition were shown for the potato leafhopper on solanaceous crops (Carlson and Hibbs 1962, Miller and Hibbs 1963). The reasons for this preference have not been investigated, but could possibly be due to microclimatic effect and behavior of the female, nutritional requirements in feeding by the female, tactile response and preference of the ovipositing female for less fibrous tissue, or any combination of the above. These factors were investigated for other leafhoppers by Saxena et al. (1974), and Saxena and Saxena (1974). They outlined a series of responses shown by the insect to its host plant. Characters which they thought were associated with acceptability of the plant included density of plant hairs, toughness of the plant surface, moisture content, sugar concentration, and organic acid content.

The general pattern in egg deposition shown by the potato leafhopper indicates that some interaction between plant and insect does exist. Information on what factors may be important in ovipositional behavior may be useful in studies of ovipositional deterrents in selection for resistant host plants.

This section reports further investigation into the ovipositional pattern shown by female potato leafhoppers in alfalfa.

b) Materials and Methods:

Alfalfa stems were collected from 2 fields in Montgomery County, Virginia during the period from June-September 1976-1977. The height of both fields was measured and plant growth stage was estimated at each sample period. In the laboratory, leaves were removed and stems were cleared and stained in a lactophenol-acid fuchsin mixture (Simonet and Pienkowski 1977). The procedure was to place stems in ca 5 L of a boiling lactophenol-acid fuchsin solution. This was made by combining 1 part lactic acid, 1 part phenol, 1 part distilled water, and 2 parts glycerin. One gm of acid fuchsin stain was added per L of solution. The stems were left in this solution for ca 15 min. to clear. They were allowed to remain in solution and cool overnight during which time the stain was absorbed into the plant tissue. Excess stain was removed from the stems by washing in warm water. Stems were then pressed between glass plates. Eggs were counted using a stereo-microscope, and their position in the plant recorded.

During 1 growth period in 1977 stems were collected weekly for analysis of sugars and structural tissue (fiber, waxes, etc.) content. After removing leaves and lateral stems, the main stems were cut into 3 cm segments, and each segment was analyzed. Stem segments were oven dried overnight and ground to a fine powder. This material was weighed and soluble substances dissolved in 20 ml of a weak H_2SO_4 (.02N) solution at 90°C. After filtering, the solution was brought up to

100 ml with distilled water, and 3 ml were drawn off and analyzed for total sugars. The undissolved tissue was dried and weighed to determine structural content. These results were correlated with the number of eggs found in 3 cm segments down the main stem during the same growth period.

c) Results and Discussion:

The pattern of oviposition in the main stem was similar in both 1976 and 1977 (Fig. 17). A plot of the percent of eggs found in 1 cm segments showed that most eggs were laid in the younger more succulent tissue found in the upper 17 cm of the stem. During the growth period alfalfa reaches lengths of 75-100 cm; therefore, all of the eggs found in the main stem were located in the upper ¼th of the plant at its peak height.

Results from stem analysis showed a rather distinct relationship between structural content and eggs (Fig. 18). There was a high negative correlation ($r = -0.9034$, $P < 0.0003$) between number of eggs found in 3 cm segments and percent structural matter. No correlation was shown between percent total sugars and eggs, or between sugars and structural matter. It should be pointed out that specific sugars, or some other nutrients such as proteins or total nonstructual carbohydrates (TNC) that may be important were not analyzed.

From these results, I cannot conclude that insoluble structural materials are the only important factors in egg deposition. However, the amount of fiber, waxes, and other structural substances do seem to have some bearing on ovipositional preference.

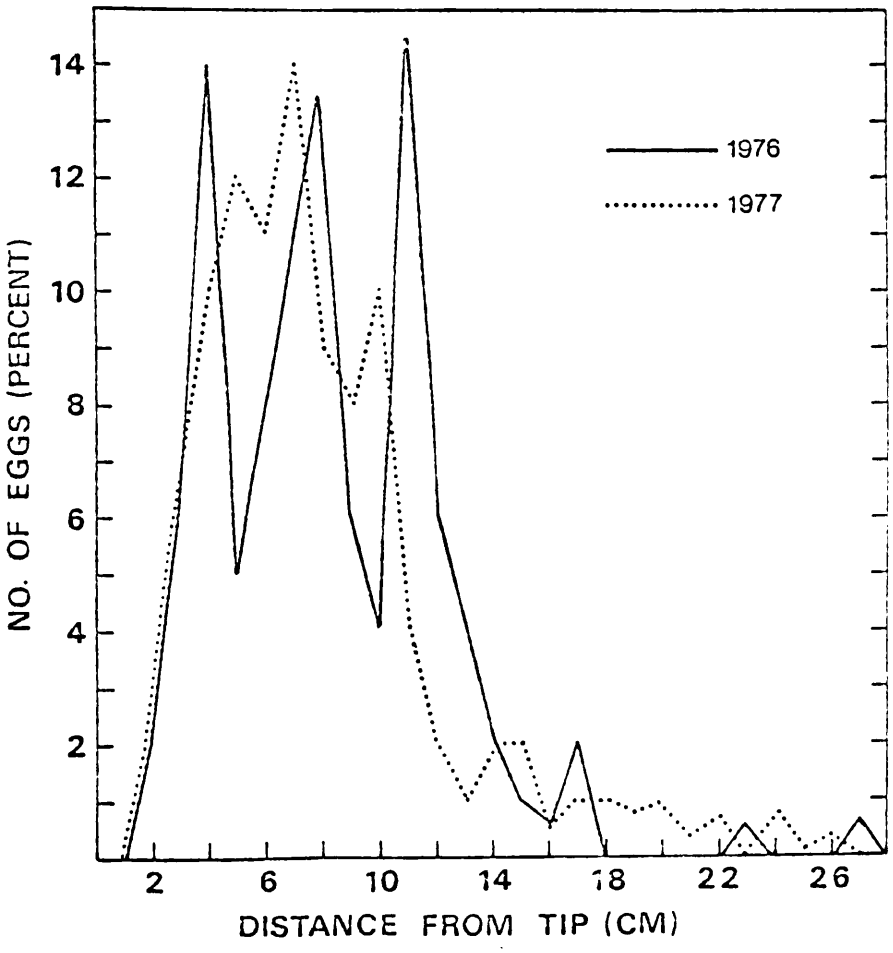

Fig. 17. Distribution of potato leafhopper eggs in the main stems of alfalfa during 1976 and 1977 expressed as a percent of the total no. eggs found.

