DEVELOPMENT, IMPLEMENTATION, AND ECONOMIC EVALUATION OF AN INTEGRATED PEST MANAGEMENT PROGRAM FOR ALFALFA IN VIRGINIA

by

John Michael Luna

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY
in
Entomology

APPROVED:

F. W. Ravlin, Chairman

R. L. Pienkowski

W. A. Allen

G. I. Holtzman

D. D. Wolf

May, 1986

Blacksburg, Virginia

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ABSTRACT

Three sampling methods for estimating abundace of alfalfa weevil (AW) larvae (Hypera postica Gyllenhal) were evaluated for both accuracy and precision. Calibration equations were developed to convert intensity estimates of AW larvae among sampling methods.

Greenhouse experiments evaluating the interaction of moisture stress and defoliation by AW larvae indicated that yield response of alfalfa to AW feeding is dependent on moisture stress levels. Field studies on the influence of AW feeding on alfalfa confirmed the importance of moisture stress in alfalfa tolerance to weevil feeding. Quadratic regression models are presented to predict yield loss and changes in stem density as a function of weevil intensity.

A sequential sampling plan was developed and validated for use in pest management decision making. Validation of the plan indicated an average error rate of 1.8%, with the number of samples needed reduced by 55% in 1980, 53% in 1981, and 28% in 1982.

A net benefit analysis the Virginia Alfalfa IPM program indicated that growers participating in the program during 1981-84 realized an estimated averge increase in net revenue of $8.80 per hectare from the alfalfa weevil scouting program, and $28.13 per hectare from the potato leafhopper scouting program.

ACKNOWLEDGEMENTS

I wish to express my most sincere appreciation to Dr. F. W. Ravlin for guidence, encouragement, and willing assistance during the investigation and preparation of this dissertation.

I also would like to thank Dr. R. L. Pienkowksi, Dr. W. A. Allen, Dr. G. Holtzman, Dr. D. Wolf, and Dr. S. Poe for their encouragment, constructive criticism, assistance in experimental design and analysis, and editoral review.

I wish to acknowledge the contributions of to the research on sequential sampling for potato leafhopper, and thank Dr. L. Kok and Tom McAvoy for use of greenhouse space and equipment.

Special thanks are extended to the County Extension Agents who have been instrumental to the success of Alfalfa IPM program: J. McKenna, A. Strecker, S. Smith, W. Morse, E. Conklin, H. Roller, A. Hankins, R. Heltzel, D. Moore, G. Abbott, W. Brown, and M. Reynolds.

And it is with deepest gratitude that I thank my wife, for her patience and encouragement.

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CHAPTER I

INTRODUCTION

Alfalfa is an important forage crop for the Virginia dairy, beef and sheep industry, with an average of 91,000 acres harvested annually in the State between 1978 and 1983 (Dunkerley and Rowley 1984). As the "queen of the forages," alfalfa is particularly important to the dairy industry as a source of protein. With current prices for alfalfa hay ranging between $100 to $120/ton, and average annual yields of 2.76 tons/acre, the Virginia alfalfa crop is valued at approximately $25 - 30 million annually. Although most alfalfa is utilized "on-farm," there is an increasing cash crop market for quality alfalfa hay. Following the recent introduction of no-till seeding technologies, alfalfa acreage within the state is increasing rapidly.

However the picture has not always been so bright for alfalfa in Virginia. Following the first reported incidence of the alfalfa weevil, *Hypera postica* Gyllenhal, in the Eastern United States in 1952 (Bissell 1953), this pest spread quickly into Virginia, causing severe yield losses in alfalfa. Growers quickly adopted the practice of adding granular heptachlor to fall and winter fertilizer applications, and excellent control of the weevil was obtained. This control practice was convenient and inexpensive, and many fertilizer companies even provided free heptachlor as an incentive for fertilizer sales (R.

Pienkowski, pers. com.). But by 1962, numerous failures were reported where heptachlor was applied the preceding fall, and in 1963 weevil resistance to heptachlor was widespread in Virginia (Bishop 1964). At nearly the same time, unacceptable residues of heptachlor were discovered in milk samples, forcing the removal of this insecticide from weevil control recommendations.

Although other insecticides were available which would control weevil when applied during first cutting, alfalfa producers became discouraged with trying to control the weevil. Acreage in the state began to decline. By the mid 1970's, alfalfa acreage had fallen to approximately 75,000 acres, a dramatic drop from the 1960 peak of approximately 265,000 acres. However not all of this acreage decline was due to inability to control alfalfa weevil. Growers were concurrently converting considerable acreage to corn for high moisture silage, but the alfalfa weevil was an important factor in this acreage decline.

Rising soybean prices in the 1970's (soybean meal is a primary source of protein in feed rations) rekindled interest in alfalfa production in Virginia. Several insecticides were available for weevil control, and prophalactic treatment of alfalfa fields in the spring with carbofuran became widely practiced. By 1981, more than 90%

of the alfalfa producers in the state routinely sprayed for alfalfa weevil control (Luna 1982).

A second insect pest. the potato leafhopper (*Empoasca fabae* Harris) was also damaging alfalfa, but because of the damage symptoms, most growers and many Extension agents were diagnosing damage from this insect as boron deficiency. In a survey of alfalfa pest management practices conducted in 44 western Virginia counties in 1981 (Luna 1982), fewer than 5% of the 204 respondents reported the potato leafhopper as an economic pest. Yet this pest was known to be a primary pest of alfalfa in the northeastern United States and southeastern Canada. Alfalfa producers were familiar with the obvious defoliation from alfalfa weevil larvae, but they had a difficulty in connecting disease-like damage symptoms such as yellowing and stunting to an insect so small it was virtually invisible to the untrained eye.

The Alfalfa Integrated Pest Management Project

An Alfalfa Integrated Pest Management (IPM) Project was initiated in 1980 by the Virginia Cooperative Extension Service, with the following overall project goals:

1. Improve forage quality and increase production per acre of alfalfa in Virginia.
2. Increase return on investment to Virginia alfalfa growers.
3. Develop an integrated pest management (IPM) program which maximizes effectiveness of

biological and cultural control of key insect pests, minimizes reliance on chemical control, and accomplishes the general goals described in 1 and 2 above.

4. Evaluate the economic impact of this IPM program on Virginia alfalfa producers.

The following report is a description of the development, implementation, and economic evaluation of the Alfalfa IPM Program initiated in 1980. "Development" is used in this report to describe essentially research activities, usually oriented toward understanding biological interactions of the alfalfa agroecosystem, or solving technical problems of the IPM program, such as deriving sampling plans or economic thresholds. Chapter II concerns the evaluation of sampling methods for the alfalfa weevil; Chapter III examines the interaction of moisture stess and alfalfa weevil feeding on alfalfa yield in a greenhouse environment; and Chapter IV concerns field experiments evaluating the impact of alfalfa weevil feeding on alfalfa yield. Chapter V changes the focus to the potato leafhopper, and describes the development and validation of a sequential sampling plan for that insect.

"Implementation" implies the application of knowledge gained during the development process to the "real world," in which educational efforts are aimed at changing clientele behavior. Implementation and development are usually concurrent activities, however, with implementation often revealing program weaknesses that need additional research. Chapter VI is a description of the implementation of an IPM program for Virginia alfalfa growers. "Economic evaluation" is the assessment of economic benefits associated with these behavioral changes, and an net benefit analysis of the Virginia IPM program is presented in Chapter VII.

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CHAPTER II

Evaluation and Calibration of Sampling Techniques Used to Estimate Abundance of Alfalfa Weevil Larvae (*Hypera postica* Gyllenhal)

ABSTRACT

Three sampling methods for estimating abundance of alfalfa weevil (AW) larvae (*Hypera postica* Gyllenhal) were evaluated for both accuracy and precision. A plastic bag/Tullgren funnel method collected significantly fewer second, third, fourth instar and total larvae than did the bucket-shake method. Calibration equations were developed to convert intensity estimates of AW larvae obtained from the plastic bag/Tullgren funnel method to bucket-shake estimates. Sweep-net sampling produced significantly lower coeffients of variation than both bucket-shake and plastic bag/Tullgren funnel sampling methods, however mean estimates of larval abundance obtained from sweep-net sampling could be reliably converted to bucket-shake estimates for only fourth instar larvae.

INTRODUCTION

Several sampling techniques are commonly used by researchers and Integrated Pest Management (IPM) practitioners to estimate abundance of alfalfa weevil (AW) larvae (Hypera postica Gyllenhal) in alfalfa. Selection of a particular technique should be based on the sampling objectives and include considerations of accuracy (how well the sampling method estimates the actual population), precision (probabilty of error associated with the sampling estimate), and cost. Estimates of absolute density (number of individuals per unit area of soil) of AW larvae are usually derived by extracting larvae from alfalfa stems clipped from measured quadrat samples. Roberts et al. (1979) compared two systems for extracting larvae, a modified Tullgren funnel and a preservative, wash, hand sorting method, assumed to be the most accurate method. Statistically significant differences between mean estimates of larval densities using the two methods were reported for 20% of the 108 paired means in the experiment, with each method giving higher estimates in about half of the cases of different mean estimates. These authors concluded the modified Tullgren funnel is an acceptable technique for extracting weevil larvae. Smart et al. (1985) mentioned a study comparing Tullgren funnel extraction with manual examination of foliage which indicated the Tullgren funnel was an "adequate" method, however no supporting data were presented. Guppy et al. (1975) used a modified Tullgren funnel to estimate larval intensities for development of fixed-precision sampling plans for AW larvae, however no evaluation was made of the sampling method.

Another sampling method, in which alfalfa stems are pulled into a bucket and shaken to dislodge the weevil larvae (henceforth called the "bucket-shake" technique), has been widely used in IPM programs in several states (Wedberg 1977; Gesell et al. 1984; Luna 1985). This method is a modification of the pan technique (Blickenstaff and Huggens 1969) in which alfalfa stems are bent over a shallow pan and shaken to dislodge larvae. The bucket-shake method usually involves collecting from 10 to 30 alfalfa stems into a bouquet before shaking, and is presumably more efficient than the pan method because the stems can be beaten vigorously against the side of the bucket to dislodge larvae contained from the alfalfa foliage. Legg et al. (1985) compared larval estimates obtained from bucket-shake sampling with total larval estimates obtained by visually inspecting the alfalfa tips after they had been shaken in the bucket and adding these to the bucket-shake estimates. Although no significant differences were detected in mean estimates, the bucket-shake method underestimated absolute stem intensities by 0.04 to 0.08 larvae per stem. These authors considered this error so small as to seldom be of consequence.

Although sweep-net sampling has been widely used and recommended as a standardized sampling method for AW larvae

(Blickenstaff 1966; Armbrust et al. 1969), several authors have demonstrated the inadequacies of the sweep-net for estimating absolute larval densities (Blickenstaff and Huggans 1969; Cothran and Summers 1972). According to Cothran and Summers (1972), relative density estimates obtained from sweep-net sampling cannot be converted to absolute density estimates, and suggest that many population studies utilizing the sweep-net "fail significantly to describe accurately the actual population pattern."

The following study was initiated to accomplish the following objectives: evaluate and compare three sampling methods for estimating abundance of AW larvae: bucket-shake, sweep-net, and a plastic bag/Tullgren funnel method, and calibrate these methods wherever possible.

MATERIALS AND METHODS

Data were collected from seven commercial alfalfa fields in 1985 in three Virginia counties (Bedford, Rockbridge, and Augusta) in conjunction with another experiment evaluating the impact of AW defoliation on alfalfa yield (Chapter IV). In that experiment a randomized block design was used, with four replications, six treatments, and 9.1 m x 9.1 m plots. Two of the treatments in each field were unsprayed controls, and sampling data for the research reported here were taken from these plots. Alfalfa stem lengths ranged from 12 to 55 cm during the experiment, and AW intensities ranged from 0.18 to 1.54

total larvae per stem (estimated using the bucket-shake method). The following is a description of the sampling methods used to estimate abundance of AW larvae.

Plastic bag/Tullgren funnel extraction method

As mentioned earlier, absolute density estimates usually involve extraction of larvae from a measured quadrat. Armbrust et al. (1969) suggested the collection of stems randomly within a research plot, however, which would generate weevil intensity per stem, rather than absolute density per unit area of land. Conversion of larval intensity per stem to absolute density can be made by multiplying larval intensity by the density of alfalfa stems per unit area, if this latter value is known. This method incorporates additional error, however, since the final estimate is the product of two means, each with an associated error term. Alfalfa stem density can be quite variable (see Chapt. IV, Fig. 8). Larval intensity per alfalfa stem was estimated for this sampling method comparison study for three reasons: (1) larval intensity estimates are the estimates derived from bucket-shake sampling in IPM programs, (2) larval intensity estimates are currently being used in the defoliation impact study mentioned above, and (3) larval intensity per stem is directly proportional to the absolute density per unit area, however this proportion is variable.

Plastic bag/Tullgren funnels samples were obtained by selecting 20 alfalfa stems within each plot, and carefully plucking them tip-first into a 20 by 40 cm plastic bag. Stems to be sampled were selected using a "systematic sampling" method in which the sampler took 2 paces (ca 1.75 m) from the plot border, reached down into the foliage without looking and selected the first stem contacted. Additional stems were similarly selected by advancing in a circular path within the plot, with 2 paces separating each sample site. According to Legg et al. (1985), systematic sampling for weevil larvae gives comparable results to simple random sampling using totally randomly selected sample sites, but is much easier and faster to use than simple random sampling.

Plastic bags from each field were placed in an ice chest until returning to the laboratory for processing. Samples were placed in modified Tullgren funnels similar to those used by Roberts et al. (1979) and larvae were collected in jars containing 70% ethanol. Samples remained in the funnels for ca. 24 hours. Larvae were sorted to instar and counted. This sampling method will henceforth be referred to as the "Tullgren funnel" method.

Although larval intensity data using the Tullgren funnel method were taken on 3-4 day intervals throughout the first growth of alfalfa, bucket-shake and sweep-net sampling was conducted on an irregular basis, depending on available labor and favorable weather. However bucket-shake and sweep-net sampling were always conducted on the same day and approximately the same time of day as the Tullgren funnel method. On each sample date for the three sample methods, 8 samples per field were taken using the Tullgren funnel and the bucket-shake methods, and 10 samples were taken using the sweep-net.

Bucket-Shake Method

Ten alfalfa stems per plot were randomly selected (using the same systematic random procedure as for the Tullgren funnel method) and pulled tip-first directly into a 30 cm dia, 19 liter bucket. The bottoms of the stems were gathered and the stems were shaken vigorously for ca. 10 seconds. A clipboard was placed over the top of the bucket while shaking to minimize loss of larvae. Larvae were poured into a jar containing 70% ethanol for later counting.

Sweep-net sampling

Because of the tendency of sweep-net sampling to remove an insect population and because of the relatively small size of the plots, sweep-net sampling was conducted in a 10 meter wide area surrounding the experimental block. Only one of the fields involved in this experiment was sprayed for weevil control, and sweep-net sampling was not conducted in this field after it was sprayed. A 37 cm dia. muslin sweep-net was used with a pendulum sweeping motion

(Cothran et al. 1975) and 10 sweeps per sample. Sweep-net contents were poured into 70% ethanol for later processing.

Analytical Procedures

Bucket-shake and Tullgren funnel sampling methods were compared by conducting T-tests of mean estimates of AW larvae by instar for each field and date in the experiment. Average mean estimates for each sampling method were compared using a paired-comparison T-test with means from each field and sample date. Linear regression analysis was used to develop calibration models to convert mean estimates obtained from Tullgren and sweep-net sampling to mean estimates obtained from bucket-shake sampling. Linear regression analyses were conducted (SAS-GLM procedure, Goodnight 1982) using sample means for each field and sample date on which sampling was conducted. Separate regression analyses were performed for each larval instar and for total larvae (four instars inclusive). In these analyses, mean estimates from the bucket-shake method were used as the independent variable and mean estimates from the other two sampling methods were the dependent variables.

Precision, the second criteria for evaluating sampling methods, was estimated by calculating the coefficient of variation (CV) (Steele and Torre 1960) by sampling method and larval instar for each field and sample date. Average CV's for each sampling method and instar were computed and compared using a distribution-free multiple comparison test based on Friedman's rank sums (Hollander and Wolf 1973).

Although cost, particularly in terms of labor requirements, is an important consideration in sampling method evaluation, detailed cost data were not taken in this study. Generally the Tullgren funnel method took considerably longer than the other methods because of additional handling time in transporting the samples to the Tullgren funnel facility and in loading and unloading the funnels. Total number of samples taken per day is limited by the number of available Tullgren funnels. Field time required for bucket-shake and sweep-net sampling were comparable, however more time was needed to sort and count the larger number of larvae collected from sweep-net sampling.

RESULTS AND DISCUSSION

Mean estimates of AW larval intensity obtained using the Tullgren funnel method differed significantly (alpha = 0.05) from bucket-shake sampling estimates in 14 to 21 percent of the fields, depending on larval instar (Table 1). Estimates of total larvae per stem differed in 28 percent of the fields. Average differences in mean estimates using the two methods were significantly different from zero ($p < .05$) for total larvae and all instar except first instars (Table 1). The Tullgren funnel method underestimated AW larval intensities in most fields, with an average error of 24.6

Table 1. Comparison of mean estimates of intensity of alfalfa weevil larvae per stem obtained from bucket-shake and plastic bag/Tullgren funnel sampling.

Instar	% of total fields in which sampling methods gave significantly different means[a]	Average difference in mean estimates	P-values	Ave % deviation from bucket-shake estimates obtained by the Tullgren method	S.E.
First	17	-0.130	0.164	147.9	113.6
Second	21	0.038	0.0429	-16.4	21.4
Third	14	0.063	0.005	-14.1	13.1
Fourth	21	0.123	0.031	-33.2	11.6
Total	28	0.210	0.003	-24.6	5.3

[a] Alpha = .05, using unpaired T-test.

percent for total larvae, and errors ranging from 14.1 to 33.2 percent for second through fourth instar larvae (Table 1). Underestimation of AW population levels using the Tullgren funnel method could result from larval mortality occuring in the plastic bag prior to loading into the Tullgren funnel (sometimes a 6-9 hour delay) or inside the Tullgren funnel itself from heat and dessication.

Regression coefficients of determination (R^2) (Table 2) indicate simple linear regression model can be used to convert mean estimates obtained from the Tullgren funnel method to bucket-shake sampling estimates for all stages except first instar (regression coefficients are presented in Table 2). Sweep-net sampling gave fairly good prediction of numbers of fourth instar larvae $P = 0.001$, $R^2 = 0.75$), however prediction of mean estimates of total larval was poor, and prediction of other larval stages was very poor (Table 2).

Although the sweep-net gave generally poor estimates of absolute weevil intensities (estimated by the bucket-shake method), the sweep-net was significantly more precise (as indicated by lower average coefficients of variation) than either the bucket-shake or the Tullgren funnel method for third and fourth instar larvae and for total larval numbers (Table 3). This is most likely due to the contagious distribution of AW larvae among stems at the fairly low population levels encountered in this study (Christensen et

Table 2. Regression parameters for predicting mean number of alfalfa weevil larvae per alfalfa stem (obtained from bucket-shake sampling) from mean estimates of larvae per stem obtained from plastic bag/Tullgren funnel sampling and from mean number of larvae per sweep obtained from sweep-net sampling.

Sample method	Instar	P-values of regression model	R^2	Linear regression coefficients[c] b_0	b_1
Tullgren	1st	0.261	0.104	---	---
funnel[a]	2nd	0.001	0.591	---	1.454
	3rd	0.001	0.826	---	1.104
	4th	0.001	0.618	---	1.326
	Total	0.001	0.670	---	1.138
Sweep-net	1st	0.042	0.323	---	0.445
	2nd	0.115	0.210	---	---
	3rd	0.141	0.186	---	---
	4th	0.001	0.746	---	0.072
	Total	0.017	0.419	0.370	0.051

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[a] Number of paired observations in regression: Tullgren funnel = 15; sweep-net = 14.

[b] Computed by SAS-GLM Procedure.

[c] Model: y = a + bx, where y = mean number of larvae per stem estimated from Bucket-shake sampling, x = mean number of larvae per stem from plastic bag/Tullgren funnel *or* mean number per sweep. b_0 = intercept, and b_1 = slope. Regression coefficients listed only for significant regressions (alpha = .05): Intercept values listed only if significantly different from zero.

Table 3. Relative precision of three sampling methods used to estimate abundance of alfalfa weevil larvae.