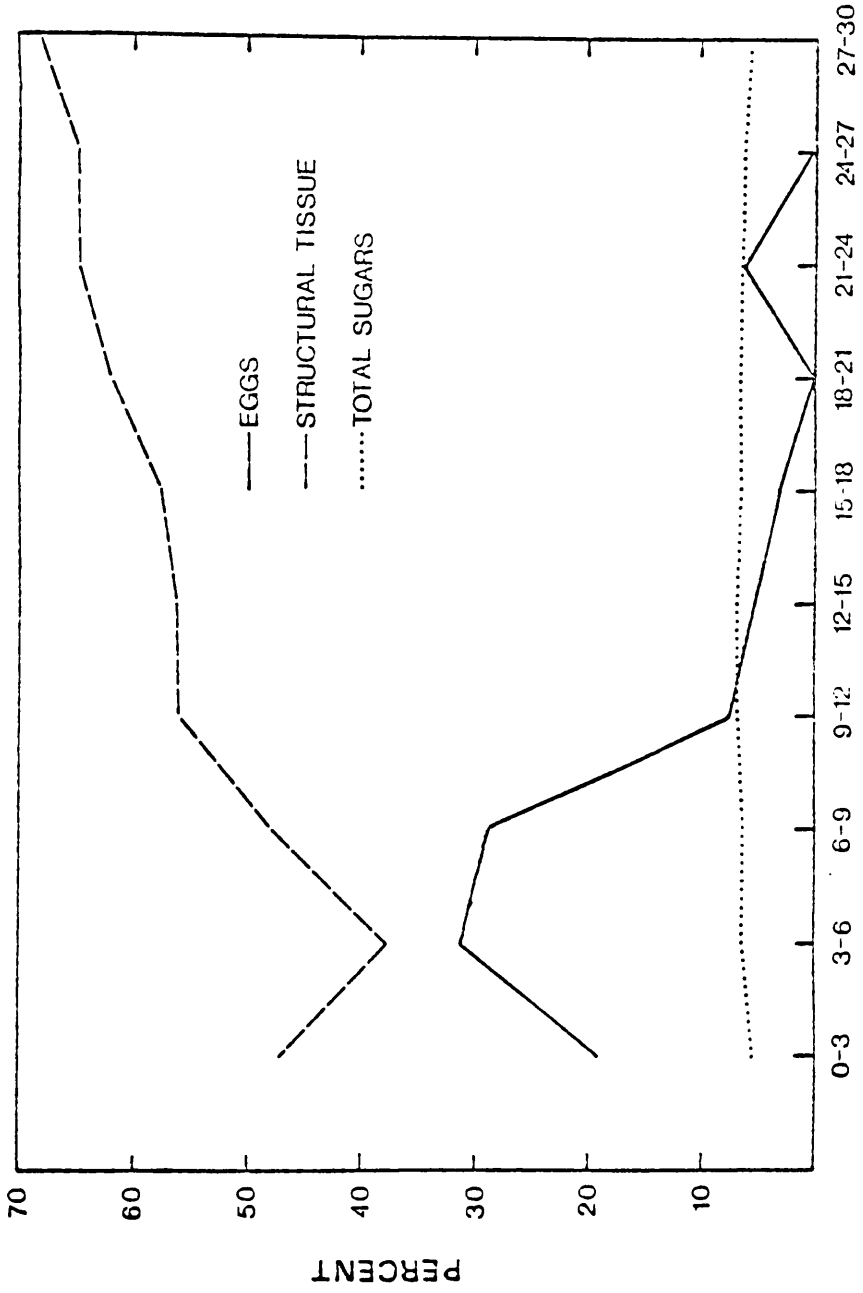

Fig. 18. Analysis of sugar content, structural content (% dry matter), and potato leafhopper eggs in 3 cm segments of the main alfalfa stem.

The leafhopper-alfalfa relationship concerning oviposition is quite complex, and more factors are important in determining ovipositional preference and behavior than are presented here. However, the above factors play an important role in determining egg distribution pattern in the stems. Those qualities which are favorable for oviposition are also qualities which make alfalfa favorable as a forage (i.e. succulent nonfibrous tissue). Attempts to alter this in developing leafhopper resistant varieties would probably alter the quality of alfalfa and make it less desirable as a hay crop for livestock.

B. FIELD POPULATION STUDIES OF THE POTATO LEAFHOPPER ON ALFALFA:

a) Introduction:

The potato leafhopper is the primary pest of summer grown alfalfa in Virginia, and can cause reductions in quality, yield, and stand duration. The severity of damage is related to the stage of alfalfa growth when the major influx of leafhoppers occurs (Kouskolekas and Decker 1968). Since alfalfa is periodically harvested, one management technique has been the adjustment of cutting schedule to reduce population levels (Searls 1934, 1935; Graber and Sprague 1933, 1935; Pienkowski and Medler 1962).

The main purpose of this research has been to evaluate population buildup by the potato leafhopper during the alfalfa growth periods. This was accomplished by studying leafhopper developmental rates and abundance in the field during the growth period, and determining the effect of harvest on the population. I consider temperature to be the

primary factor controlling population buildup of the leafhopper on alfalfa. The influence of many other factors which are operating have not been investigated.

b) Materials and Methods:

During the summers of 1976 and 1977 potato leafhopper populations and alfalfa development were monitored in 2 fields in Montgomery County, Virginia. Samples were collected at least every 2 wk. (except immediately after harvest) for eggs, nymphs, and adult potato leafhoppers. To sample for eggs, 100 stems were collected from each field on each sampling date. Stems were brought into the laboratory, cleared and stained using the lactophenol-acid fuchsin technique, and eggs were counted. Nymphs were sampled using the dichlorvos-carton technique by selecting 80 3-stem alfalfa bouquets in 1976, and 100 3-stem bouquets in 1977. Adults were sampled using the backpack D-Vac insect suction collector, and taking 100 10 suck samples in 1976, and 60 10 suck samples in 1977.

Five single stems and 5 3-stem bouquets were collected every 20-30 paces for egg and nymphal samples. Consecutive 10 suck samples were collected at .5 m intervals for adults by placing the D-Vac hose over the alfalfa for ca 2 sec. at each suck. Alfalfa height was measured, and field growth stage was visually approximated at each sampling period. Alfalfa density as stems/m^2 was also estimated for each field by counting the no. of stems in a .092 m^2 area on 3 different occasions for both fields in 1976, and on 2 different occasions in 1977. Maximum-minimum temperatures were obtained from the National Oceanic

and Atmospheric Administration (1976, 1977) for both years from the official weather station in Montgomery County, Virginia located ca 2 miles from both fields.

In order to evaluate the effect of harvest on potato leafhopper nymphal populations, samples were collected at 2-3 day intervals after harvest during 1977. This phase of sampling was conducted by selecting 3-stem bouquets at 20-30 paces. A diversity of sample types was obtained by biasing the sample and selecting a sample of stubble residue, a sample of incompletely harvested alfalfa which had stems with leaves, and a sample of uncut alfalfa if available. When counting these samples in the laboratory, the no. of nymphs and a stem description was recorded.

c) Results and Discussion:

i) Population Abundance: Population trends for all developmental stages of the potato leafhopper are shown in Fig. 19-22. In general, during 1976 (Fig. 19 and 20) population buildup was slower than in 1977 (Fig. 21 and 22). This was possibly due to a late cold spell in the spring of 1976 which may have affected the adult population. However, in each case (except the Fall of 1977) buildup of egg and nymphal populations is rapid. This can be partially attributed to the fact that gravid females are migrating into the growing succulent alfalfa. They begin oviposition and egg buildup occurs between sample periods since the time between samples was, in many cases, shorter than the egg development cycle. This was also true for the nymphal stages.

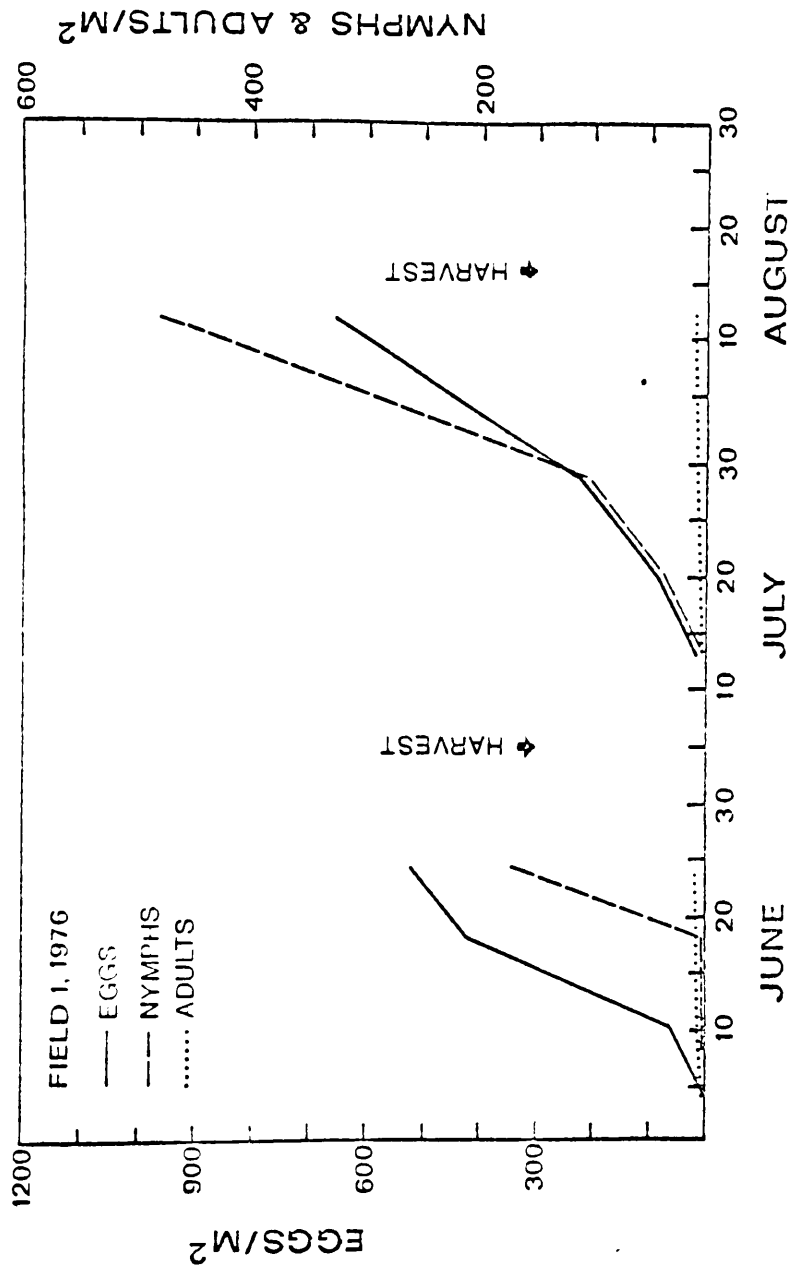

Fig. 19. Population levels of potato leafhopper eggs, nymphs, and adults during 1976 in Field 1.