	Mean coefficients of variation			
	sample method			
Larval instar	Sweep-net	Bucket-shake	Tullgen funnel	n[1]
First	168	203	134	7
Second	64	98	97	10
Third	43 a[2]	81 b	72 b	12
Fourth	39 a	81 b	72 b	11
Total Larvae	32 a	55 b	46 b	12

---

[1] Number of sets of matched observations (blocks) used for multiple comparison tests.

[2] Means followed by different letters within a row are significantly different at alpha = .05 (Friedman's Rank Sums).

al. 1977). Since the sweep-net is a volumetric sampling method, sweeping literally thousands of individual alfalfa stems per sample, inter-stem variability in larval intensity would not be an important source of variability in sample results.

The plastic bag/Tullgren funnel sampling method significantly underestimated population levels of AW larvae when compared to estimates obtained from bucket-shake sampling. This underestimation was reasonably consistant, however, and calibration equations are presented to convert Tullgren funnel estimates to bucket-shake estimates. Although sweep-net sampling can be used to give fairly reliable estimates of fourth instar larval intensity per alfalfa stem, sweep-net sampling is not recommended for estimation of abundance of other larval instars and total number of larvae. Although a number of investigators continue to use sweep-net sampling in order to compare results with data gathered in previous years, results of this experiment support the conclusions of Blickenstaff and Huggans (1969) and Cothran and Summers (1972) that sweep-net sampling is inappropriate for estimating abundance of AW larvae.

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CHAPTER III

Influence of Moisture Stress and Alfalfa Weevil Defoliation on Alfalfa Growth

Development of dynamic economic injury levels for pest management decision making necessitates an understanding of crop growth response to many environmental factors, as well as to the particular pest species of interest. Many agronomic crops, such as soybean, potato and alfalfa, tolerate moderate levels of insect defoliation without significant yield loss. This tolerance is often based on compensatory physiological mechanisms by the plant which are dependent upon environmental conditions such as soil fertility and available soil moisture (Painter 1951).

The importance of moisture stess in limiting crop growth is a well-documented phenomenon, and reviews of the extensive literature on water stress effects are provided by Crafts (1968) and Hsiao (1973). Response of alfalfa to moisture stress has been reported by Carter and Sheaffer (1983) and Abdul-Jabbar et al. (1985). Although a comparably extensive literature exists concerning the influence of alfalfa weevil (AW), _Hypera postica_ Gyllenhal, feeding on alfalfa growth (see Chapter IV), there has been no reported work examining the interaction of moisture stress and AW defoliation on alfalfa growth and yield.

During the development and implementation of an integrated pest mangagement (IPM) program for alfalfa growers in Virginia in 1980-82 (see Chapter VI), observations were made indicating the need to incorporate some index of available soil moisture in pest control decision-making guidelines for the alfalfa weevil. The action threshold used for decision making in this program was adapted from Gesell (1978) and contained two variables, the average stem length of alfalfa within a field and the average number of alfalfa weevil per alfalfa stem. In wet, rainy springs, the alfalfa appeared to be better able to tolerate a given AW population level than in dry seasons. These empirical observations prompted the following study to evaluate the combined influence of moisture stress and defoliation by AW on alfalfa growth.

MATERIALS AND METHODS

Experiment 1.

The purpose of this experiment was to examine the influence of initial tap root weight on alfalfa growth. Dormant eight-month old alfalfa plants (Var. = Saranac AR) were dug from a field near Blacksburg, VA, on Feb. 25, 1983. Plants were wrapped in moist newspaper and taken to a greenhouse where they were washed, air dried for ca. 10 min. and weighed to the nearest 0.1 g. Sixty plants were transferred to 18 cm dia by 22 cm deep plastic pots containing a potting mix of 2:2:1:1 peat, vermiculite, perlite, and weblite. Soil was watered to saturation every 3-4 days until the plants were harvested on April 25. All leaflets were removed from each plant and placed in paper bags. The remaining stems were clipped ca. 2.5 cm above the soil line, and leaflets and stems were dried for 24 hours at 58° C, and weighed. Prior to harvest the number of stems per plant (stem density) equal to or longer than 5 cm was counted. Linear regressions were conducted using leaf, stem, total plant weights, and leaf/stem weight ratios as the dependent variables and initial tap root weight as the independent variable.

Experiment 2.

The purpose of Experiment 2 was to evaluate the influence of moisture stress on alfalfa response to feeding by the alfalfa weevil. Alfalfa plants were dug on March 23, 1983, from the same field as for Experiment 1 and initial root weights were determined similarly. Three plants were transplanted into 25 cm dia x 25 cm deep plastic pots with a potting mix consisting of a clay loam soil mixed with peat and vermiculite in a 10:2:1 ratio. Plants were arranged in a triangle within the pots (125 total pots), each plant separated by ca. 8 cm. Each plant within a pot was numbered with a small wooden stake in the soil and each pot was also numbered. Plants were watered to runoff every 3 to 4 days and fertilized on April 19 with 2 g/pot of Peters^R 15-30-15 fertilizer. A few alfalfa weevil larvae began appearing on the potted plants soon after bringing them into the greenhouse, and all plants were sprayed with a synergized pyrethrin (Raid^R) on April 11. On April 12, the three longest stems on each alfalfa plant were labeled by looping a 3 mm wide piece of colored plastic tape around the base of the stem. Lengths of these same three stems on each plant were measured every 4 to 6 days until plants were harvested.

A 3 x 5 factorial experiment was established on April 27 with three levels of moisture stress (high, medium, and low) and 5 levels of insect intensity (0, 2, 3, 4, and 5 per stem), with 6-8 replications (pots) of three plants per pot for each treatment. One hundred pots containing the most uniformly growing plants were selected for the experiment and treatments were randomly assigned to the pots. Each weevil treatment contained 20 pots, with each moisture stress level within weevil treatments containing 6-8 pots. Each set of moisture stress treatments within weevil treatments was randomized on the greenhouse benches. Pots were placed close together on the benches, but separated to prevent touching of alfalfa foliage between pots.

Alfalfa weevil larvae were obtained by picking alfalfa stems from a nearby alfalfa field on April 26 and placing in modified Tullgren funnels for 24 hr. Fresh alfalfa was placed in collection jars under the funnels. The next day camel's hair brushes were used to place small larvae (ca.

2nd instar) on the potted alfalfa plants at the designated treatment densities.

Moisture stress levels were obtained by withholding water from the pots for varying time intervals. At each irrigation, pots were watered to saturation. Low moisture stress treatments received irrigation on April 26, April 30, May 4, and May 10; medium stress treatments were watered on May 2, May 6, and May 10; and high moisture stress treatments were watered only on May 4.

A non-destructive, relative sampling method was used to estimate total leaf area of one tagged stem per plant on a weekly interval. This method is described as follows: (1) a simple leaflet size-class gauge was made from card-stock which represented the average large and small leaflet sizes encountered on alfalfa plants (Fig. 1), (2) the center leaflet of each alfalfa trifoliate leaf on the selected stem was compared to the "leaflets" on the gauge to classify the leaflets into a small, medium, or large leaflet catagory (the "medium" catatory was any leaflet that was between the small and large sizes), and (3) the total number of leaflets of each size class per stem was recorded. Total leaf area per stem was then estimated by summing the products of the number of each leaflet size class multipled by the known area of the leaflet gauges (small = 1.1 cm^2, large = 3.6 cm^2, with the medium size-class designated as the mean of the small and large leaflet size classes). This leaf area

Fig. 1. Gauge used to estimate leaflet size classes, used for estimating total leaf area per stem of alfalfa.

estimation technique was a relative sampling method intended for comparing treatment effects, not estimating actual leaf area.

Prior to harvest, the number of stems per plant (called stem density in this discussion) was determined by counting all stems longer than 10 cm. All treatments were harvested on May 13 as described for Experiment 1. For the one stem on each plant for which leaf area measurements were being taken, leaflets were removed from the stems, and leaflets and stems weighed separately.

Because of suspected movement of alfalfa weevil larvae among plants within a pot, all data analyses were performed on per plant means for each pot. Analysis of covariance was conducted to examine the influence and interactions of treatments and initial tap root weight on alfalfa yield, stem density, and leaf area, and leaf/stem ratios. Where initial tap root weights significantly influenced response variables, mean values for response variables were adjusted to account for this influence (Steele and Torre 1960; Goodnight et al. 1982)). Pairwise comparison of adjusted means are based on least square means tests (Goodnight et al. 1982).

RESULTS AND DISCUSSION

Experiment 1.

Regression analysis revealed highly significant correlations between tap root weight and yield components

(Table 1 and Fig. 2). More than half of the variation in yield could be attributed to variation in initial tap root weight. Stem density per plant was highly correlated with intitial tap root weight ($p = .0001$), however the fit of a linear regression model to the data was rather poor ($R^2 = .22$)

Experiment 2.

Factorial analysis of variance of weevil intensity and moisture stress indicated no significant (alpha = 0.05) interactions for any of the response variables measured. Weevil/moisture stress interactions were significant ($p = .09$) for leaf area only at harvest time. Initial weight of the alfalfa tap root was also a significant factor in yield and stem density, but not in leaf area. Although moisture stress and weevil intensity did not exhibit significant interaction in the analysis of variance, moisture stress significantly altered the crop response to weevil feeding.

Leaf Area: Both medium and high levels of moisture stress significantly ($p<.02$) reduced final leaf area at time of harvest compared to low moisture stress treatments, however leaf area response to medium and high moisture stress treatments was very similar (Fig. 3). It should be emphasized that the irrigation schedules used to impose moisture stress levels were rather arbitrary. Ideally the "medium" moisture stress treatment would produce

Table 1. Influence of initial tap root weight of alfalfa on yield components.

Yield component	N	P-values	R^2	Regression Coefficients[a] b_0	b_1
Leaf weight	60	.0001	0.51	0.529	0.061
Stem weight	60	.0001	0.48	0.215	0.056
Total Plant weight	60	.0001	0.53	0.747	0.116
Stem density	60	.0002	0.22	3.516	0.212

[a] Linear regression model, $Y = b_0 + b_1X$, where Y = yield component, b_0 = intercept, and b_1 = slope, and X = initial tap root weight. All units are grams per plant.

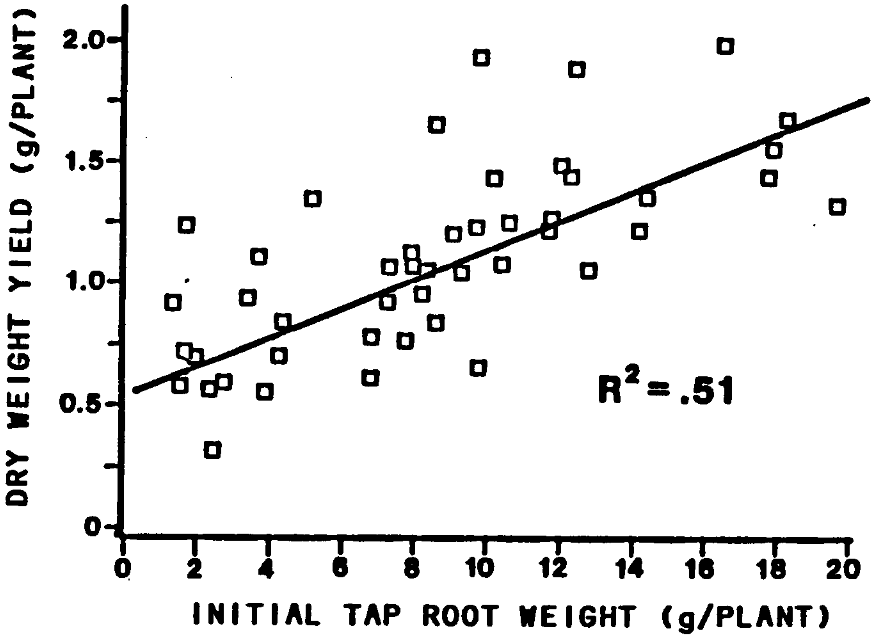

Fig. 2. Influence of initial tap root weight of alfalfa plants on forage yield of alfalfa.

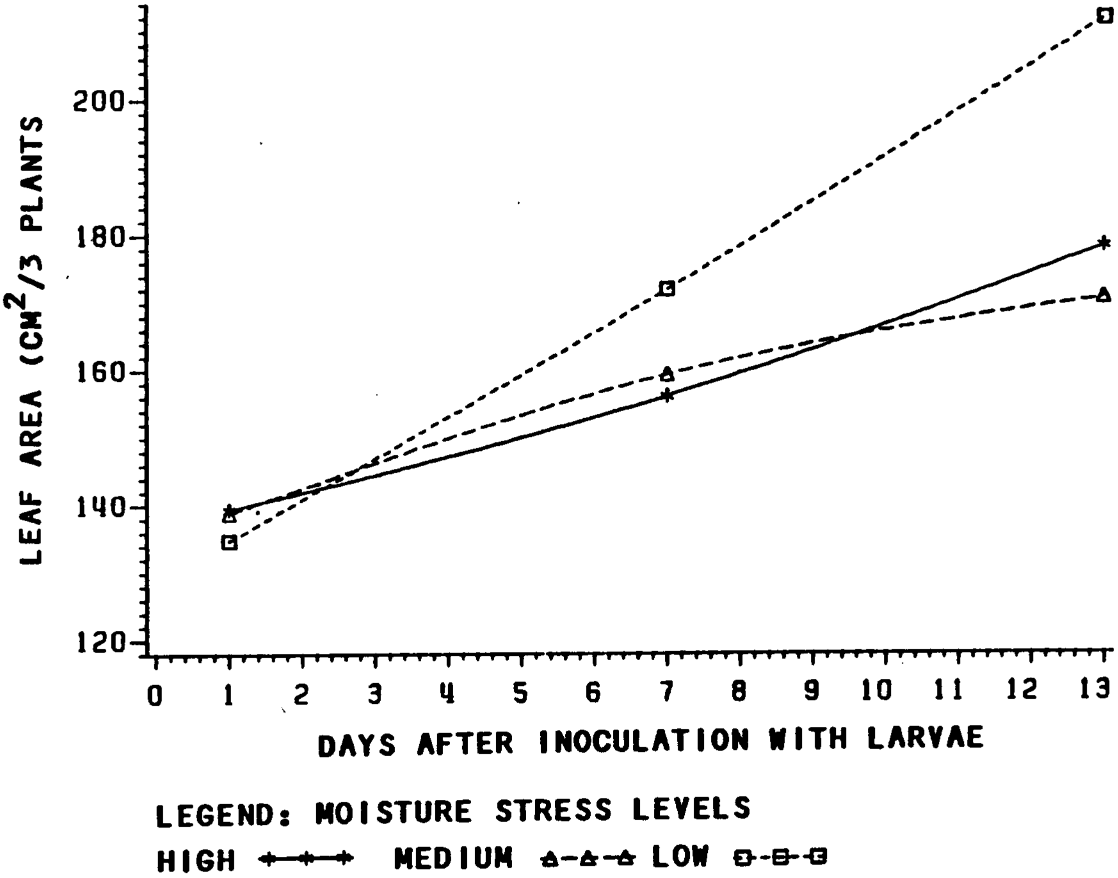

Fig. 3. Moisture stress effects on leaf area, pooled across weevil intensity levels.

intermediate moisture stress levels in the plant, however this was not controlled by the experimental treatments.

Leaf area response to weevil intensity (pooled across all moisture stress levels) was highly significant ($p < .02$) on all three sample dates (Fig. 4). Moisture stress had nonsignificant influence on leaf area response to weevil feeding on dates 1 and 7, however effects were significant ($p = .02$) on date 13 (Fig. 5A-C). Although increasing weevil intensity generally decreased leaf area in all three moisture stress levels, the similarity between 0 and 4 LPS on day 13 is rather surprising and unexplainable.

Stem Density

High and low moisture stress treatments produced significant differences ($p = .006$) in the number of stems per alfalfa plant (Table 2), however no differences between low and medium or medium and high moisture stress treatments were detected (alpha = .05). No significant differences (alpha = .05) were detected in stem density among weevil intensity treatments as weevil treatment levels increased from 0 - 2 LPS, but weevil levels greater than 3 LPS caused significant decreases in stem density compared to 0 and 2 LPS (Table 3). The reduction in stem density in response to moisture stress is reflected in the production of stems by the plant in response to weevil feeding (Fig. 6). The change in stem density with the change in weevil intensity per stem (slope) is similar for high and low moisture stress levels.

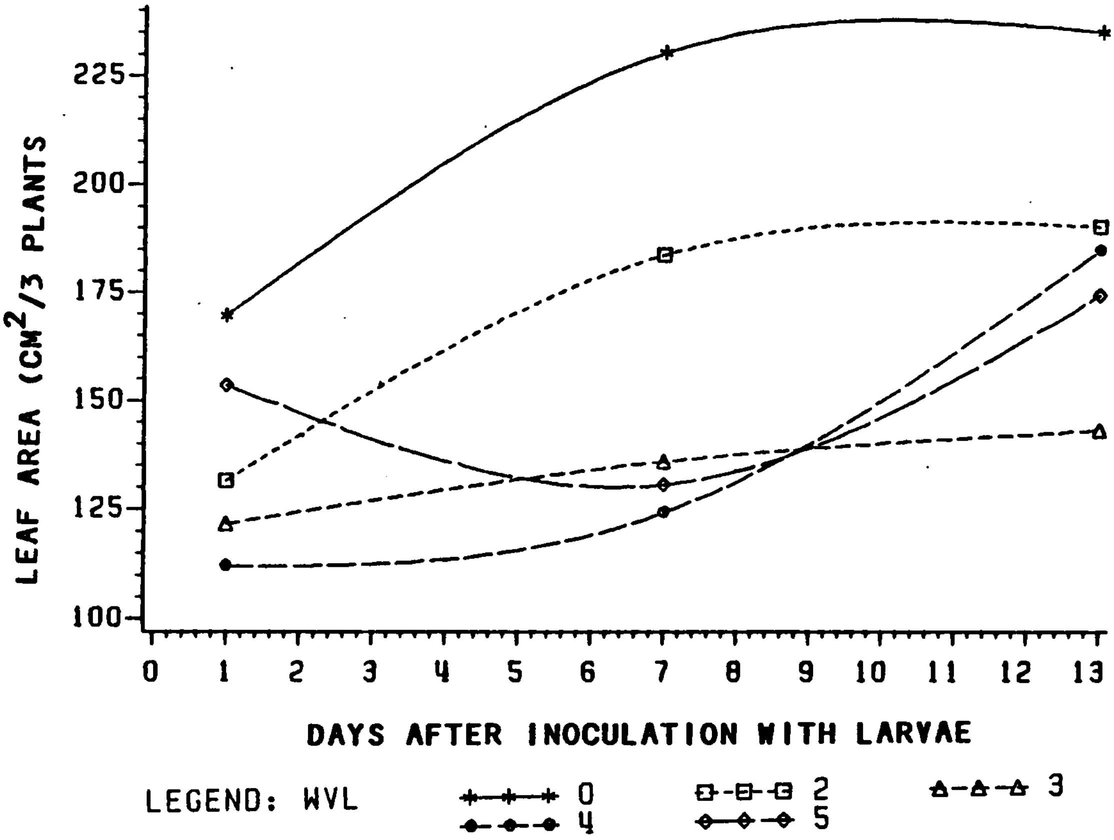

Fig. 4. Weevil intensity effects on leaf area, pooled across moisture stress levels.

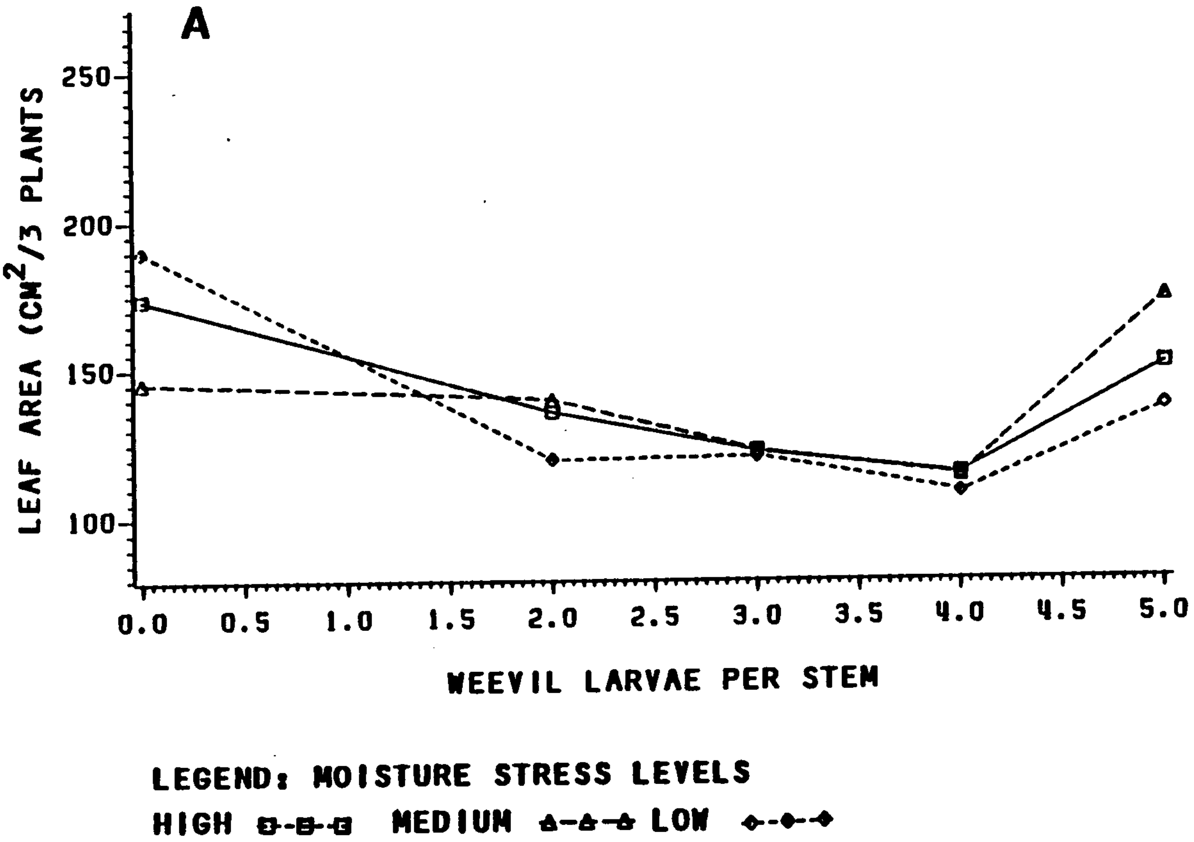

Fig. 5A. Moisture stress effects on leaf area response to weevil feeding (one day after inoculation with weevil larvae).

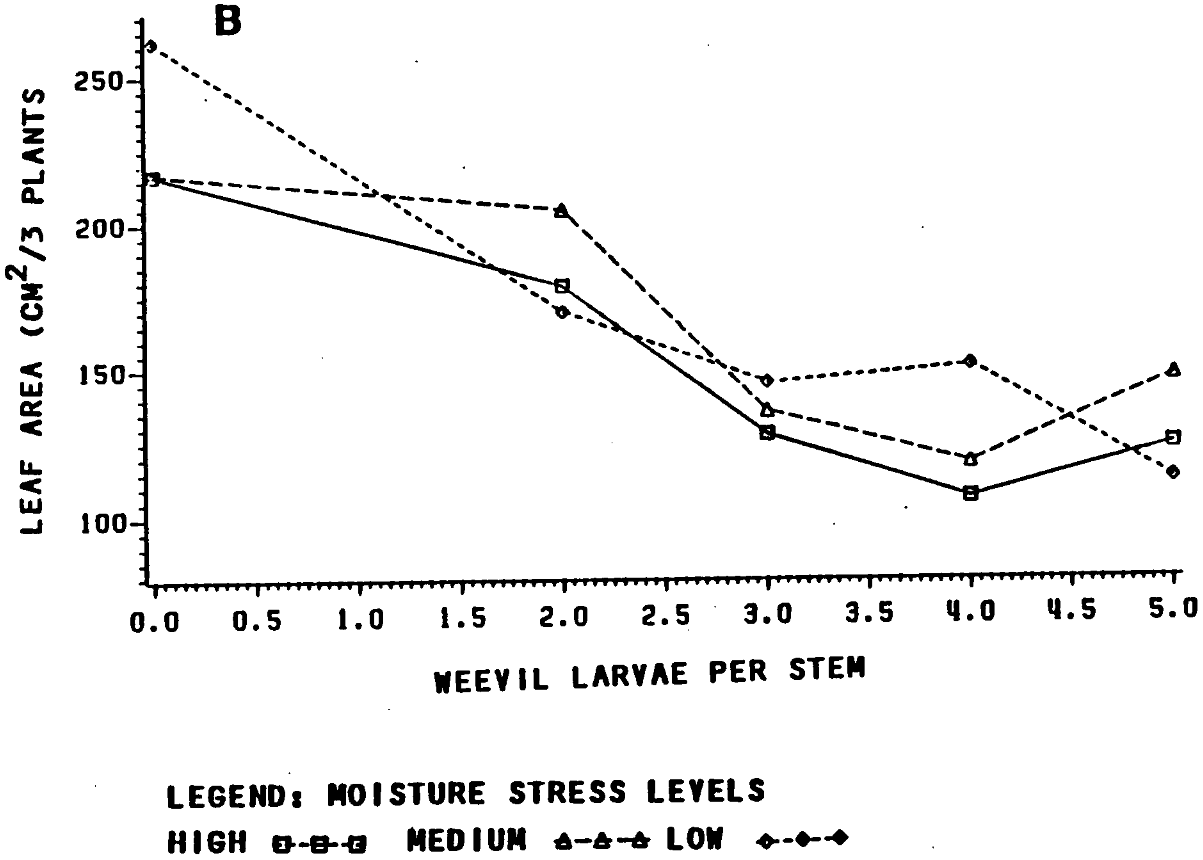

Fig. 5B. Moisture stress effects on leaf area response to weevil feeding (7 days after inoculation with weevil larvae).

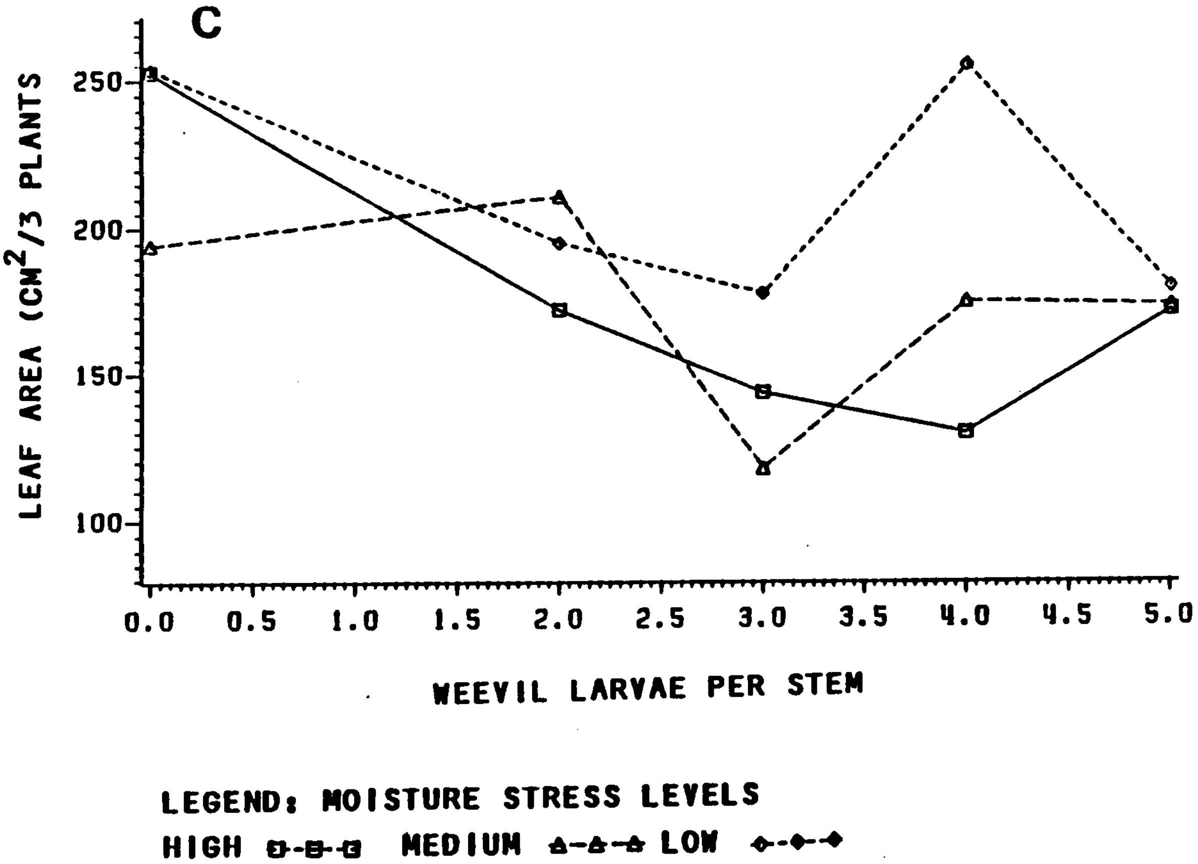

Fig. 5C. Moisture stress effects on leaf area response to weevil feeding (13 days after inoculation with weevil larvae).

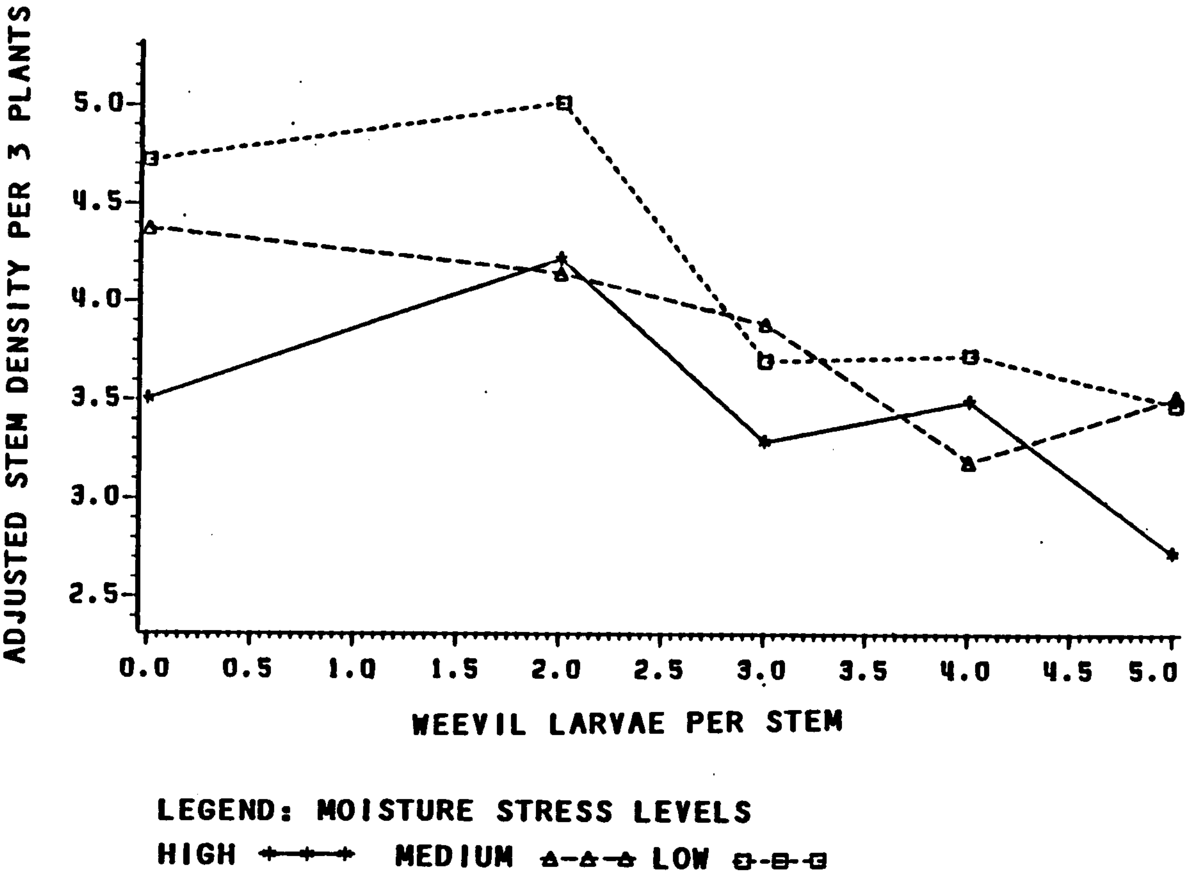

Fig. 6. Influence of moisture stress on alfalfa stem production in response to changes in intensity of alfalfa weevil larval infestation.

Table 2. Influence of moisture stress on number of stems per alfalfa plant (pooled across all weevil intensity treatments).

Moisture stress level LSMean(J)	Adjusted mean number of stems per plant[1]	STD ERR	prob. > |T| H_0: LSMean(I) =			
			I/J	1	2	3
High	3.47	0.16	1	.		
Medium	3.82	0.17	2	0.135	.	
Low	4.14	0.17	3	0.006	0.176	.

[1] Means adjusted to account for differences in initial root weights of alfalfa (Proc GLM/LSMeans: Goodnight et al. 1982).

Table 3. Effects of weevil infestation intensity on number of stems per alfalfa plant (pooled across all moisture stress levels).

No. weevil larvae /stem	Adjusted mean number of stems per plant[1]	STD ERR	Prob. > $\lvert T \rvert$ H_0 : LSMean (I) = LSMean (J)					
			I/J	1	2	3	4	5
0	4.17	0.23	1	.				
2	4.46	0.21	2	0.339	.			
3	3.64	0.21	3	0.096	0.007	.		
4	3.54	0.23	4	0.057	0.004	0.760	.	
5	3.24	0.21	5	0.004	0.001	0.191	0.322	.

[1] Means adjusted to account for differences in initial root weights of alfalfa (PROC GLM/LSMEANS : Goodnight et al. 1982).

The different slope shown by the medium moisture stress treatment is most likely due to the irrigation regime used for the medium stress treatment.

Yield

No treatment effects were detected in the analysis of variance of leaf weight to stem weight ratios, thus total plant yields were used in the analyses. Following trends shown already for other response variables, both high and medium moisture stress levels reduced yield below the low moisture stess level, with no significant differences (alpha = .05) detected between high and medium moisture stress levels. Linear regression using adjusted mean yield as the dependent variable and weevil intensity as the independent variable gave fair predictibility ($R^2 = 0.66$, $p = 0.09$) of yield change as a function of weevil intensity (Fig. 7).

Moisture stress significantly influenced alfalfa yield response to weevil feeding, with high moisture stress levels significantly (alpha = .05) reducing yield below low moisture stress treatments for all levels of weevil densities (Fig. 8). Regression analyses of adjusted yield vs. weevil intensity for each moisture stress level indicated a significant slope coefficient and good predictive capability for the low moisture stress treatment (Fig. 9), but not for medium and high moisture stress treatments (Table 4).

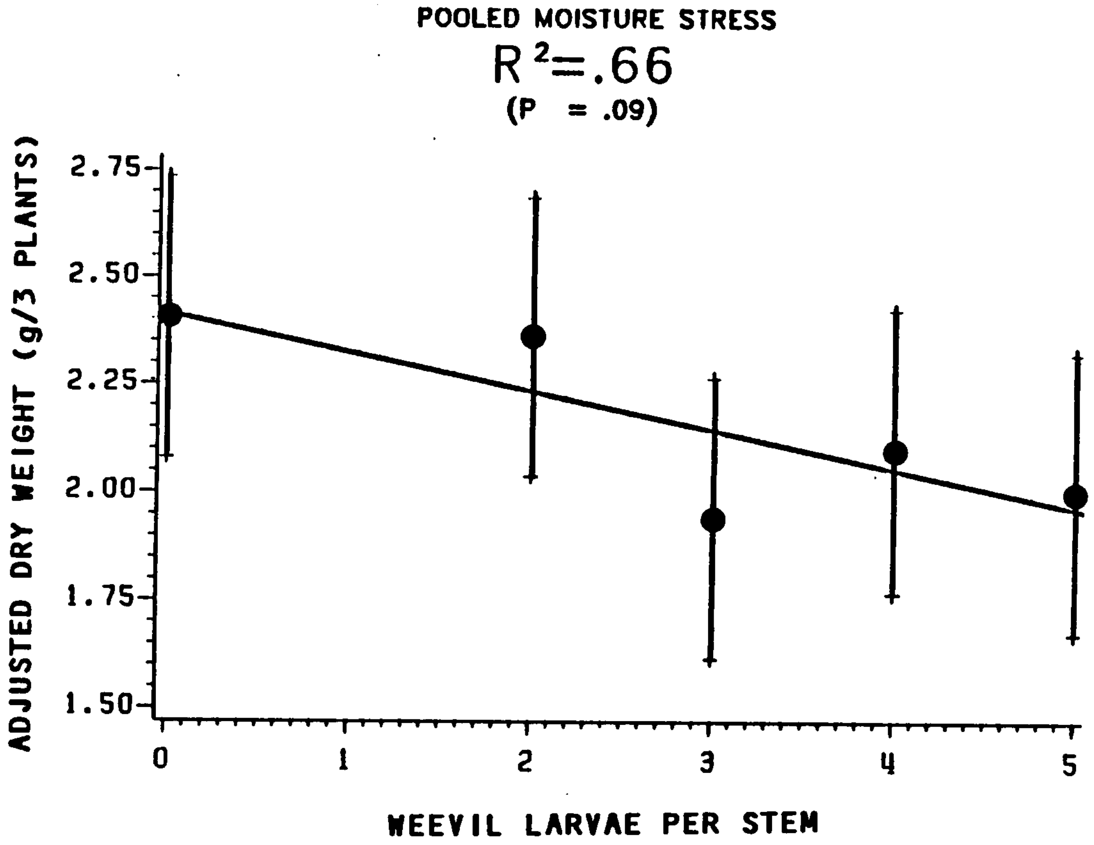

Fig. 7. Prediction of yield as a function of weevil intensity: pooled moisture stress levels (vertical bars are 95% confidence intervals).

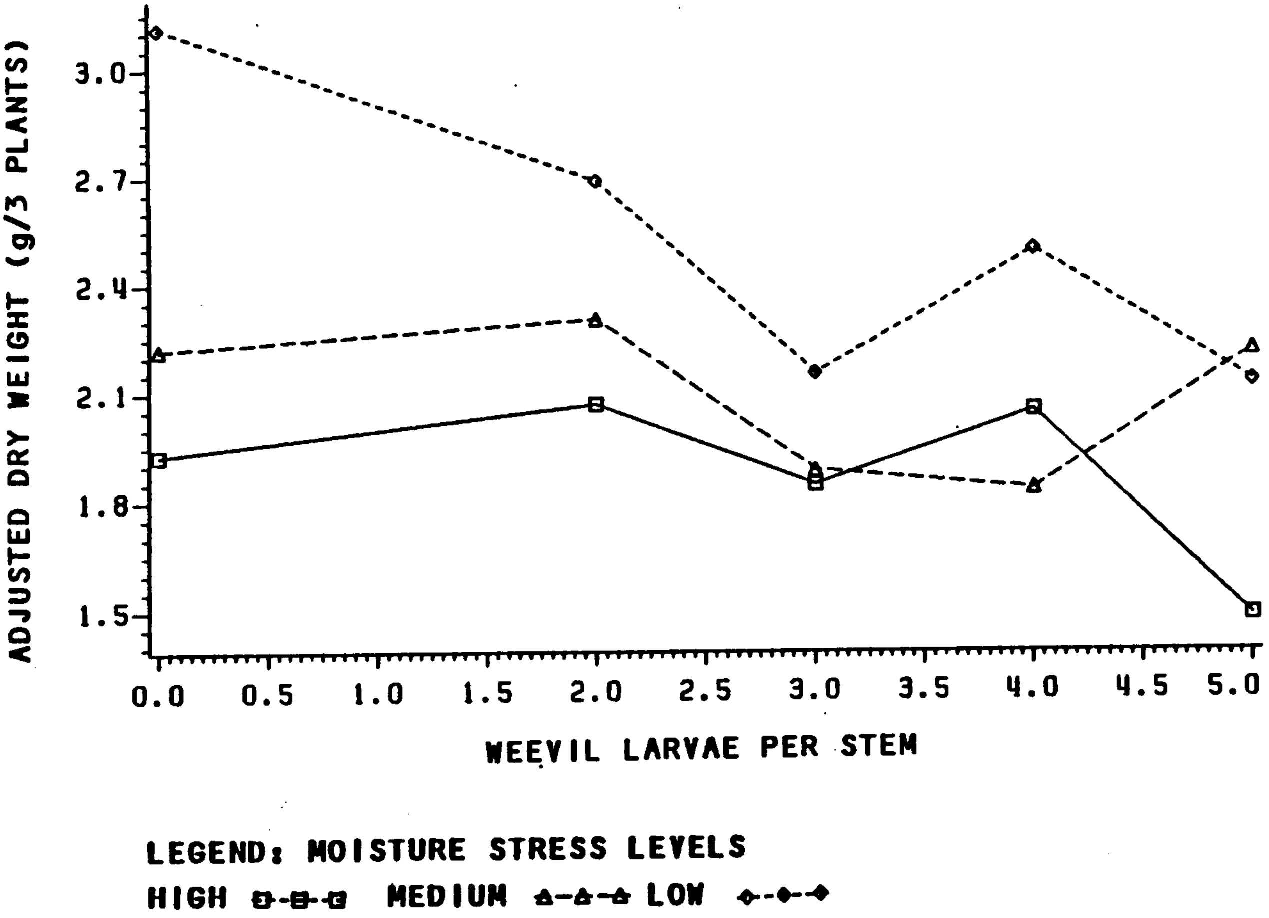

Fig. 8. Influence of moisture stress on alfalfa yield response to changes in intensity of alfalfa weevil larval infestations.