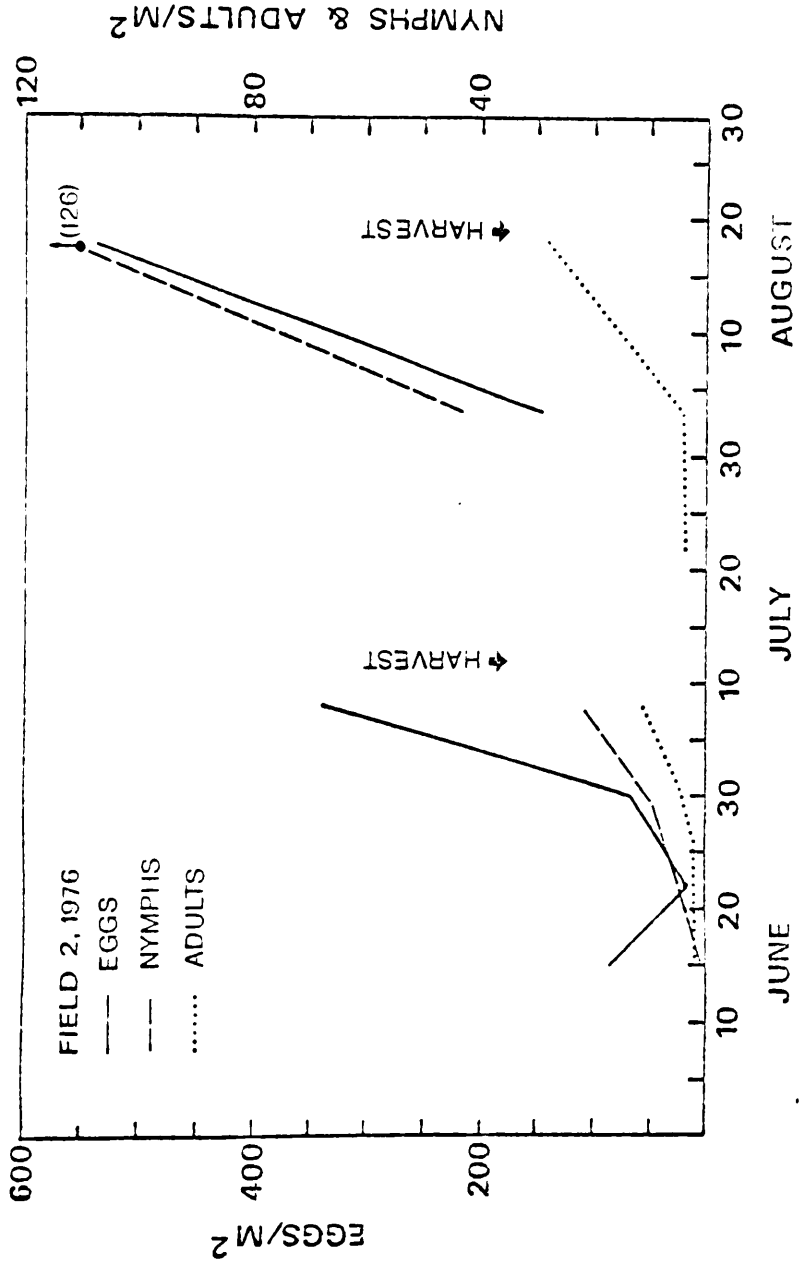

Fig. 20. Population levels of potato leafhopper eggs, nymphs, and adults during 1976 in Field 2.