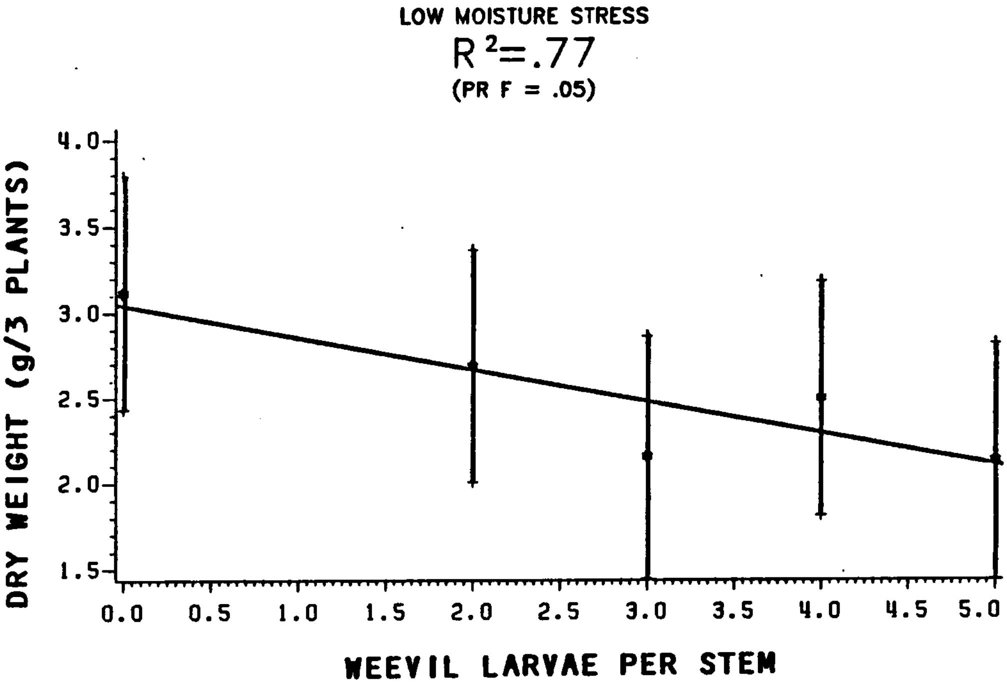

Fig. 9. Prediction of yield as a function of weevil intensity: low moisture stress levels (vertical bars are 95% confidence intervals).

Table 4. Regression coefficients for predicting yield loss from weevil intensity per stem.

Moisture stress	P-value	R^2	Regression coefficients[a] b_0	b_1
Pooled	0.094	0.66	2.413	-0.09
Low	0.051	0.77	3.038	-0.186
Med	0.550	0.13	2.206	-0.04
High	0.365	0.27	2.057	-0.06

[b] Linear regression model, $Y = b_0 + b_1X$, where Y = yield (g/3 plants), b_0 = y-intercept, and b_1 = slope, and X = number of weevil larvae per stem.

The yield-loss models presented above describe yield reponse for alfalfa grown in containers under greenhouse conditions, and are not intended for extrapolation to field conditions. These experiments clearly indicate, however, the importance of including a moisture stess factor in development of yield loss models and economic injury levels. For field use, a simple classification of fields between "high" or "low" moisture stess could greatly improve the accuracy of decision-making for weevil control. Additional field studies are needed in which yield response to weevil feeding is quantified under measured levels of moisture stress or soil moisture availablity.

These experiments also indicated a need to incorporate initial tap root weight as a parameter in a yield-loss model. These data could possibly be obtained by taking a sample of alfalfa tap roots prior to breaking of winter dormancy. Obviously the costs associated with gathering additional site-specific field data to increase the accuracy of an economic injury level model must ultimately be balanced against the potential economic benefits of this improved accuracy.

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CHAPTER IV

Influence of the Alfalfa Weevil, *Hypera postica* (Gyllenhal) on Alfalfa Yield in Virginia

ABSTRACT

Field experiments using an insecticide gradient technique were conducted in 1984-85 to quantify the influence of alfalfa weevil (*Hypera postica* Gyllenhal) feeding on alfalfa yield. Quadratic regression models were used to describe yield loss and change in alfalfa stem density as a function of cumulative weevil-days. The ability of alfalfa to compensate for moderate levels of defoliation by the alfalfa weevil is apparently dependent on soil fertility factors.

INTRODUCTION

Although the importance of the alfalfa weevil (AW) as a pest of alfalfa has declined dramatically in the northeastern United States and southeastern Canada in recent years, this insect continues to be a primary pest of alfalfa in the southern and midwestern United States. In Virginia, a geoclimatic transition state between the warmer southern states and colder northern states, AW is a persistant problem every year, requiring extensive insecticidal control. Severity of infestations generally depend on location within the state. Severe problems usually occur annually in the Piedmont area east of the Blue Ridge mountains. In the Shenandoah and Roanoke Valleys and most of southwestern Virginia, AW is an intermittent problem with moderate severity, and in the mountain highlands, the weevil is not considered an economic pest.

In the Virginia Alfalfa IPM pilot project, conducted in the Shenandoah Valley from 1980-1982 (see Chapter VI), action thresholds from IPM programs in other states were evaluated, and an empirical modification of the Pennsysvania action threshold (Gesell 1978) was made in an effort to adapt to Virginia bioclimatic conditions (Fig. 1). This action threshold enabled a 40% reduction in insecticide use in the IPM pilot project, however considerable uncertainty in pest management decision-making persisted.

Since the introduction of AW into the eastern United States in 1952, considerable work has been published concerning the influence of AW feeding on alfalfa growth and yield. Koehler and Pimentel (1973) used growth chamber and field cage techniques in an attempt to determine economic injury levels for AW in New York. They suggested an economic injury level of 56 larvae/stem, but they did not report the height of alfalfa at time of infestation. That threshold is nearly twentyfold higher than the 1-3 larvae/stem suggested by Wilson (1973). In laboratory

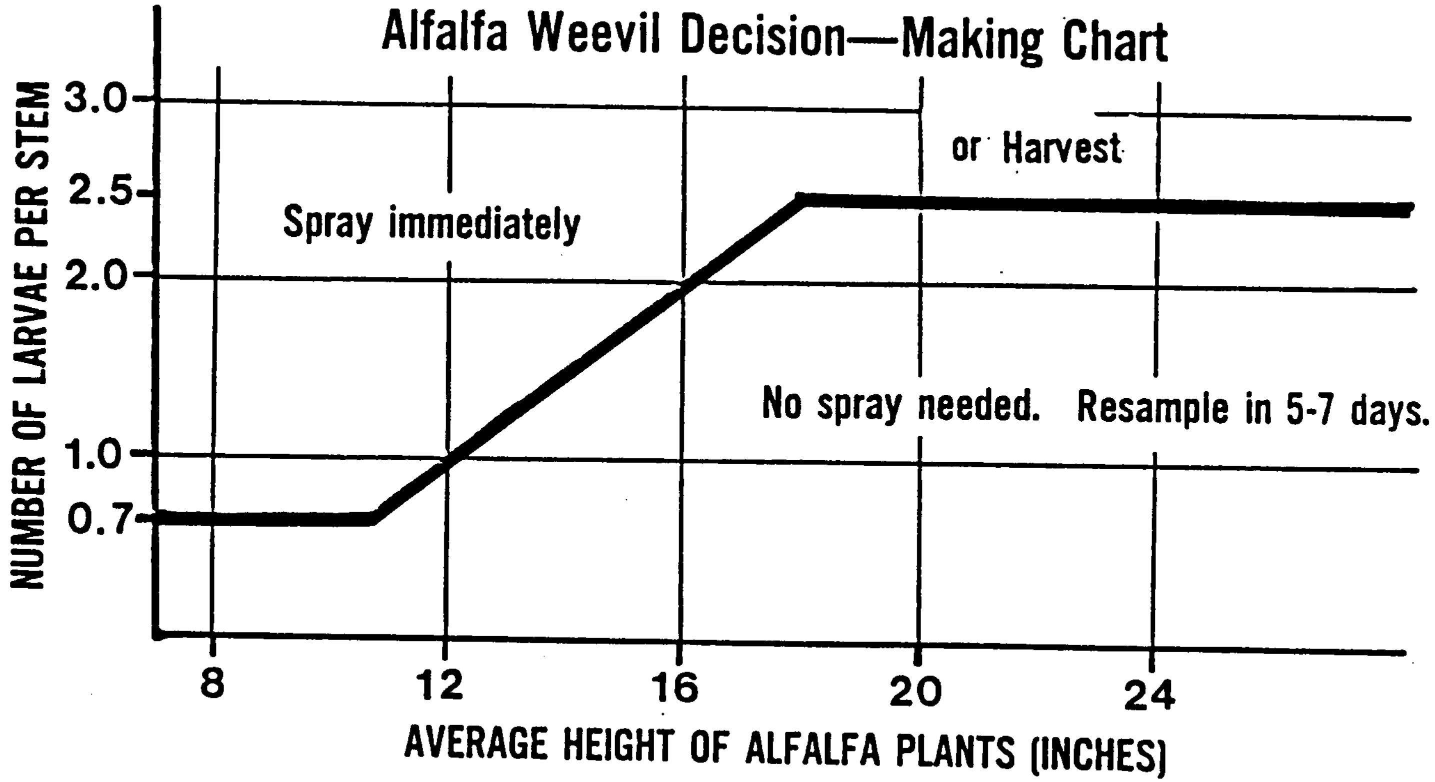

Figure 1. Decision-making chart for management of alfalfa weevil in the Virginia Alfalfa Pest Management Program.

studies of alfalfa consumption by AW, Koehler and Pimentel noted that insect food consumption could account for only about 50% of the total weight loss in alfalfa plants after 10 days of larval feeding. They conjectured that this unaccounted loss was due to loss in photosynthetic potential of the plant.

Cothran and Summers (1974) evaluated visual economic thresholds for the Egyptian alfalfa weevil (*Hypera brunneipennis* Boheman) and detected no significant yield losses in moderately damaged alfalfa. These authors did not consider the correlation between yield loss and insect intensities.

Koehler and Rosenthal (1975) used pre-season applications of heptachlor to establish field gradients of Egyptian AW larvae in California fields. These authors showed statistically significant (alpha = .05) regression relationships between yield and the average number of larvae/sweep at larval-density peaks, but between years fitted relationships differed dramatically. Although the y-intercepts of these regressions differed (indicating seasonal climatic effects on yield potential), the slopes were similar, thus the authors used an average slope to estimate an average yield loss of 4.13 kg for each additional larva/sweep.

Showalter et al. (1975) established varying intensities of AW larvae on individual alfalfa stems enclosed by 5 cm by

48 cm pyrex piping. Multiple regression coefficients are reported predicting growth rate and yield from larvae per stem and initial height of alfalfa at time of infestation, however no validation data were presented to support these predictive models. Also plants were grown in containers, trimmed to 4 stems/pot and the stems enclosed in pyrex tubes. These highly artificial conditions were likely to have produced different results than field grown alfalfa.

Liu and Fick (1975) examined yield and quality losses due to AW by spraying field plots with heptachlor. No significant differences in yield or crude protein were observed in the first cutting between treated and untreated plots with weevil intensities of 2.7 larvae/stem in 1971 and 1.1/stem in 1972. However, significant reductions in _in vitro_ true digestible dry matter were observed in the second cutting in 1972, primarily due to delayed regrowth from feeding on crown buds by a low densities of larvae that survived the first harvest.

In a companion study, Fick and Liu (1976) examined indirect effects of AW defoliation on alfalfa, particularly root reserves as measured by total nonstructural carbohydrates(TNC), alfalfa development rate and canopy structure. Significant reductions in TNC were observed at larval intensities of 3/stem, as was a delayed morphological development. Larval populations greater than 2/stem significantly reduced (alpha = .05) canopy height and leaf percentages.

Hintz et al. (1976) used varying rates of heptachlor to establish gradients of larval intensities within alfalfa fields. A linear reduction in yield as a function of weevil larvae/stem was reported, however the estimated slope of the regression line, ie. the yield loss per larva, varied from 22 to 900 kg/ha/larva across fields and years. These authors also presented an exponential decay curve relating yield loss/larva to stem length at time of peak density of 3rd instar larvae. This supports the commonly accepted hypothesis that the earlier (phenologically) the plant is attacked, the greater the impact of larval feeding (Wilson 1973). Hintz et al. (1976) suggest that the higher losses associated with the shorter stems were attributed more to a loss of growth potential (stems and leaves) resulting from defoliation rather than to the actual leaf weight loss.

Berberet et al. (1981) also used varying rates of heptachlor to establish intensity gradients of AW larvae in nonirrigated alfalfa fields in Oklahoma. Linear regression equations were reported which predicted estimated mean yield losses in first and second cuttings as a function of peak larval intensity per stem in the first cutting. These regressions were highly significant (p = .001), but neither correlation coefficients nor coefficients of determination were reported. According to the authors, yield of alfalfa at 1st harvest decreased ca. 188 kg/ha for each additional larva/stem.

Fick (1982) used manual defoliation of greenhouse-grown alfalfa to simulate feeding damage by the AW. A linear regression of yield on percent defoliation was significant (R^2 = .40). Although Fick claims the removal of entire petioles simulates weevil feeding, Hammond and Pedigo(1981) showed that transpiration rates from soybean leaves either by insects or paper punch were significantly greater than when artificial defoliation removed whole leaflets. Because transpiration rates, photosynthetic rates, and yield are positively correlated (Arkley 1963; Garrity et al. 1982), the validity of whole leaflet removal to simulate insect defoliation is questionable.

No studies have been reported quantifying the impact of AW on alfalfa yield in Virginia. In order to develop a more accurate decision-making guidelines for AW in Virginia, the following study was conducted in 1984 and 1985 to describe the quantitative relationship between alfalfa weevil abundance and alfalfa yield.

MATERIALS AND METHODS

Efforts to describe relationships between crop loss and pest damage have traditionally followed one of three approaches: (1) modification of natural populations, (2) establishment of artificial populations, and (3) damage simulation (Poston et al. 1983). The first approach was chosen for the following experiments.

1984 Field Experiments

To create a gradient of insect intensities within a field, variable rates of insecticide (phosmet) and times of application were used. A randomized complete block design was chosen, with 9.14 x 9.14 m (30 x 30 ft) plots, 4 replications, and the following 6 treatments: (1) 0.11 kg AI/ha (0.10 lb/a) insecticide, applied April 20 , (2) 0.34 kg/ha (0.30 lb/a) applied 4/20, (3) 1.12 kg/ha (1.00 lb/a) applied 4/20, with a second application of 0.56 kg/ha (0.50 lb/a) applied May 5, (4) 0.11 kg/ha (0.10 lb/a) applied 5/5, (5) 0.34 kg/ha (0.30 lb/a) applied 5/5, and (6) no insecticide applied (control treatment). This experimental design was replicated in 6 commercial alfalfa fields in Montgomery County, located in southwestern Virginia. Insecticide was applied using a CO_2-powered backback sprayer equipped with a 0.91 m (3 ft) boom and fan-jet nozzles, 1.26 kg/cm^2 (18 psi) pressure with 225 l/ha (24 gal/A) of water.

Alfalfa weevil larval populations were sampled on 3-4 day intervals from April 16 to May 14, 1984. In each plot twenty randomly selected alfalfa stems were pulled directly into 20 x 40 cm (8 x 16 in) plastic bags, stored in an ice chest, and returned to the laboratory. Each bag of stems was placed in 25 cm (10 in) dia. modified Tullgren funnels equipped with 60-watt light bulbs for 24 hours. Larvae were collected in jars containing 70% ethanol, sorted to instar based on size and color, and counted.

Six random alfalfa stem length measurements were also made in each plot on the same day insects were sampled. Final yield estimates were obtained by mowing a 0.91 m (3 ft) wide swath through the center of each plot, raking the mowed hay onto canvas tarps and weighing using milk scales accurate to 0.04 kg (0.1 lb). Subsamples (approx. .25 kg (0.5 lb)) were placed into cloth bags and placed under the raked hay in each plot to retard evaporative and respiratory losses until all yield samples were taken. Subsamples were returned to the laboratory for determination of percent dry matter.

Alfalfa stem densities were estimated at the same time that final yields were taken. A 0.1 m^2 quadrat was randomly selected in each plot and the number of alfalfa stems longer than ca. 15 cm (6 in) were counted. Daily maximum and minumum temperature data were obtained from the National Oceanic and Atmospheric Adminstration (NOAA) weather station in Blacksburg, ca. 13 km (8 mi) from the study sites.

1985 Field Experiments

Because of low AW populations in Montgomery County in 1984, experiments were moved in 1985 to Bedford, Rockbridge and Augusta counties where weevil populations occur at damaging levels in most years. Experiments were conducted in five alfalfa fields in Bedford County, located in the southern piedmont, and three fields each in Rockbridge and Augusta Counties, located in the southern Shenandoah Valley. Experimental design and sampling procedures were similar to those used in 1984, but with the following modifications: treatment number 3 received 1.12 kg AI/ha (1.0 lb /a) of phosmet, but did not receive the second application as in the 1984 experiment; treatment number 4 received 1.12 kg AI/h (1.0 lb/a) of carbofuran (Furadan 4F) instead of the split application of phosmet. All fields were sprayed on April 11-13. Both treatments 5 and 6 were unsprayed in 1985, and data from these treatments were pooled for analysis.

Sample size for estimating alfalfa stem densities was increased in 1985 to two 0.1 m^2 samples per plot. Final yield was estimated as in 1984, however one subsample was taken from each plot for forage quality analysis. Analyses for percent crude protein and acid digestable fiber were performed by the Virginia Tech Forage Testing Laboratory. Soil samples of the upper 15 cm layer were taken at harvest, and determination of pH, percent organic matter, and major plant nutrients were made by the Virginia Tech Soil Testing Laboratory.

A Campbell CR-21 Micrologger housed in a standard weather shelter was used in both study areas to record maximum and minumum daily air temperatures from January 1 through the first harvest of alfalfa (May 10 - 15). Equipment malfunction occured periodically and daily maximum and miniumum temperature data were obtained for these dates from the NOAA weather station nearest to the study sites (Lexington station, ca. 9 km from the Rockbridge Co. sites, 28 km from the Augusta Co. sites, and the Bedford station, ca. 7 km from the Bedford Co. sites.)

Analytical Procedures

To obtain a value that represents the cumulative feeding impact of the entire larval period, a "cumulative weevil degree day" (CUMWD) value was calculated using the following procedure:

(1) Thermal degree-days (Celsius) were calculated using a modified sine wave method (Allen 1976) with a lower developmental threshold of 10 °C (Litsinger and Apple 1973; Guppy and Mukerji 1974). No upper developmental threshold was used. Degree-day accumulation was initialized on Nov. 1, 1983 for the 1984 experiments, since peak fall oviposition occurs at this time (Hilburn 1986). In 1985, however, subfreezing temperatures in January are believed to have killed all fall-layed eggs (Hilburn 1986), so degree-day accumulation was initialized on Jan. 1, 1985. All sampling dates were converted to cumulative degree days for subsequent analysis.

(2) In order to weight the relative defoliation impact of the larval instars, the following weighting values were derived from a published laboratory feeding study

(Koehler and Pimentel 1973): fourth instar = 1; third instar = 0.45; second instar = 0.06; and first instar = 0.03. Weevil counts for each sampling date were then multiplied by these weighting values and summed to give an "adjusted" fourth-instar equivalent.

(3) Estimates of mean fourth-instar equivalents per treatment within fields were calculated for each sample date and these means were plotted against cumulative degree-days. The total area under each curve is calculated, giving a cumulative weevil-day (CUMWD) value for each treatment. This variable was used as the independent variable in subsequent regression analyses.

RESULTS AND DISCUSSION

Weevil infestations were exceptionally light in Montgomery Co. in 1984, with only 2 of the 6 fields in the experiment having substantial populations (peak larvae/stem = 3.2 and 3.4). Population densities were also low in 1985 because of the winter egg kill in January, with only 3 of the 11 fields in the experiment containing weevil populations high enough to cause obvious visible damage (peak larva/stem = 1.2). Consequently only data from 2 fields in 1984 (Compton and Styne) and 3 fields in 1985 (Sterrett, Shomo, and Mackey) were used for analyses of weevil influence on alfalfa growth.

Weather conditions during the first growth of alfalfa were radically different between the two years (Table 1,

Table 1. Precipitation in Rockbridge County, VA, in 1984 and 1985.

	Precipitation (cm)[1]	
Month	1984	1985
January	12.57	14.37
February	32.00	21.72
March	28.17	15.47
April	32.00	7.29
May	38.61	29.41

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[1] Data from National Oceanic and Atmospheric Administration, Climatological Data, Virginia, Vols. 94-95, 1984-85.

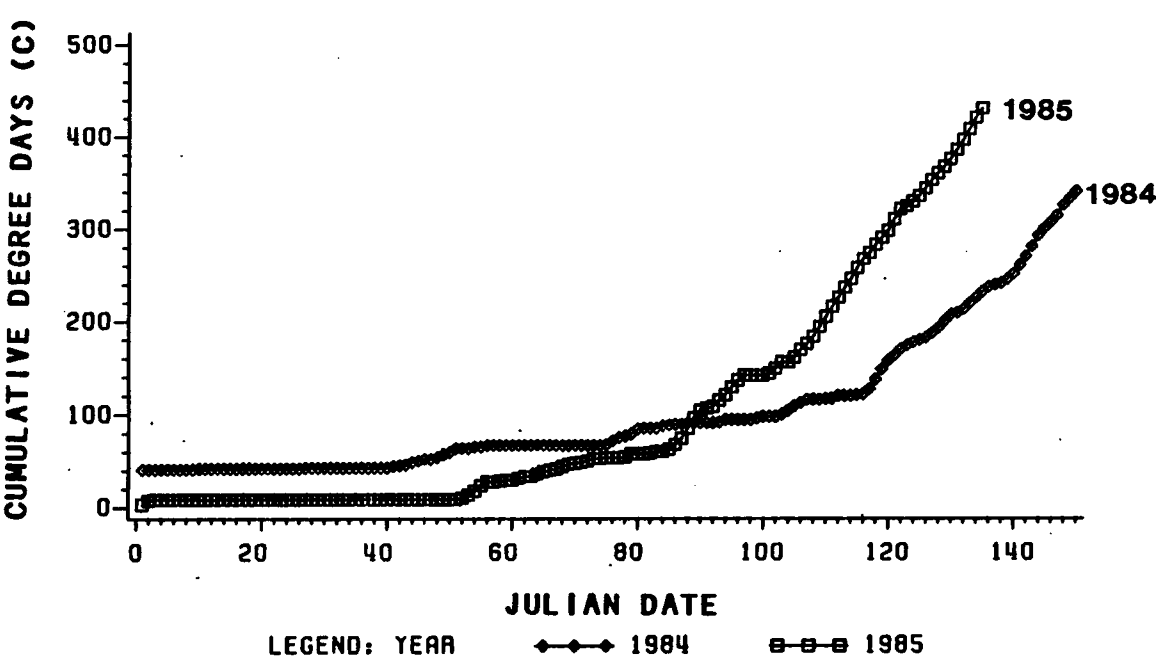

Figure 2. Cumulative degree-days Celsius (base temperature = 10° C) for 1984-85. Degree-day accumulation in 1984 is initialized with 41 degree-days accumulated from Nov. 1 to Dec. 31, 1983.

Fig. 2). Preciptation was 4.37 cm (1.87 in) above normal in March and April, 1984, but in 1985 precipitation was 11.33 cm (4.46 in) below normal in Bedford County and 7.95 cm (3.13 in) below normal in Rockbridge County. The extreme drought in April, 1985, reduced alfalfa yields in most alfalfa fields in the experiment. The high moisture conditions in 1984 permitted an epizootic of *Erynia* sp., an entomopathogenic fungus, to develop which decimated weevil populations during the first week of May (approx. 160-210 DDC).

Temperatures were considerably cooler in the spring of 1984 than in 1985, and these differences were reflected in degree day accumulations (Fig. 2). As mentioned earlier, subfreezing temperatures in January, 1985, (possibly combined with abnormally warm late fall and early winter temperatures in 1983) killed most of the overwintering AW egg population. Winter egg mortality was not nearly so severe in 1984 (Hilburn 1986). Because of these weather extremes between the two years, results for each year will be discussed separately.

1984 Field Experiments

Plotting mean CUMWD (by treatment) against cumulative degree days for each field (Fig. 3) allows a visual evaluation of the insecticide treatments in creating a gradient of insect intensities within a field. Treatments 1, 2, 3, and 6 separated fairly well (final CUMWD values are

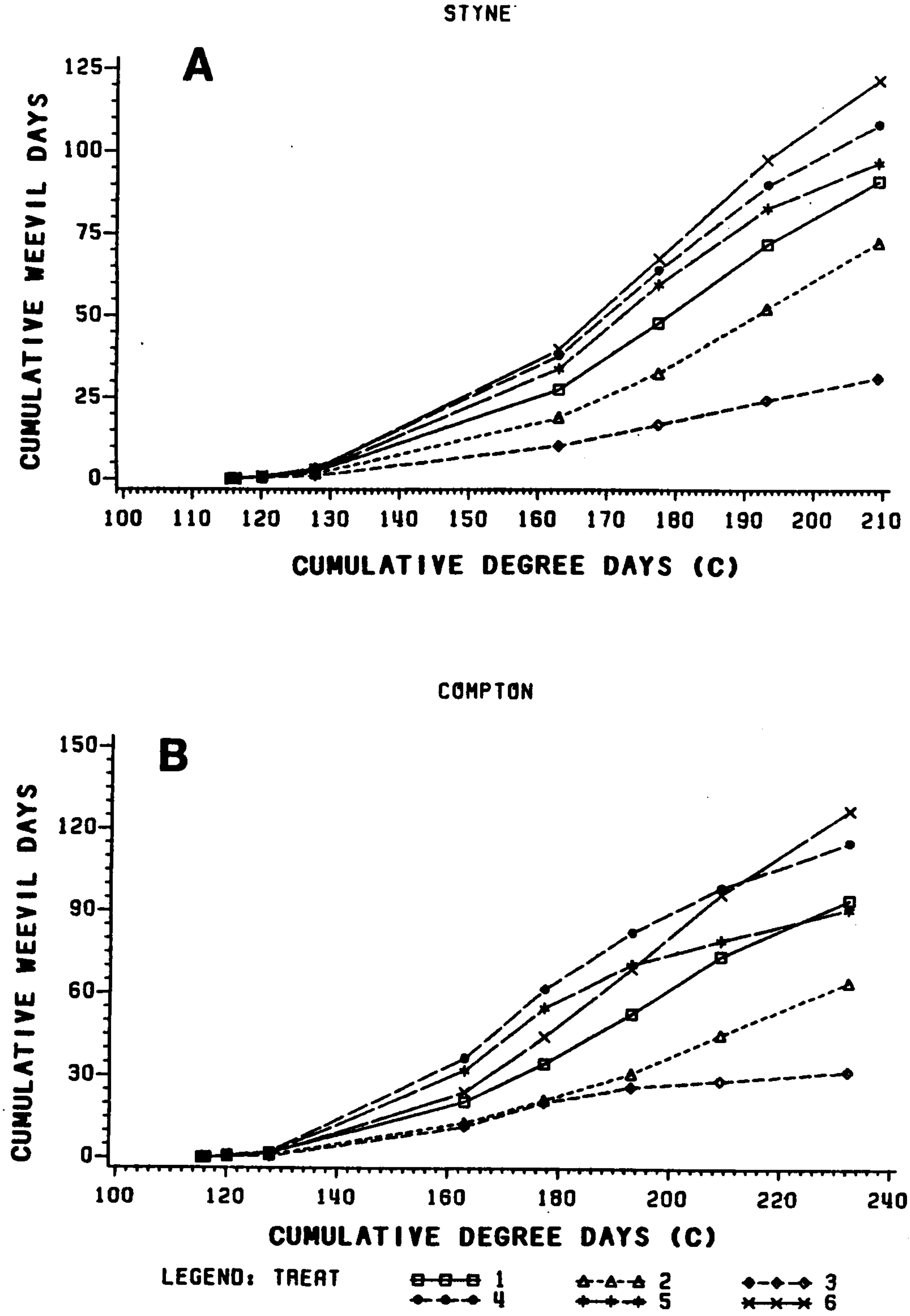

Figure 3. Cumulative weevil-days for 1984 fields (A) Styne and (B) Compton.

nearly equidistantly spaced on the y-axis), however treatments 4 and 5 do not separate clearly because these treatments were imposed at a later date in the season. Also the insecticide rates and application times used for Treatment 3 provided less than the desired complete control of the weevil larvae, with 25 to 30 weevil-days accumulating by the harvest date.

To evaluate the relationship between yield and CUMWD, regression analyses (quadratic model) were conducted for both the Styne and Compton fields using dry matter yield as the dependent variable and CUMWD as the independent variable. The regression was significant for the Styne field p = .08, R^2 = .82) but not for the Compton field (p = .56, R^2 = .32). Yield response to weevil feeding varied dramatically between the two fields (Fig. 4). In the Styne field, weevil feeding up to about 85 weevil-days caused a decrease in yield, followed by an apparent trend toward increasing yield at high weevil levels. In the Compton field, weevil feeding caused no significant change in yield (Table 1). Regressions of stem density on CUMWD (Fig. 5) were not significant at alpha = .20 for either field, and coefficients of determination indicated poor model fit of the data (Table 2).

1985 Field Experiments

The insecticide treatments used in 1985 created gradients of insect intensities in some fields (Fig. 6A and

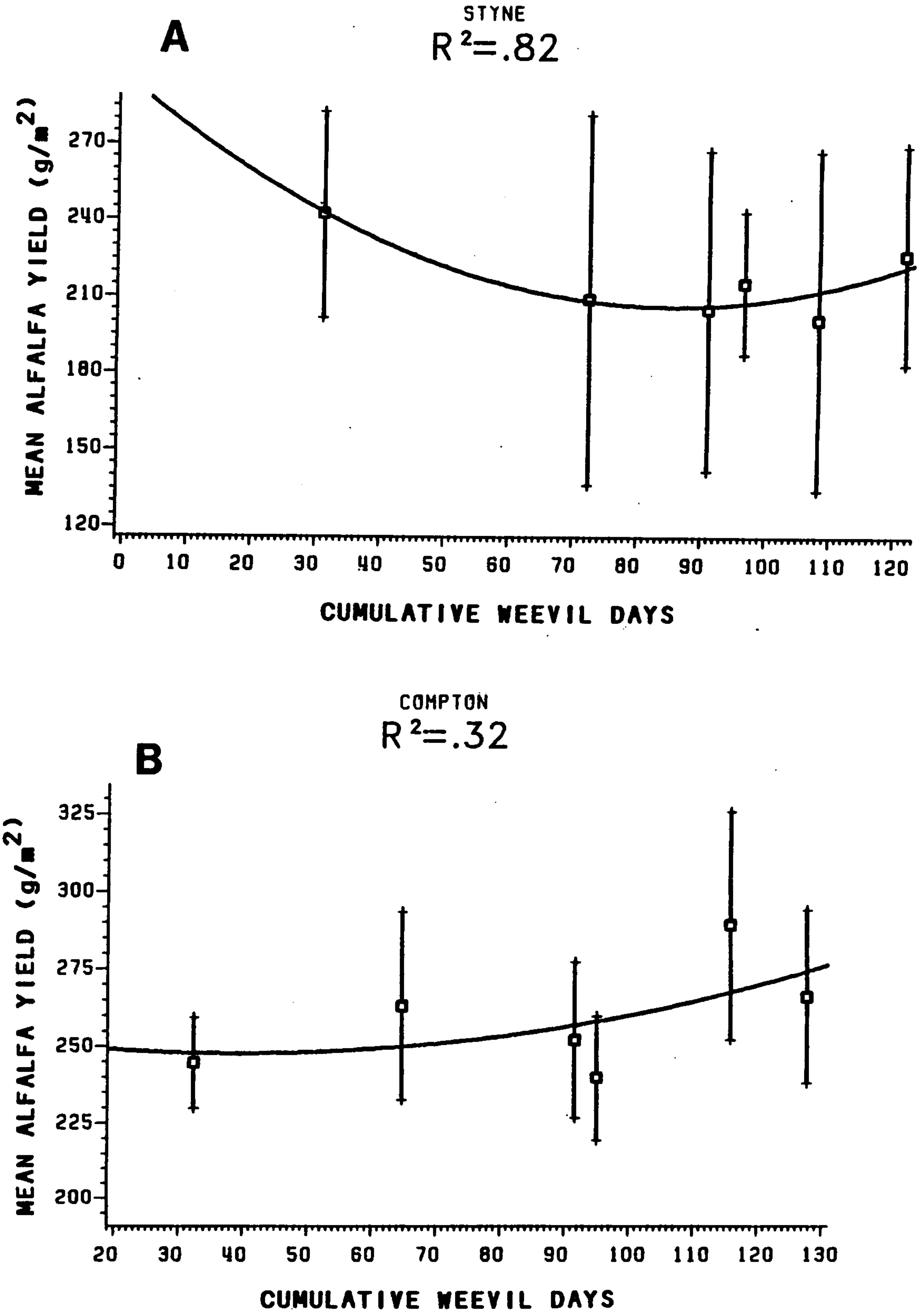

Figure 4. Alfalfa dry weight yield as a function of mean cumulative weevil-days for 1984 fields (A) Styne and (B) Compton. Vertical bars are 95% confidence intervals (alpha = .05).

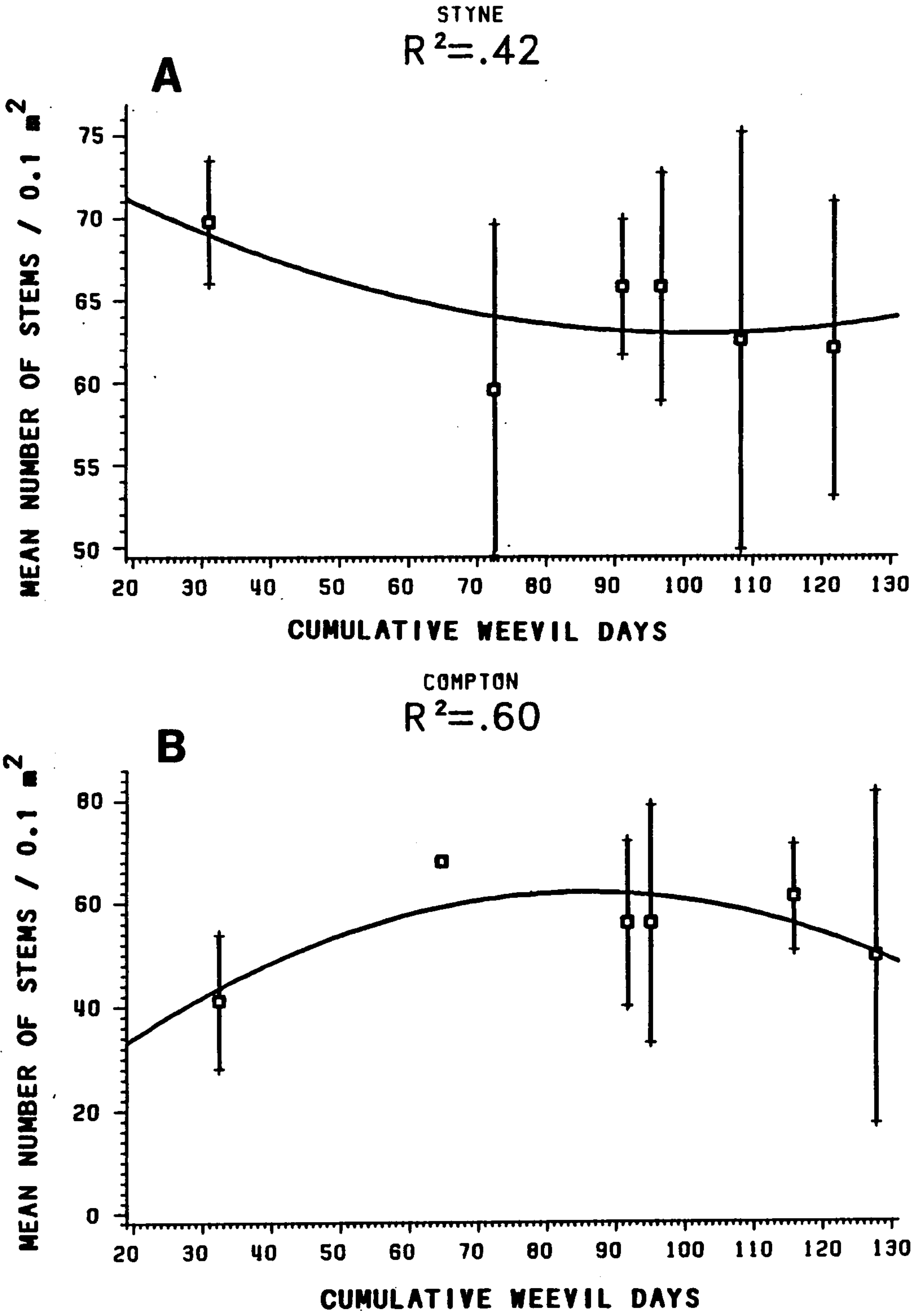

Figure 5. Alfalfa stem density per m^2 as a function of mean cumulative weevil-days for 1984 fields (A) Styne and (B) Compton. Vertical bars are 95% confidence intervals (alpha = .05).

Table 2. Regression parameters and coeffieients for quadratic models predicting dry weight yield and alfalfa stem density as a function of cumulative weevil days.

		Dry weight yield					Alfalfa stem density				
Year	Field	P-value	R^2	b_0[a]	b_1	b_2	P-value	R^2	b_0	b_1	b_2
1984	STYNE	.08	.82	296	-2.103	0.012	.45	.41	N.S.	--	--
	COMPTON	.54	.33	N.S.[b]	--	--	.26	.59	N.S.	--	--
1985	MACKEY	.14	.86	348	-3.53	0.03	.19	.81	38.47	0.507	-0.005
	SHOMO	.67	.33	N.S.	--	--	.09	.91	42.67	0.547	-0.005
	STERRETT	.20	.80	393	-2.461	0.021	.18	.82	49.97	-0.007	0.003

[a] Regression coefficients for the quadratic regression model $Y = b_0 + b_1X + b_2X^2$, where Y = dry weight yield (g/m^2) or number of stems/ 0.1 m^2, b_0 = Y-intercept, and b_1 = slope, and X = cumulative weevil days.

[b] Not significant at alpha = .20.