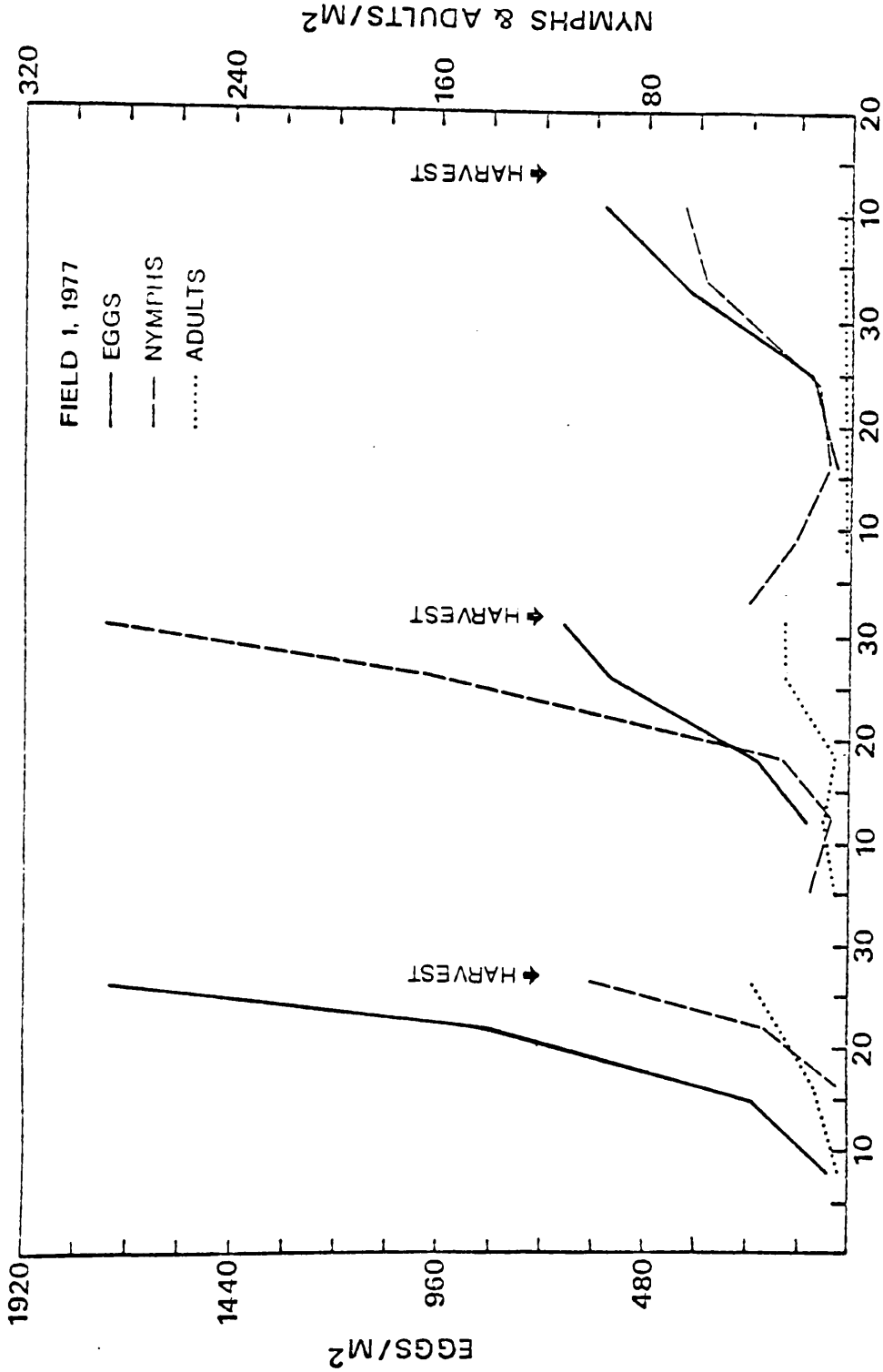

Fig. 21. Population levels of potato leafhopper eggs, nymphs, and adults during 1977 in Field 1.

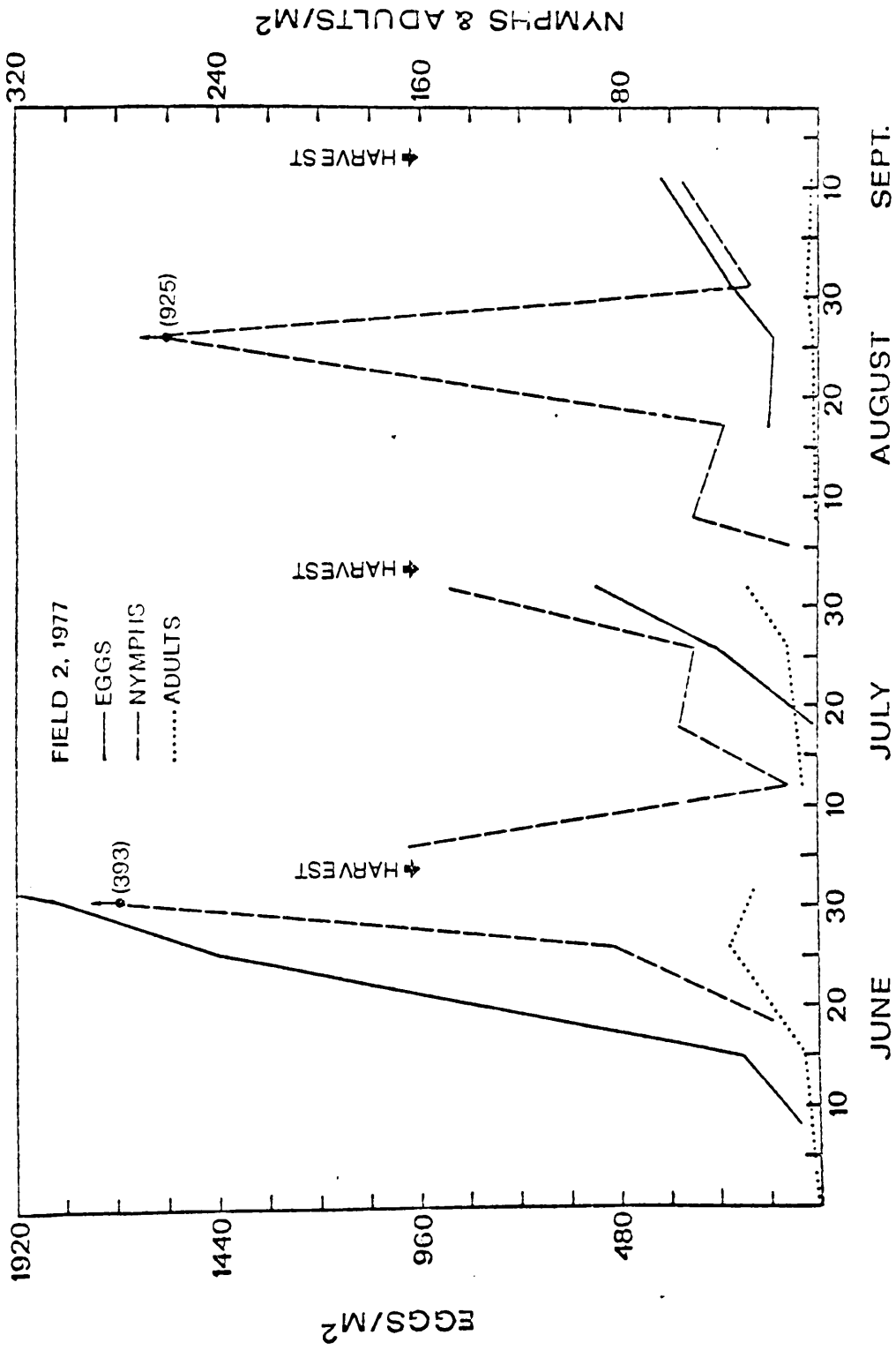

Fig. 22. Population levels of potato leafhopper eggs, nymphs, and adults during 1977 in Field 2.

ii) Harvest as a Morality Factor on Potato Leafhopper Populations: It has long been recognized that potato leafhopper management on alfalfa can be best achieved through the cultural practice of manipulation of harvest date. Searls (1934, 1935) and Graber and Sprague (1933, 1935) recommended delaying the first harvest for a 10 day period, thereby reducing the population by destroying a large portion of eggs laid by the incoming migrants. This was shown to be more complex than previously thought (Poos and Westover 1934). Also, the arrival and spread of the alfalfa weevil, Hypera postica Gyllenhal (Coleoptera: Curculionidae) has made it disadvantageous to delay the first cutting. However, Pienkowski and Medler (1962) showed that manipulation of harvest definitely would affect potato leafhopper buildup in alfalfa.