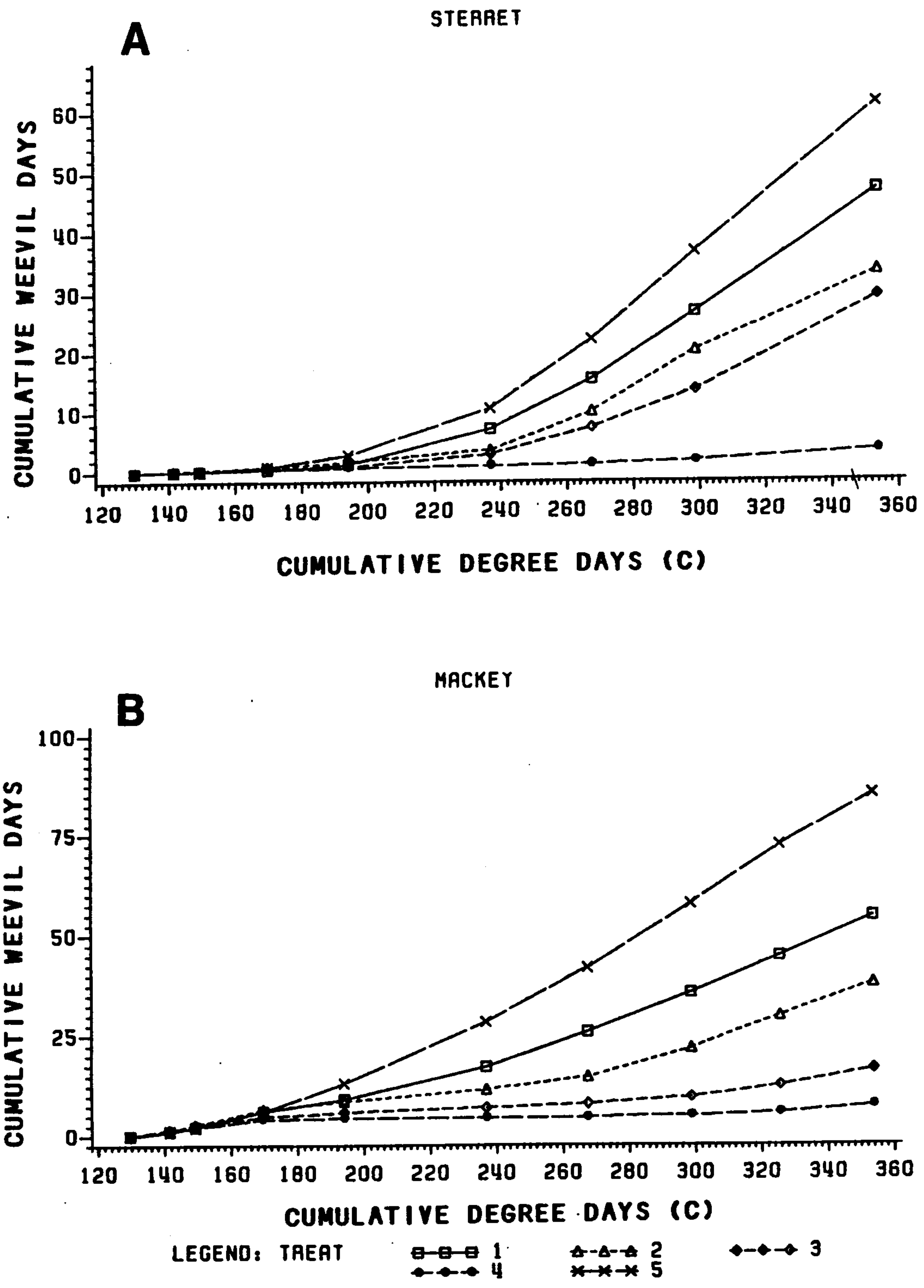

Figure 6. Cumulative weevil-days for 1985 fields (A) Sterrett, (B) Mackey, and (C) Shomo.

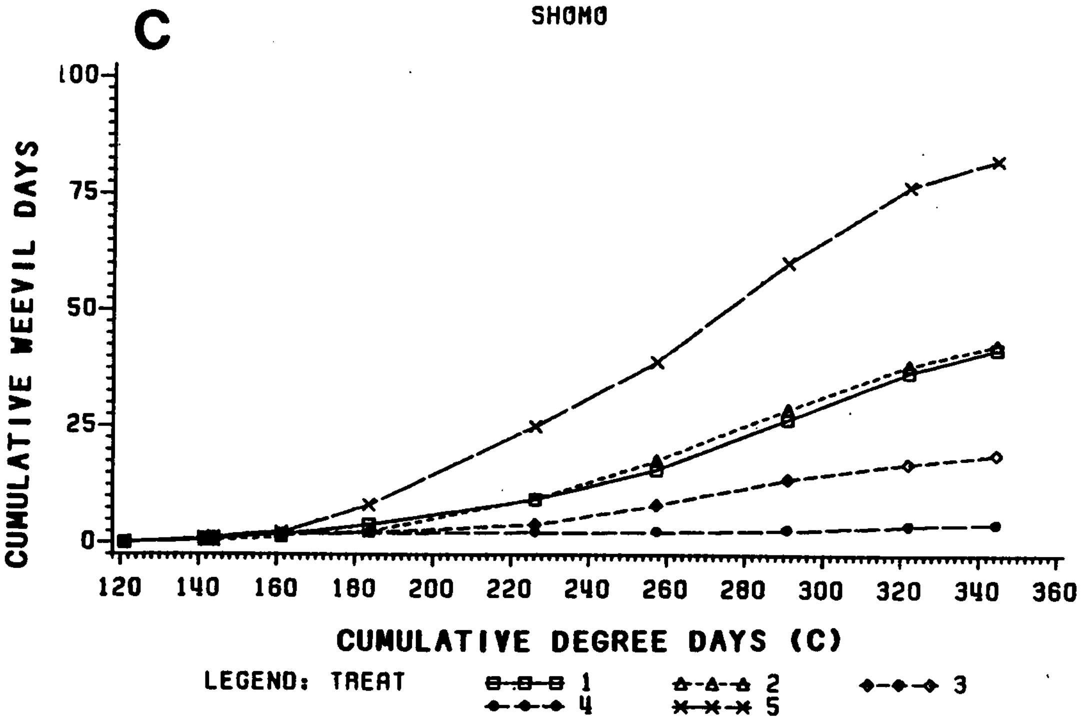

Figure 6. (Continued) Cumulative weevil-days for 1985 fields (A) Sterrett, (B) Mackey, and (C) Shomo.

6B), but separation of treatment effects was less distinct in the Shomo field (Fig. 6C).

Yield declined as a function of cumulative weevil days in the Sterrett and Mackey fields, (Fig. 7), (R^2 = .80 and .86 respectively). Model significance was relatively poor, however, with p-values of .20 and .13 (Table 2). In the Shomo field, yield could not be predicted from cumulative weevil-days, as indicated by both low R^2 values and high p-values (Table 1).

Alfalfa stem density increased as weevil feeding increased for all three fields, as indicated by regressions of stem density against weevil-days (Fig. 8). Coefficients of determination were greater than .80 for all fields, however p-values for model significance ranged from 0.09 to 0.19.

Regression models describing the relationship between CUMWD and final stem length of the alfalfa or forage quality parameters, percent protein and acid digestible fiber were not significant (alpha = .20) and low R^2-values indicated poor model fit.

In evaluating the influence of AW feeding on alfalfa yield, (Fig. 4,5,7,8), conditions within individual fields apparently influence the yield loss and stem density functions. Several factors obviously influence alfalfa growth and yield: variety, age of stand, soil type and

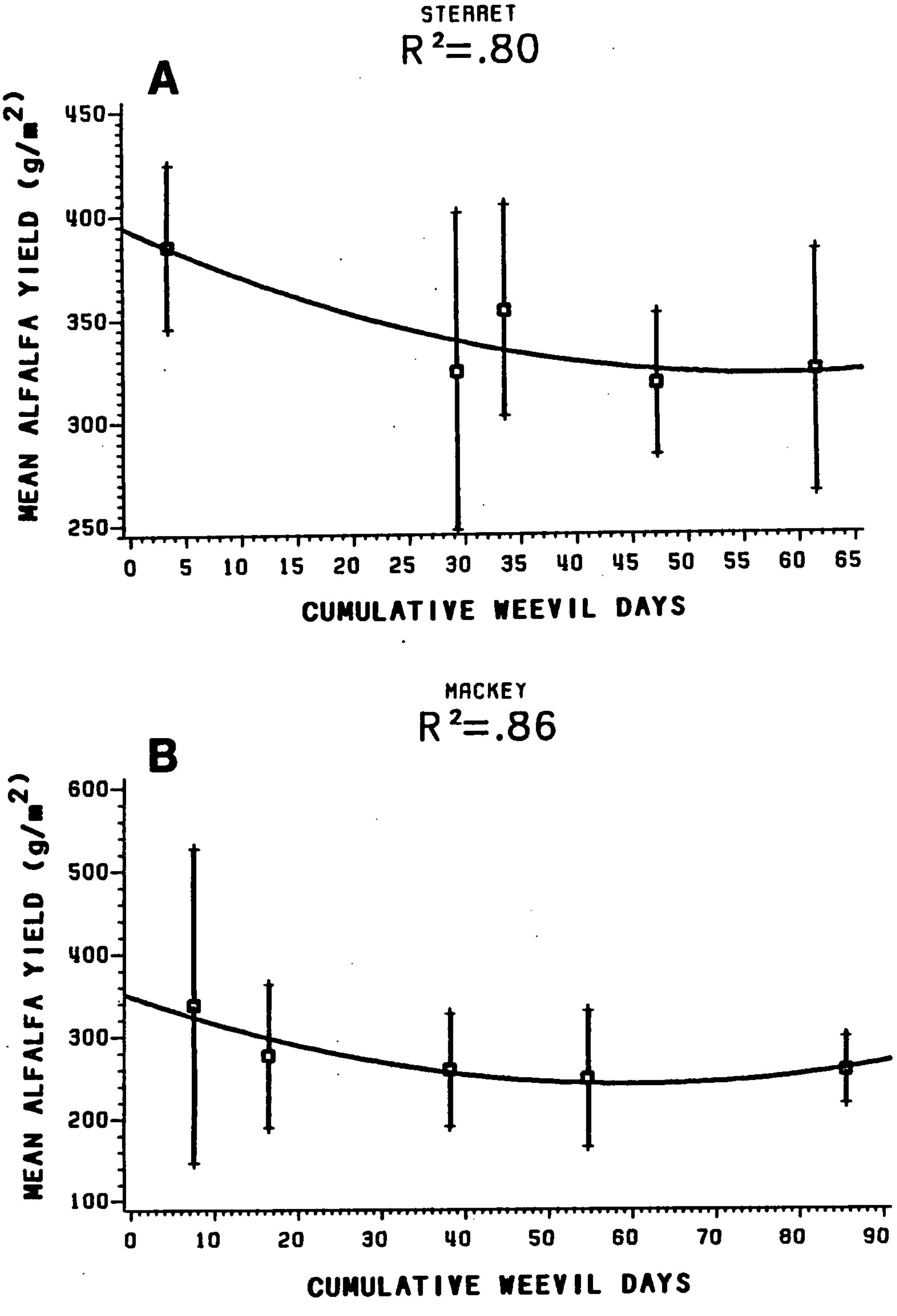

Figure 7. Alfalfa dry weight as a function of mean cumulative weevil-days for 1985 fields (A) Sterrett, (B) Mackey, and (C) Shomo. Vertical bars are 95% confidence intervals (alpha = .05).

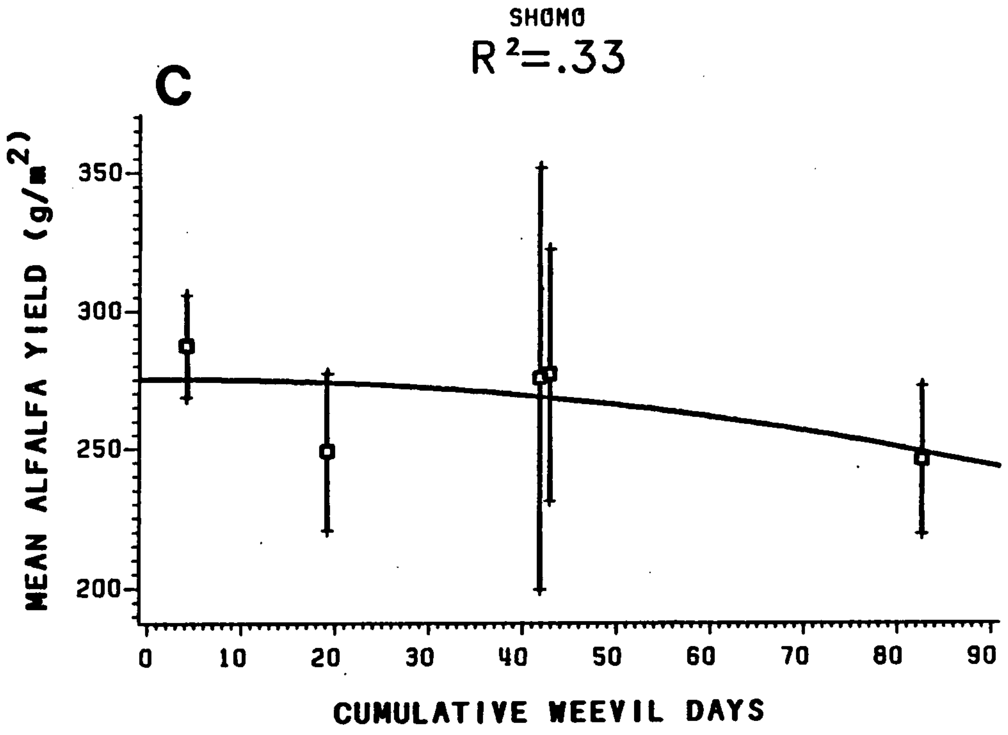

Figure 7. (Continued) Alfalfa dry weight as a function of mean cumulative weevil-days for 1985 fields (A) Sterrett, (B) Mackey, and (C) Shomo. Vertical bars are 95% confidence intervals (alpha = .05).

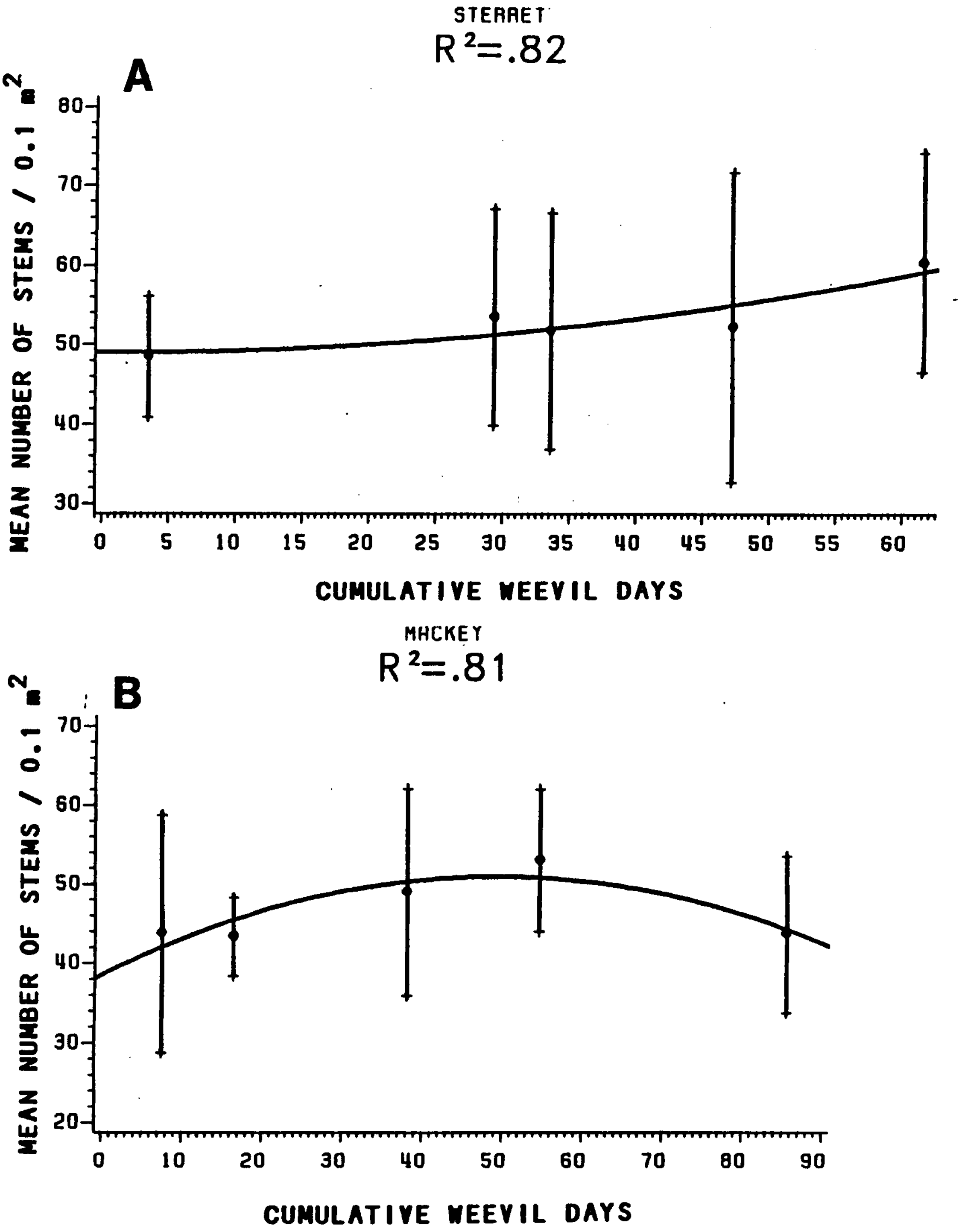

Figure 8. Alfalfa stem density per m^2 as a function of cumulative weevil-days for 1985 fields (A) Sterrett, (B) Mackey, and (C) Shomo. Vertical bars are 95% confidence intervals (alpha = .05).

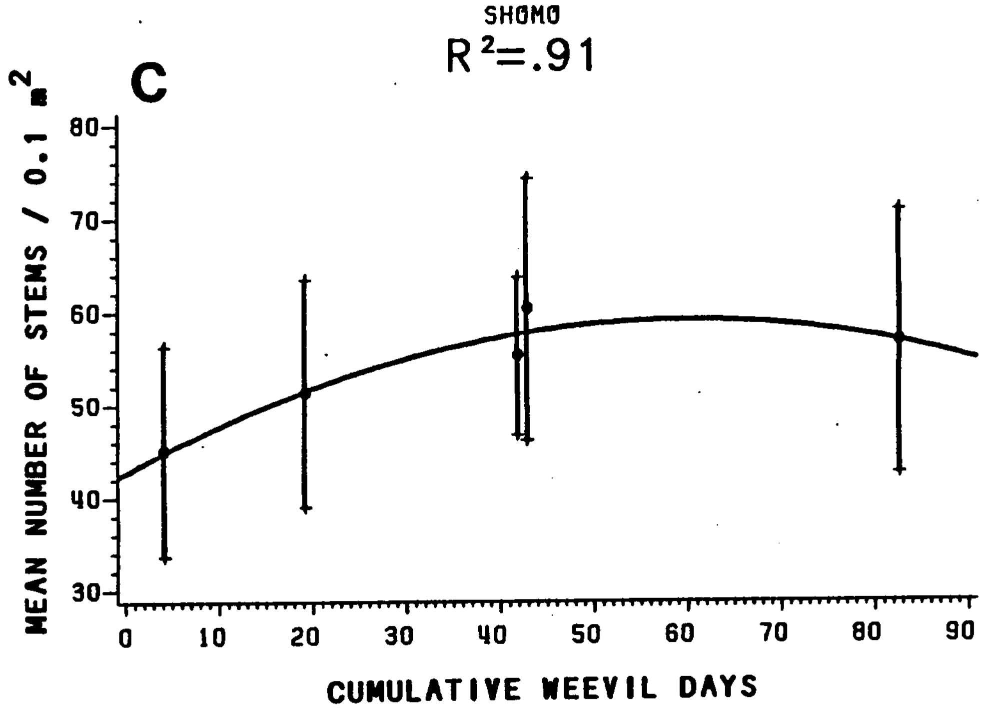

Figure 8. (Continued) Alfalfa stem density per m^2 as a function of cumulative weevil-days for 1985 fields (A) Sterrett, (B) Mackey, and (C) Shomo. Vertical bars are 95% confidence intervals (alpha = .05).

fertility, available soil water, insect damage, weed competition, and previous cultural management. Ideally a factorial experiment conducted for several years would be necessary to explain the relative importance and interaction of these variables, however such an experiment would be extremely expensive.

In the experiments described above, information available to characterize individual fields include general soil classification information (National Coop. Soil Surveys, 1934, 1977, 1985) and soil fertility data obtained from soil tests. From comparing alfalfa response to weevil feeding with this soil information (Table 3), two hypotheses are suggested:

1. Alfalfa yield loss to AW depends on the soil fertility level (i.e. proportional yield loss to a given level of weevil infestation is less for well fertilized fields than in poorly fertilized fields.
2. The ability of alfalfa to increase lateral branching (stem density) as a function of increasing weevil levels is also determined by soil fertility.

In the 1984 study, the Compton field contained a Ross well drained river bottom soil, apparently in an excellent state of fertility, as indicated by rapid stem elongation rates. Ross soils are generally characterized by a high

Table 3. Alfalfa varieties, planting dates, soil classification, and fertility of fields.