The effect of harvest on potato leafhopper populations could be very closely followed using the sampling techniques previously described. By plotting the levels of abundance of eggs, nymphs, and adults; and estimating the days to development (based on °Days), effect of harvest on abundance would be seen.

Fig. 23 shows a single growth period of alfalfa with the buildup of potato leafhopper eggs, nymphs, and adults. Harvest during this period was on June 27. Based on thermal accumulation the last date on which an egg laid will hatch (egg hatch date); the last date on which a nymph will be able to develop to an adult (nymph-adult emergence date); and the last date on which an egg laid will have sufficient time to develop to an adult (egg-adult emergence date) are

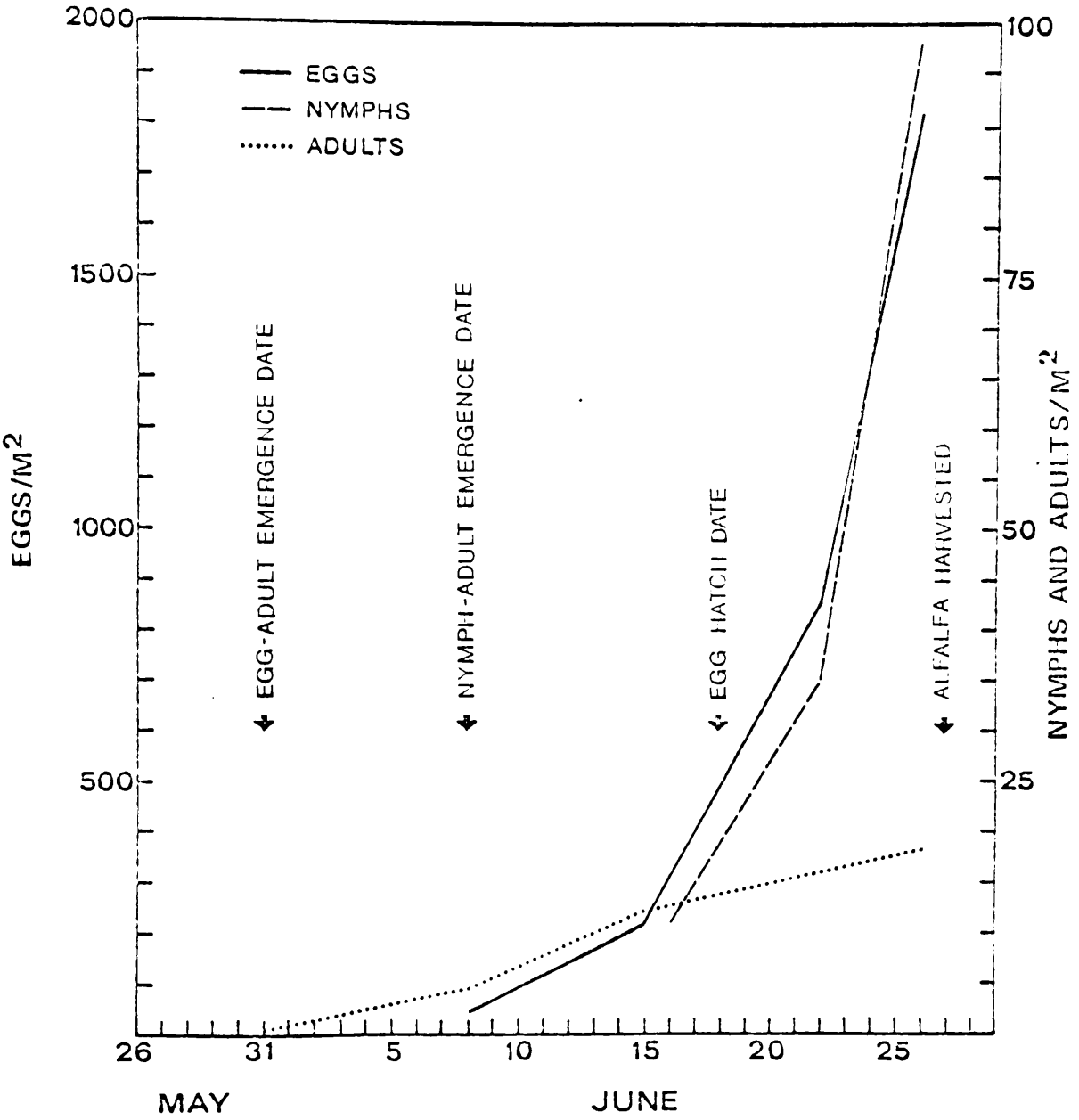

Fig. 23. Survival periods for eggs and nymphs of the potato leafhopper in relation to harvest of alfalfa.

seen. From these data, no adults would develop before harvest, although some eggs were probably laid earlier than indicated by Fig. 23. Also, this is only an estimate, and development could be faster or slower by a few days. During this period the observed data support this experimental data. On the last sample date before harvest (June 26), no nymphs above the third instar were found. Similar guidelines occurred for each growth period in both fields. From these data, the tremendous mortality caused by harvest can be seen. This assumes 100% mortality at harvest which does not occur in nymphs, and probably does not occur in eggs.