					Soil fertility[1]			
						ppm		
Year	Field	Variety	Planting date	Soil type	pH	P	K	%OM
1984	Styne	unknown	unknown	Berkes-Groseclose	6.5	27	86	---
	Compton	unknown	unknown	Ross	samples not taken			
1985	Mackey	Saranac AR	Aug. 1983	Frederic complex	5.0	17	56	2.4
	Shomo	Saranac AR	Aug. 1983	Frederic complex	6.3	49	157	2.9
	Sterrett	Classic	Apr. 1982	Frederic complex	5.6	60	157	2.7

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[1] Soil fertility data from standard soil tests conducted by the Soil Testing and Plant Analysis Laboratory, VPI & SU, Blacksburg.

organic matter content and a high level of natural fertility. (Unfortunately soil samples were not taken in this field). The Styne field, however, contained a rocky, poorly drained soil (Berkes-Groseclose), which was potassium deficient (potassium is a key nutrient for alfalfa growth) as determined from soil tests (Table 3). Berkes-Groseclose soils are generally characterized by low organic matter content and low natural fertility, with a high content of coarse rock fragments to inhibit root growth.

Comparing yield-loss functions for these two fields (Fig. 4) shows that yield generally declined with increasing CUMWD in the Styne field, however yield generally increased with increasing weevil-days in the Compton field. Stem densities also increased with increasing weevil-days in the Compton field (Fig. 5a) but declined in the Styne field (Fig. 5b).

In the 1985 study, the influence of soil fertility on crop response to weevil feeding is also indicated. The yield-loss functions (Fig. 9) for the Sterrett and Mackey fields are similarly shaped, although the Mackey field has a lower y-intercept. The slopes of the regression models in the range of 5 to 65 weevil-days, however indicate a more rapid yield loss with increasing weevil-days in the Mackey field (statistical comparisons of slopes were not conducted because of small sample size). Soil test data for these two fields (Table 3) show that the pH of the Mackey field (5.0)

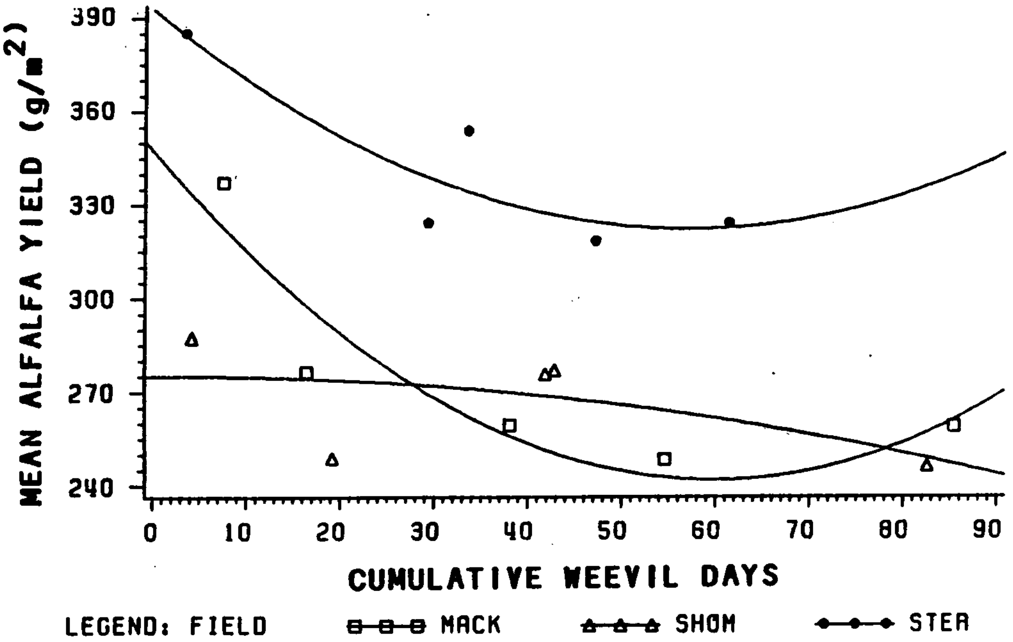

Figure 9. Field influence on alfalfa yield response to weevil feeding (1985).

was very low for optimum alfalfa growth, and was low enough for the crop to be experiencing possible aluminum toxicity (Hawkins, pers. comm.). Also both phosphorus and potassium levels for the Mackey field were low for optimum alfalfa growth.

The Sterrett field had considerably better soil fertility (Table 3), with much higher levels of phosphorus and potassium, and a pH of 5.6. Although this pH is still below optimum for alfalfa growth (6.2 to 6.5), it is above the pH level of 5.0 which can induce aluminum toxicity in alfalfa. Organic matter content was also 0.3 percent higher than in the Mackey field. This difference may have had conderable effect in water holding capacity of the soil in an extremely droughty year like 1985.

Soil fertility was highest in the Shomo field (Table 3) with high levels of potassium and phosphorus, a pH of 6.3, and 2.9 percent organic matter. Although this field had the lowest yield of the three fields in 1985 (possibly related to soil structure or rainfall differences), there was a nonsignificant ($p = .67$, $R^2 = .33$) loss in yield as a function of increasing weevil-days (Fig. 7). All three fields in the 1985 study contained Frederick-Complex soils (Table 3), which are characterized as generally low in organic matter content with medium natural fertility. Considerable differences in soil characteristics among these fields could occur within the Frederick soil group, however the scale of soil mapping prevented any further differentiation.

The relative ability of the three alfalfa fields to produce additional stems in response to weevil feeding (Fig. 10) is also apparently dependent on the relative soil fertility of the fields. The increase in stem density in response to increasing weevil levels in the 1985 experiments and in the Compton field in 1984 suggests this may affect yield compensation by the alfalfa crop under relatively low weevil infestation levels. The stem density increase possibly results from removal of apical dominance, since weevil feeding occurs primarily at the growing tips. This compensatory response could possibly account for much of the relatively poor correlation between weevil levels and dry matter yield. Peak total larval population levels in 1985 were only 1.2 larvae per stem, which is fairly low infestation level. Higher weevil levels could possibly overwhelm the compensatory response exhibited in this study, as indicated in the greenhouse study described in Chapter III.

Calculation of cumulative weevil-day values appears to be a useful technique in developing yield-loss relationships, however this technique does not consider the relative timing of the damaging stages of a pest in relation to the crop phenology. In alfalfa, crop height at the appearance of third and fourth instar larvae is particularly

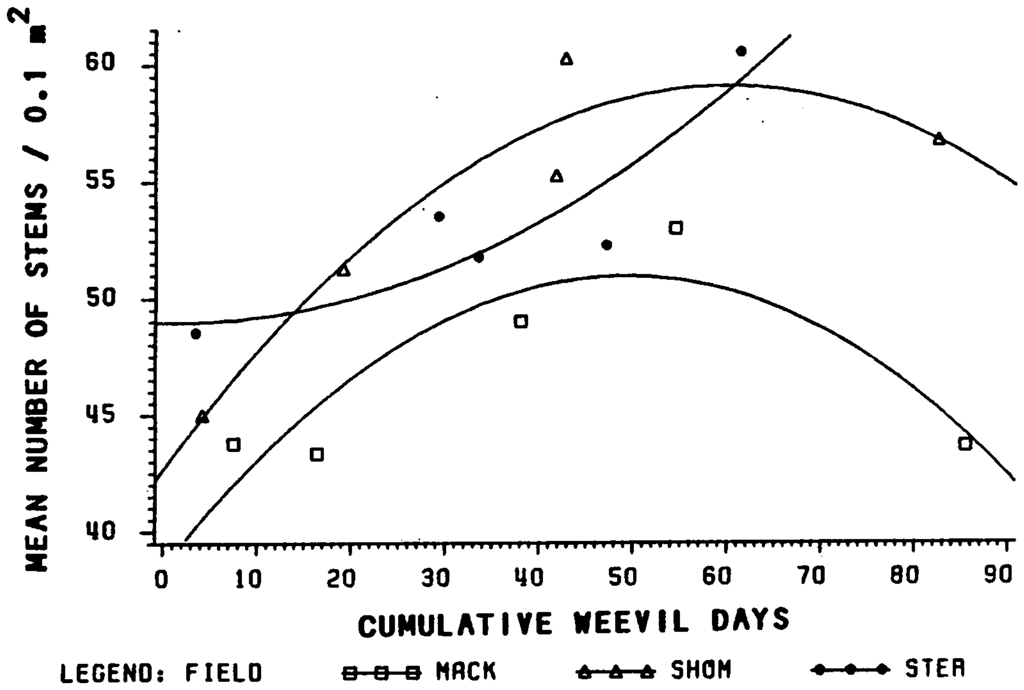

Figure 10. Field influence on alfalfa stem density response to weevil feeding (1985).

important in determining the ability of the crop to withstand damage. In the experimental design used these experiments, however, this is an uncontrolled variable.

Increasing stem density is one apparent means by which the alfalfa crop compensates for AW feeding, and this compensation is apparently dependent on overall soil fertility levels. Additional research is needed to incorporate relative soil fertility parameters into a yield-loss prediction model for AW. Additional work is also needed to include data with higher weevil infestation levels and in seasons with more rainfall.

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CHAPTER V

Development and Validation of Sequential Sampling Plans for Potato Leafhopper in Alfalfa

ABSTRACT

Sequential sampling plans were developed for pest management decision making of potato leafhopper (Empoasca fabae Harris) in alfalfa. Sweep net sampling of adult plus nymphal leafhoppers in 5 western Virginia counties was used for plan development. Validation of the plan using 3 years of data from the Virginia Alfalfa Pest Management Project resulted in an average error rate of 1.8%, with a range among years of 0.4% to 3.9%. Sampling requirements, in terms of the number of samples needed, was reduced by 55% in 1980; 53% in 1981; and 28% in 1982.

INTRODUCTION

The purpose of sampling in pest management programs is usually to determine whether pest population levels are above or below specified action thresholds. Sequential sampling procedures, as described by Waters (1955) and others (see Pieters, 1978, for a bibliography of sampling plans for insects) allow a variable number of samples to be taken, with fewer samples required at high and low population levels than at intermediate levels. Thus, sequential sampling is a method of optimum allocation of sampling labor to reach management decisions based on a specified level of risk.

This paper describes the development and field validation of a sequential plan for the potato leafhopper (Empoasca fabae Harris) in alfalfa. The potato leafhopper is a serious economic pest of alfalfa throughout the Midwestern and Northeastern United States, causing yield and protein loss and reducing stand longevity. Management of this insect is particularly difficult because control measures often need to be implemented one to three weeks prior to the appearance of visual damage symptoms (Gesell 1978).

Integrated Pest Management (IPM) programs in several states utilize sweep net sampling to estimate leafhopper population levels (Gesell 1978; Dively 1982; Christenson 1982; Luna 1983). However, sample unit size (number of sweeps per sample) and sample size (number of samples per field) vary considerably among pest management programs. Action thresholds, or the pest population level at which control measures are recommended, also vary among programs, but generally follow the plant height-dependent recommendations of Pennsylvania State University (Gesell 1978). The sequential sampling plan discussed in this paper is based on sweep net sampling units and action thresholds currently recommended in the Virginia alfalfa pest management program

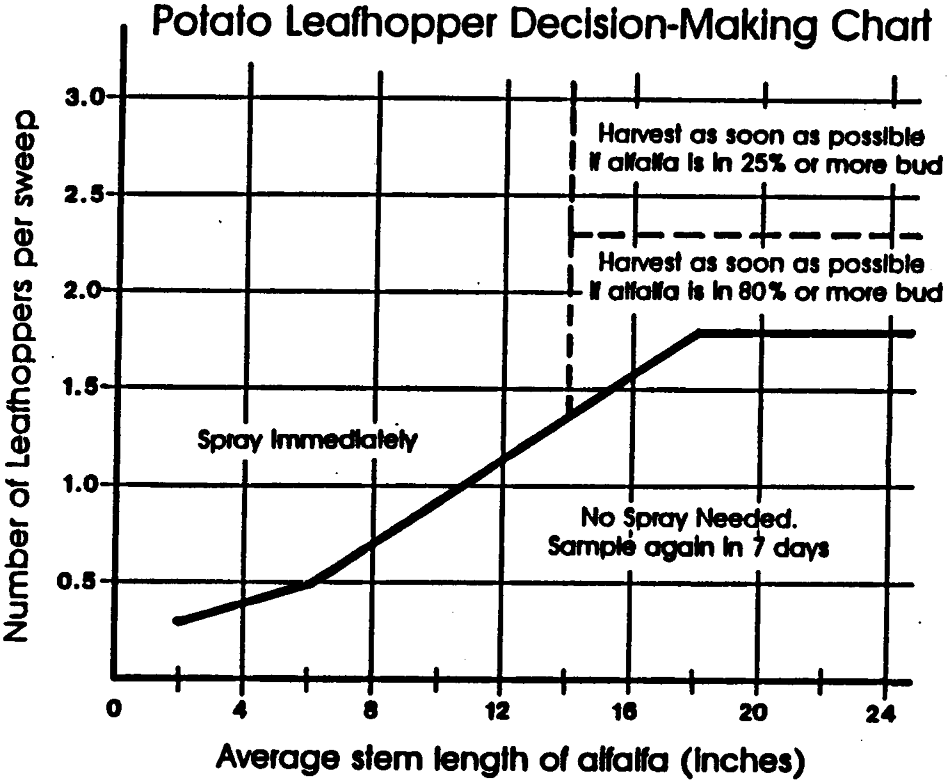

Fig. 1. Decision-making chart used in Virginia for potato leafhopper pest management in forage alfalfa.

(Luna 1983). These action thresholds (Fig. 1) have been modified from Gesell (1978) to respond to Virginia growing conditions.

METHODS AND MATERIALS

Determining population spatial distribution

Prior to the development of a sequential sampling plan, the mathematical distribution of the insect counts for the sampling unit being used must be determined (Waters 1955). In order to maintain a high level of counting accuracy while developing the relationship of sweep net samples of adults to absolute density, Fleischer et al. (1982) used a 5-sweep sample unit, which they showed to follow a Poisson series in alfalfa that had been cleanly harvested. Although using a larger sample unit (10 sweeps/sample) decreases field counting accuracy at high densities (Fleischer and Allen 1982), it facilitates the detection of leafhoppers at low densities in early regrowth, which is of prime importance in management decision making. A 10-sweep sample is currently used in the Virginia Pest Management program and combined adult plus nymphal leafhopper counts are used for management decision making. Although sweep net sampling gives low density estimates with poor precision for leafhopper nymphs (Simonet et al. 1978), nymphal counts are useful as evidence that significant within-field reproduction has begun, and thus is an indicator of potential damage to the alfalfa.

To examine the frequency distribution of 10-sweep samples of combined adult and nymphal leafhopper counts, 5 individuals sampled leafhoppers from June through August 1981 in 54 alfalfa fields in 5 counties in western Virginia (Rockingham, Augusta, Rockbridge, Montgomery, and Franklin). The sweep-net sampling technique used pendular sweeps of a 38-cm (15-in) diameter sweep net to collect adult and nymphal potato leafhoppers. Leafhoppers were counted in the field as the sweep net was unrolled and adult and nymphal counts recorded separately. A sample consisted of 10 pendular sweeps, with 15 samples taken per field per date. The lengths of 10 randomly selected alfalfa stems also were recorded during each field visit. A total of 126 replicates were obtained, representing a wide array of crop heights and insect population levels.

The frequency distribution of leafhopper samples in each field was tested for agreement with the Poisson series using a chi-square test of the variance to mean ratio (Elliot 1977; Meyers 1978). Adult leafhopper counts were analyzed separately from combined counts of adults plus nymphs. When counting adults only, 82% of the 126 replicates did not disprove a Poisson series at alpha = 0.05. When adult plus nymphal counts were analyzed, 58% of the replicates did not reject a Poisson series. The other 42% of the replicates rejected the Poisson series at alpha = 0.05 with a chi-square value above the critical level, suggesting a contagious distribution for leafhopper in these fields. This apparent clumping of the combined adult plus nymphal counts appears to be related to population density. Among 73 fields with densities below the economic threshold, 50 fields, or 68%, did not reject a Poisson series. Among 51 fields with densities above the economic threshold, only 38% did not reject the Poisson series at alpha = 0.05.

In selecting an appropriate mathematical model of the population dispersion for a sequential sampling plan, the temporal age-class distribution within the fields, as well as the management objectives of sampling, must be considered. Because the harvest process usually removes leafhopper eggs and kills most nymphs (Simonet and Pienkowski 1979), damage to the susceptible early regrowth of an alfalfa field usually is caused by adult leafhoppers which have survived the harvest or have moved into the field from adjacent areas. Chemical control is most effective when application is made on short alfalfa (usually less than 30-36 cm) before extensive clogging of the plant's vascular system occurs (Gesell 1978). Therefore, sampling to optimize timing of chemical control is critical during this initial growth phase of the crop, prior to the appearance of many leafhopper nymphs from within-field reproduction. Thus treatment decisions are predominately influenced by counts of adult leafhoppers at relatively low densities.

Early harvest is a second tactic used in leafhopper management which influences sampling objectives. Early harvest can be used to prevent further damage when high densities of leafhopper are present and the crop is too tall to justify spraying (Fig. 1). Harvesting, as mentioned earlier, also inflicts high mortality on leafhopper eggs and nymphs. Usually by the time early harvest is warranted as a management tactic, 3 to 5 weeks have elapsed since the previous cutting and considerable within-field reproduction of potato leafhopper has occurred. High numbers of leafhopper nymphs often can be found at this time.

In consideration of the predominant proportion of adult leafhoppers during the critical sampling period for timing chemical control and the strong agreement of the field data for adult leafhoppers with the Poisson series, this frequency distribution was chosen to develop the sequential sampling plan.

Development of the sequential sampling plan

Every sequential plan is defined by one or more pairs of parallel lines. Samples are taken sequentially with the cumulative number of organisms plotted against sample number. Continued sampling is indicated when coordinates fall between the parallel decision lines; sampling is stopped and a decision made when coordinates fall on either side of the area between the parallel lines. These decision lines are calculated using the following formulas (Waters 1955):

d_2 = bn - h_2 (lower line)

d_2 = bn + h_2 (upper line)

where b = the slope of the lines and h_1 and h_2 are the respective Y-intercepts. Slopes and intercepts are calculated as follows:

$$b = \frac{m_2 - m_1}{\log_e m_2 - \log_e m_1} \qquad (2)$$

$$h_1 = \frac{\log_e \frac{1-.}{}}{\log_e m_2 - \log_e m_1} \qquad (3)$$

$$h_2 = \frac{\log_e \frac{1-.}{}}{\log_e m_2 - \log_e m_1} \qquad (4)$$

where m_1 and m_2 = class limits (defined by the investigator), alpha = the probability of rejecting a true hypothesis, and beta = the probability of accepting it when false. Alpha and beta are risk values specified by the investigator and need not be equal. Alpha and beta values of 0.05 were chosen for the development of a potato leafhopper sequential plan giving a risk of making an erroneous decision of 1 in 20 fields.

Influence of class limit values on sampling plan accuracy and number of samples required

The class limits values, m_1 and m_2 which specify infestation categories, are usually based on some prior knowledge of the economic threshold level. As can be seen from equations 3 and 4 for calculating y-intercepts of the decision lines, (h_1 and h_2), the closer m_1 and m_2 are in value, the larger h_1 and h_2 will be. From the equations (1) for the decision lines, it follows increasing h_1 and h_2 will increase the distance between the decision lines. In theory, this reduces the chance of erroneous decisions, since the "continue sampling" zone will be larger, however, the number of samples required will increase.

Although one object of sequential sampling is to reduce unnecessary sampling, a compromise must be struck between time savings and accuracy. Used here the term "accuracy" means agreement with a fixed sample plan in making pest management decisions. As Allen et al. (1972) pointed out, one must keep in mind that the object of sequential sampling in pest management is to make decisions, not estimate population parameters, such as mean and variance.

To evaluate the influence of class limit parameters on sampling plan accuracy and sample size requirements, a FORTRAN computer program was written to compare results of fixed sampling plan decisions with sequential plan results. Provision was made to vary class limit values for the sequential plan and to specify a minimum and a maximum number of samples taken with the sequential plan. Although agreement with a fixed plan often can be obtained with only one sample using the sequential plan, a minimum of three samples was specified to reduce risk of error. A maximum of six samples per field for the sequential plan was arbitrarily determined because of scouting cost considerations.

Because the economic threshold values for potato leafhopper in Virginia are dependent on alfalfa stem height, 5 separate sequential plans were developed for the following size categories of stem heights: 0-17.8 cm (0-7.0 in), 17.9-26.2 cm (7.1-10.3 in), 26.3-34.8 cm (10.4-13.7 in), 34.9-43.2 cm (13.8-17.0 in), and greater than 43.2 cm (17.0 in). The data set described earlier with 126 replicates in 54 fields, with 15 samples per field, was used for the analyses. Five sets of class limit values were evaluated for each stem height size category, changing class limit values by 0.5 units for each simulation. Alpha and beta values were held constant at 0.05 throughout the analysis.