Samples collected during 1977 after harvest indicate that, although cutting date is important in reducing populations, the harvesting technique plays a significant role in potato leafhopper buildup on the subsequent regrowth.

Fig. 24 shows results obtained after harvest on a composit of samples over several postharvest periods. The resulting curve indicates that within 7-10 days after harvest the nymphal population is diminished by about 95%. This loss may be through death or emergence as adults. The egg stage has been largely destroyed as there was no appreciable addition to the nymph stage from eggs during this period. This is generally true, although in 1 field sampled 5 days after harvest, a discrepancy was observed. Loss by mortality was much less here (ca 50%) indicating a high survival of nymphs and eggs which are hatching, and adding to nymphal abundance.

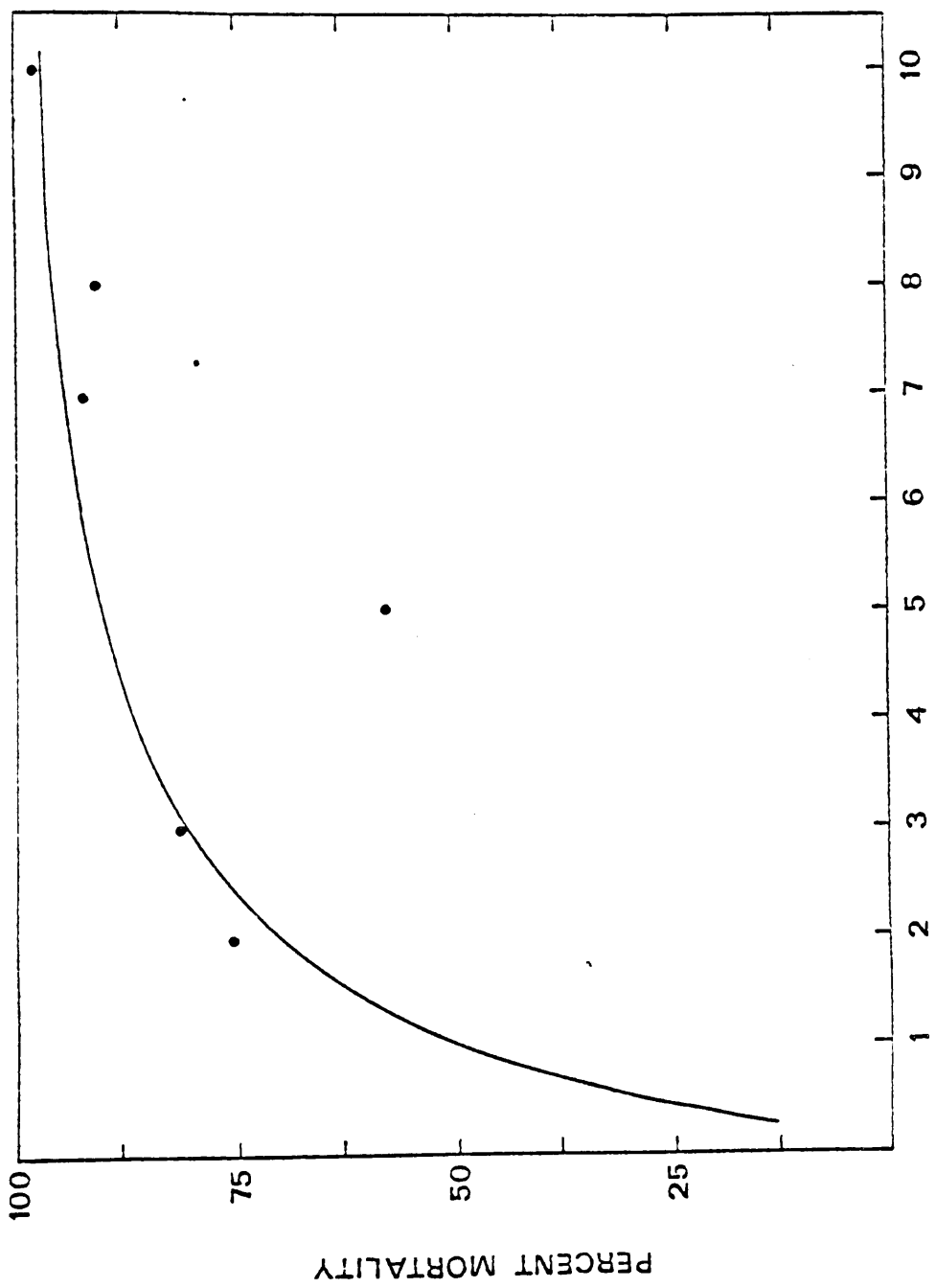

Fig. 24. Postharvest mortality of nymphs based on a composit of samples collected in 1977.

Perhaps a clearer picture of this can be seen in Table 15. The no. of nymphs described as a percent found on the different stem types sampled (stubble, stubble with leaves, uncut alfalfa, and regrowth) indicates either a movement from the stubble or a higher survival on the more succulent stems. Finally, when regrowth does begin nymphs migrate to these succulent young stems. Thus, a resident leafhopper population is available to feed on the alfalfa during regrowth.

The adults migrate from alfalfa fields at harvest (Poston and Pedigo 1975) which is a survival mechanism shown by the leafhopper in this unstable habitat. The only method of nymphal survival is to locate succulent food material. If it cannot do this it will not survive. Clean harvest practices can further reduce population levels by causing a higher mortality on both eggs and nymphs.

When an alfalfa field is poorly cut at harvest, the leafhopper population can continue to increase. This is obvious in nymphal abundance in Field 2, 1977 (Fig. 22) when surviving nymphs from the previous harvest caused a marked population increase. Adults can more easily locate suitable tissue for feeding and ovipositon in a poorly harvested field. The result is an expanding growing population which is present at regrowth. This population can cause severe damage, and significant reduction in both quality and yield of alfalfa.

Another consideration in harvest management besides clean harvest of the field is to harvest adjacent fields as close to the same date as possible. Also, fence rows should be cleared of any alfalfa that

Table 15. Percent of potato leafhopper nymphs found on different stem types during the postharvest period.

Postharvest distribution of nymphs in alfalfa.

Days Postharvest	Nymphs collected (%)			
	Stubble	Stubble with leaves	Uncut alf.	Regrowth
2	27	29	44	-
5	5	36	59	-
8	-	25	-	75

cannot be harvested, which would serve as a habitat for adults and nymphs at harvest.

VI. SUMMARY

Potato leafhopper populations were studied on alfalfa grown in Virginia. Sampling plans were developed for each growth stage (egg, nymph, and adult) on two alfalfa fields in Montgomery Co., Virginia during June-September, 1976 and 1977. Samples were collected at least every 2 wk except immediately after harvest.

The egg stage was sampled using the whole alfalfa stem, with the main and lateral branches, as the sample unit. One hundred stems were collected on each sample date. Stems were cleared and stained in a lactophenol-acid fuchsin mixture to detect eggs. Eggs were located in the upper 27 cm of the main stem and in the lateral stems. No eggs were found in leaf mid-ribs. Based on a sample size of 100 stems, the population could be estimated within 20% C.V. during much of the alfalfa growth period.

Nymphs were sampled using ice cream cartons containing dichlorvos-resin squares. A three-stem alfalfa bouquet sample unit was shown to be above 90% efficient in recovering nymphal potato leafhoppers. Based on a sample size of 100 stems per field, the population could be estimated within 20% C.V.

Adults were sampled using a D-Vac backpack insect collector. The sample unit was ten 0.092 m^2 sucks. Based on 60 samples per field, the population could be estimated within 10 to 20% C.V.

Laboratory studies were conducted to determine oviposition rate for adults, and developmental thresholds and rates for eggs and nymphs. Oviposition was consistent from 18 to 29°C. Above and below this

temperature range oviposition ceased or was greatly reduced. Developmental thresholds for eggs and nymphs were 7.6°C and 9.4°C respectively.

Using developmental rates and maximum-minimum temperatures, the effect of harvest on egg and nymphal abundance was studied. Mortality was high after harvest, and harvest time is important in reducing potato leafhopper abundance. Clean harvest practices were also important in reducing egg and nymphal survival, and in reducing population buildup of potato leafhoppers.

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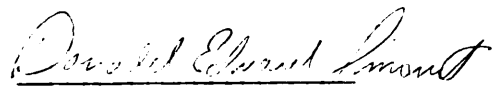
VITA

Donald Edward Simonet was born in Orlando, Florida on March 26, 1946 to F. B. and Katherine (Jacobsen) Simonet. After graduating from William R. Boone High School (Orlando, Florida) in 1963, he entered Emory and Henry College, Emory, Virginia. In 1967 he graduated with a B. A. degree in Biology and taught at Marion Jr. High School, Marion, Virginia for two years. In 1970 he enlisted in the U.S. Navy for four years active service. After leaving the military he enrolled in Virginia Polytechnic Institute and State University. He completed the M. S. degree in Entomology in 1975, and is currently pursuing a Ph.D. in Entomology. He is a student member of the Entomological Society of America, associate member of Sigma Xi, and member of the Virginia Academy of Science, International Organization for Biological Control, Gamma Sigma Delta, Phi Kappa Phi, and Phi Sigma Society. He was married to Leslie Diane Quesenberry, daughter of M. S. and Agnes Quesenberry, Jr. of Big Stone Gap, Virginia on August 5, 1967. They have one daughter, Whitney Anne born March 31, 1976.



Donald Edward Simonet

POPULATION STUDIES OF THE POTATO LEAFHOPPER, EMPOASCA FABAE (HARRIS), ON ALFALFA, MEDICAGO SATIVA L.

By

Donald Edward Simonet

(Abstract)

The potato leafhopper, Empoasca fabae (Harris), is a primary pest of alfalfa grown in Virginia. Sampling techniques and sampling programs for each growth stage (egg, nymph, and adult) were developed to study the population dynamics of this insect. Distribution patterns exhibited by each stage have been used to determine sample unit size and optimum number of samples. The sampling technique was also evaluated in field population studies.

The egg sampling technique, which used an acid fuchsin stain and lactophenol clearing solution, was efficient in estimating egg densities within 20 to 30% C.V. about the mean based on 100 single stems collected on each sample date. The nymphal sampling technique using 0.946 liter ice cream containers with dichlorvos squares (ca 1.2 cm^2) glued in the bottom of the container was efficient in estimating nymphal densities within 20 to 30% C.V. based on 100 three-stem bouquets collected on each sample date. The adult sampling technique was efficient within 10 to 20% C.V. about the mean based on sixty 0.92 m^2 samples collected with a vacuum backpack insect collector (D-Vac ® manufactured by D-Vac Co., Riverside, Calif.).

Developmental rates for eggs and nymphs and ovipositional rates of adult females in laboratory studies were determined at several temperatures. Egg and nymphal development rate increased with increasing temperatures from 13 to 32°C. The development followed a linear relationship between upper and lower threshold levels. Oviposition rate was consistent between 18 to 29°C, but ceased above and below these temperatures.

Developmental rates and maximum-minimum daily temperatures were used to study the effect of alfalfa harvest on egg and nymphal abundance. Mortality was high after harvest, and harvest time was important in reducing potato leafhopper abundance. Clean harvest practices were also important in reducing egg and nymphal survival, and in reducing population buildup of potato leafhoppers on early regrowth of alfalfa.