Validation of a sequential sampling plan

Before a sequential sampling plan is implemented in an IPM program, the plan should be validated with field data collected independently from data used in plan development. Ideally, these validation data should include a wide array of insect densities, crop phenologies, and weather conditions, and should be taken across several years to include seasonal variability. Validation data also should be taken by several individuals to include this source of variability. Criteria for acceptance of a sequential sampling plan depend, of course, on individual program requirements. For implementation in the Virginia IPM program, a 5% probability of making a wrong decision using the sequential plan was our predetermined acceptance criteria.

To validate the potato leafhopper sampling plan, three years' field data from the Virginia IPM program was used. All sampling was conducted using a 38 cm diam sweep net, with 10 sweeps per sample. In 1980 and 1981, from 6 to 10 samples were taken per field using the fixed sampling plan, and in 1982, sample size was 4 to 8 samples per field. The varying sample size in the fixed sampling plan was an effort to stabilize sampling intensity among fields of varying size. A minimum number of samples (6 in 1981 and 4 in 1982) were taken in fields comprising 10 or fewer acres, with one additional sample taken for approximately each 5-acre increase in field size. A maximum number of 10 samples in 1981 and 8 samples in 1982 was arbitrarily determined. Although the sequential sampling plan described in this paper was used by field scouts during August 1982, only data collected prior to its implementation was used for sampling plan validation. In 1980, two scouts obtained 126 replicates from 30 alfalfa fields in 5 western Virginia counties. (This is a different data set than the 1981 data described earlier which was used for sampling plan development and also contained 126 replicates.) Validation data from 1981 included 471 replicates from 99 fields, involving 6 scouts, and in 1982 two scouts obtained 902 replicates from 225 fields. The FORTRAN program described earlier compared decisions made by the fixed plan with decisions using the sequential plan.

RESULTS AND DISCUSSION

Sequential plan development and application

Analysis of class limit selection on the accuracy and required sample size for a sequential sampling plan reveal few consistent trends for stem heights of 0-17.8 cm (Table 1. An expected decrease in required sample size is associated with increasing differences in class limit values. For adult leafhoppers, there is an associated decrease in accuracy with decreased sample size; however, the accuracy response of the plan using adults plus nymphs is not consistent. For other stem heights, changing class limit values had little effect on accuracy, and only for stem heights greater then 43.2 cm was a relationship observed between sample size requirements and class limit differences. We concluded, therefore, that within the range tested, the selection of class limit values was not critical to the development of sequential sampling plans for potato leafhopper in alfalfa. Intermediate class limit values that bracketed the fixed action thresholds were chosen for further sampling plan validation.

Sequential sampling plans may be displayed graphically or in tabular form. Slope and intercept values for the sequential sampling plan decision making lines are presented

Table 1. Influence of class limit values on number of samples required and accuracy of a sequential sampling plan.

Number of fields sampled	Total samples for fixed plan	Crop height	Class Limits		Adults		Adults & Nymphs	
			M_1	M_2	errors	samples req'd	errors	samples req'd
53	827	0-7	2.5	3.5	1	233	0	227
			2	4	1	173	1	176
			1.5	4.5	1	170	1	173
			1	5	2	170	0	171
			.5	5.5	4	160	3	161

in Table 2. However, for practical application in the field, a table of critical decision making values was found easier to use than graphs, and these values are shown in Table 3. This table (with crop height categories in inches rather than centimeters) was printed on a 3 x 5 inch card, and used by field scouts in late summer 1982.

To use the sequential plan in the field, the scout takes 3 random samples of 10 sweeps per sample. The total number of adult plus nymphal leafhoppers for all 3 samples is determined. At each sampling site, 3 random stem lengths are measured, with an extra stem length measured at the last site (giving a total of 10 stems, for easy division). The average stem length is calculated and the appropriate plant height selected from Table 3. For example, if after 3 samples from alfalfa 18 cm or less in height, 4 or fewer leafhoppers were found, no treatment is recommended; if 13 or more leafhoppers are found, treatment is recommended. If between 5 and 12 leafhoppers are found, no decision is reached, and the sampler takes a fourth sample. The table is again consulted using the total leafhopper count for 4 samples. Sampling stops when a decision has been reached. If no decision is reached after six samples, the sampler uses the data to compute an average number of leafhoppers per sweep and refers to the decision making chart shown in Fig. 1.

Table 2. Slope and intercept values for sequential sampling plan decision making lines.

Stem Height	Slope[1]	Intercept
0.17.8 cm	2.485	1.829
17.9-26.2 cm	5.786	3.155
26.3-34.8 cm	10.451	5.495
34.9-43.2 cm	14.860	8.751
> 43.2 cm	17.481	25.736

---

[1] Slope (b) and intercept (h_1,h_2) values for the linear functions $d_1 = bn-h_1$ and $d_2 = bn + h_2$.

Table 3. Critical values for a potato leafhopper sequential sampling plan.

		Cumulative Number of Potato Leafhoppers		
Plant height	Number of samples	No treatment needed		Treatment needed
0-18 cm	3	4	CONTINUE SAMPLING	13
	4	7		16
	5	10		19
	6	13		22
18-26 cm	3	13		23
	4	19		29
	5	25		35
	6	31		41
26-35 cm	3	23		41
	4	34		51
	5	44		62
	6	55		72
35-43 cm	3	30		59
	4	45		74
	5	60		89
	6	75		104
> 43 cm	3	35		69
	4	52		87
	5	70		104
	6	88		122

Field validation of sequential sampling plans

A comparison of fixed versus sequential sampling plan decisions are shown in Table 4. The sequential sampling plan performed well in all 3 years, with less than 4% error in 1980 and 1981, and a very low 0.4% error rate in 1982 (used here, "error" means disagreement with fixed sampling plan results). The low error rate in 1982 can be partly attributed to abnormally high leafhopper population levels in which the sequential plan quickly categorized the population levels. In 1980 and 1981, leafhopper levels were low to moderate with considerable variability among fields. When no decision could be reached using the sequential plan (column 6 of Table 4), the fixed sampling plan and decision making chart (Fig. 1) were used. This was not considered an error of the sequential plan, since it did not produce a decision differing from the fixed sampling plan. The sequential plan also reduced the number of required samples, a principal objective in developing a sequential plan. Total sample numbers were reduced by 55% in 1980; 52% in 1981; and 27% in 1982.

In conclusion, the sequential sampling plan reported here for potato leafhopper in alfalfa is reliable, can be used easily in the field, and can reduce significantly the number of samples required for pest management decision making.

Table 4. Validation of a sequential sampling plan using field data from 1980-82.

Year	Total fields sampled	Total samples using fixed plan	Total samples for sequential plan	Number of correct decisions using the sequential plan	Number of fields in which no decision was reached using the sequential plan[1]	Number of errors	% error
1980	126	1,178	524	111	10	5	3.9
1981	470	3,627	1,722	424	28	18	3.8
1982	902	4,425	3,243	754	144	4	0.4

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[1] When no decision was reached using the sequential plan, the fixed sampling plan and decision making chart (Fig. 1) were used.

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CHAPTER VI

Implementation of an Integrated Pest Management Program for Virginia Alfalfa Producers

In less than thirty years since the landmark publication of "The integrated control concept" (Stern et al. 1959), the integrated pest management (IPM) paradigm has become widely accepted within the scientific agricultural community. At the farm level, however, IPM is still largely a novel concept, with pest control accomplished primarily through the use of pesticides (Perkins, 1982). Although "IPM programs" have been developed in most states and many nations for many cropping and forestry systems, it is estimated that at least 90 percent of the potential for IPM implementation remains to be achieved (Yarn and Steinhauer, 1980).

The term "implementation" can apply to an individual farmer's adoption and usage of a particular technology or practice, but in the context of this discussion, implementation is defined as the process of converting alternative management strategies into actual practice. In this paper an "IPM program" is defined as a comprehensive strategy for the management of pests which optimizes economic, ecological, and sociologial objectives. IPM programs are most commonly developed on a commodity basis and implemented by Cooperative Extension Service personnel, however in some states private consultants are also involved in implementing IPM. Implementation involves education and persuasion of farmers to change their current pest management practices, but often involves the creation of new information gathering and dissemination organizations (i.e. scouting programs) that transcend the traditional educational role of the Extension Service.

While IPM certainly includes such crop-specific factors as economics and pest ecology, other sociological and political factors (called non-entomological factors by Corbet, 1981) play an important role in IPM implementation. Like any other innovation, IPM is evaluated by potential adopters, and the rate of adoption generally depends on five attributes of the innovation (Lambur et al. 1985): relative advantage, compatibility, complexity, trialability, and observability. These attributes are described in detail by Lambur et al. (1985).

As described in Chapter 1, research and implementation in IPM are ideally concurrent activities, closely tied by information feedback loops. As IPM programs are implemented on farms, new information needs are identified which can be addressed by appropriate research. As research develops new information on crop/pest systems, this information can be incorporated into the IPM program. Because of the dynamic nature of agricultural ecosystems, IPM programs for pests within these ecosystems require periodic reevaluation and appropriate modifications.

In the implementation process, a technical as well as philosophical question emerges: When is the development and implementation of an IPM program completed? Since IPM is a philosophical approach to pest control as well as a complex cluster of technologies (Lambur et al. 1985), the answer to this question depends on one's working definition of IPM as well as specific program goals. Focusing on the ecological orientation of IPM might suggest that IPM is accomplished when the agroecosystem has been studied and manipulated to the degree that acceptable levels of natural control of pest organisms are occuring and no off-farm energy inputs such as pesticides are required for pest control. The economic component of IPM, on the other hand, emphasizes the optimization of short-term economic return , minimizing the importance of ecological consequences of particular pest control practices. Obviously in practice IPM compromises these two extremes. Pragmatism and the ability to develop working programs within the constraints of existing farming systems has been a hallmark of IPM programs for the past two decades.

There are many levels of comprehensiveness in IPM development and implementation, as illustrated by Poston et al.'s (1983) four levels of economic thresholds. These authors suggest that the appropriate level of IPM technical complexity is determined by the particular pest/crop situation to be managed, as well as resource and technology limitations. Thus a great deal of subjectivity is involved in determining not only to what extent the development and implementation processes of an IPM program are "complete" or "adequate", but also to whether a particular pest management system should even be called "integrated".

Because of the prevailing dependence on insecticides for agricultural insect pest control, IPM programs inexorably place initial efforts on modulating insecticide use (i. e. field scouting and the use of action thresholds). Indeed, success of IPM programs is commonly measured in units of reduced insecticide usage (Good 1977). While programs involving only scouting and nominal treatment thresholds are often criticized as not really "IPM", I consider scouting and the use of nominal treatment thresholds to be the minimal requirements of an IPM program. Ideally multiple pests and multiple control tactics are integrated into an IPM program, however, as mentioned above, the degree to which this is feasible depends on the particular pest/crop situation and available resources for research and implementation activities.

In my opinion, IPM programs are adequate if they involve research-based pest monitoring and treatment thresholds, and give some measurable level of improvement over pre-IPM pest control practices. Measurable variables to quantify improvement could be such things as pesticides reduced, increased net profit, reduced environmental contamination, or reduced managerial stress. There is also an implicit assumption for program adequacy that all reasonable effort (within resource constraints) has been made to integrate non-chemical controls into the IPM program.

Implementation of an Alfalfa IPM Program in Virginia

In 1980 an integrated pest management program for Virginia alfalfa producers was established with the following goals:

1. Improve forage quality and increase production per acre of alfalfa,
2. Increase return on investment to alfalfa growers
3. Develop an IPM program which maximizes effectiveness of biological and cultural control of key insect pests and minimizes reliance on chemical control, and accomplishes the general goals described in 1 and 2 above.
4. Evaluate the economic impact of this IPM program on Virginia alfalfa producers

Based on existing information about the relative importance of the insect pests attacking alfalfa in Virginia, two target pests, the alfalfa weevil (AW) and the potato leafhopper (PLH), were identified as candidates for inclusion in a management program. During the spring and summer, 1980, insect populations were sampled weekly on 580 acres of alfalfa on 28 cooperating farms in 6 western Virginia counties. Because of the administrative imperative to implement an IPM program as soon as possible, the following first-year objectives were established: (1) determine current pest management practices used by Virginia alfalfa producers, (2) to collect seasonal abundance data on the target pests and determine whether other pests needed to be included in the IPM program, and (3) to evaluate (more qualitatively than quantitatively) what were considered the most feasible IPM practices (sampling methods, action thresholds, cultural control methods, and modification of chemical control.)

An additional purpose in this first year was to get to know county Extension agents and innovative farmers in principle alfalfa growing counties. Just as extension programs have traditionally focused initial efforts on innovative, "early adopter" farmers, I needed to determine who the innovative, early adopter county Extension agents were. Some of the Extension agents I met were very lukewarm to negative concerning the need for IPM in their counties; other agents were quite enthusiastic. Because of the important role of Extension agents in IPM program implementation, I decided to concentrate my work in counties where the agents were supportive of the IPM philosophy.

Grower Survey Conducted

A survey was conducted in the fall, 1981, to determine current pest management practices used in alfalfa. Surveys were mailed out of county Extension offices to 1,134 alfalfa growers in 44 western Virginia counties. Results of this survey were published (Luna 1982) and are included in Appendix A. Of particular interest to the development of the IPM program was that most alfalfa growers (89%) sprayed insecticides routinely for alfalfa weevil control, whereas less than 5% used insecticides for potato leafhopper control. An initial hypothesis was then developed (based in part on data collected in 1980) that an IPM program utilizing regular field sampling for pest abundance, coupled with action thresholds for insecticide application decision-making, could reduce unnecessary insecticides for weevil control. This system would, on the other hand, quite likely increase the amount of insecticides being used for potato leafhopper control, however there would be associated increases in yield and forage quality due to timely pest control.

The Pilot Project Phase, 1981-82

In 1981 a grant was obtained from Virginia Agricultural Foundation to initiate a "pilot program" in alfalfa pest management. Two field scouts were hired to monitor pest abundance and crop phenology in alfalfa fields in 4 counties in the Shenandoah Valley. Alfalfa weevil populations were monitored on 720 acres on 20 farms and potato leafhopper populations were monitored on 1436 acres on 31 farms. Sampling methods and action thresholds were adapted from Pennsylvania (Gessel 1978). The Virginia Agricultural Foundation grant paid for all scouting expenses, thus the program was free to all participating growers.

In 1982 this Pilot Program was expanded to include 2,649 acres on 71 farms in the AW scouting program and 3,744 acres on 85 farms in the PLH scouting program. After the 1981 season, empirical modifications of the action thresholds were made in an effort to make the thresholds more responsive to Virginia growing conditions. The Pennsylvania decision-making guidelines for AW (Fig. 1) contained considerable ambiguity, with a large "warning" zone, but an actual treatment threshold of 2.7 larvae per stem, regardless of alfalfa crop height. At fairly short stem heights, this threshold permitted defoliation that was considered unacceptable to many of the growers in the program. Although no yield loss measurements were taken to verify visual observations, a decision was made to modify the Pennsylvania decision-making chart to a single decision line (Fig. 1) which was more conservative (i.e. recommended insecticide applications at lower pest intensities). For the potato leafhopper, action thresholds also appeared to be too liberal, permitting excessive yellowing and stunting to occur. An empirical modification of the action threshold for

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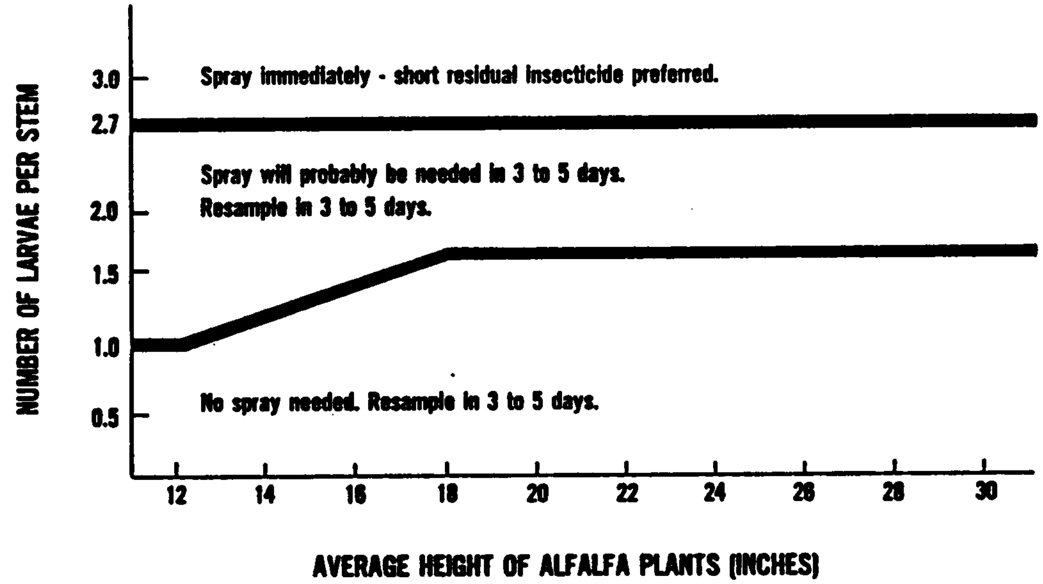


VIRGINIA DECISION — MAKING CHART

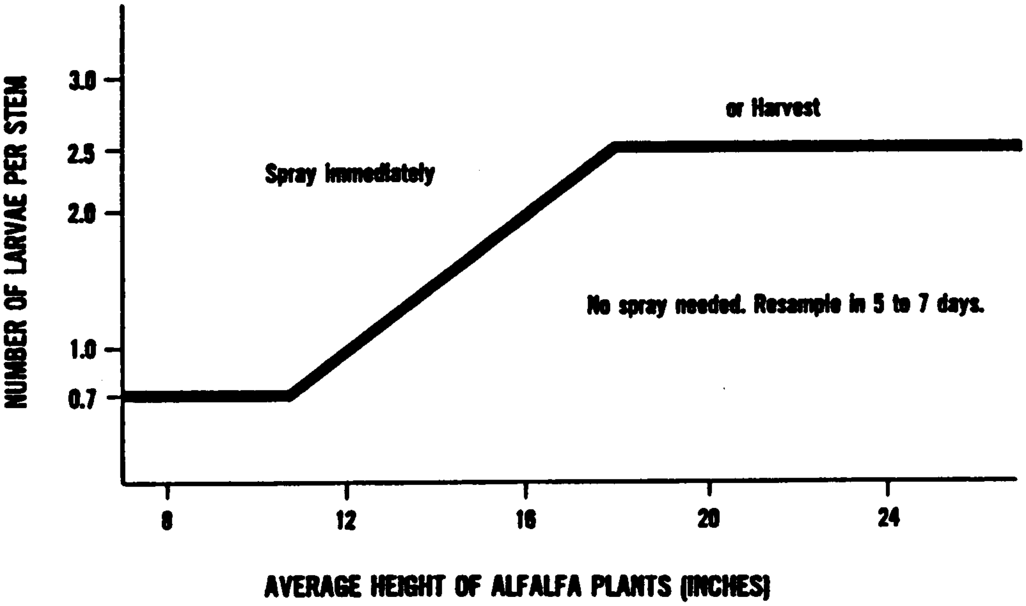


Fig. 1. Decision-making charts for alfalfa weevil control Pennsylvania (top graph), and Virginia (lower graph).

PLH was made as follows: (1) in all fields where treatment was not recommended and unacceptable damage occured, mean values of PLH per sweep and alfalfa stem height from the earliest sampling date within the cutting when damage occured were plotted on the old decision-making chart, (2) a new threshold line was drawn to include a majority of these data points (excluding obvious outliers) in the "spray immediately" catagory (Fig. 2).

In spite of these threshold modifications, the 1982 Pilot Program revealed that problems still existed with the action threshold for the alfalfa weevil. In several fields, weevil populations were below the new threshold and no insecticides were applied, however extensive defoliation and obvious yield loss occured. These problems appeared to be related to drought stress occuring in late April and early May. Rather than continue attempting empirical modification of an action threshold for AW, I decided to discontinue implementation efforts for the AW component of the alfalfa IPM program until additional research on economic injury levels for this insect could be conducted (see Chapters 4 and 5).

Additional factors leading to this decision included the relatively low economic benefits from the IPM program in several counties where weevil problems were most severe (Table 1). In Rockbridge and Augusta counties, most fields required treatment for AW in both years of the Pilot

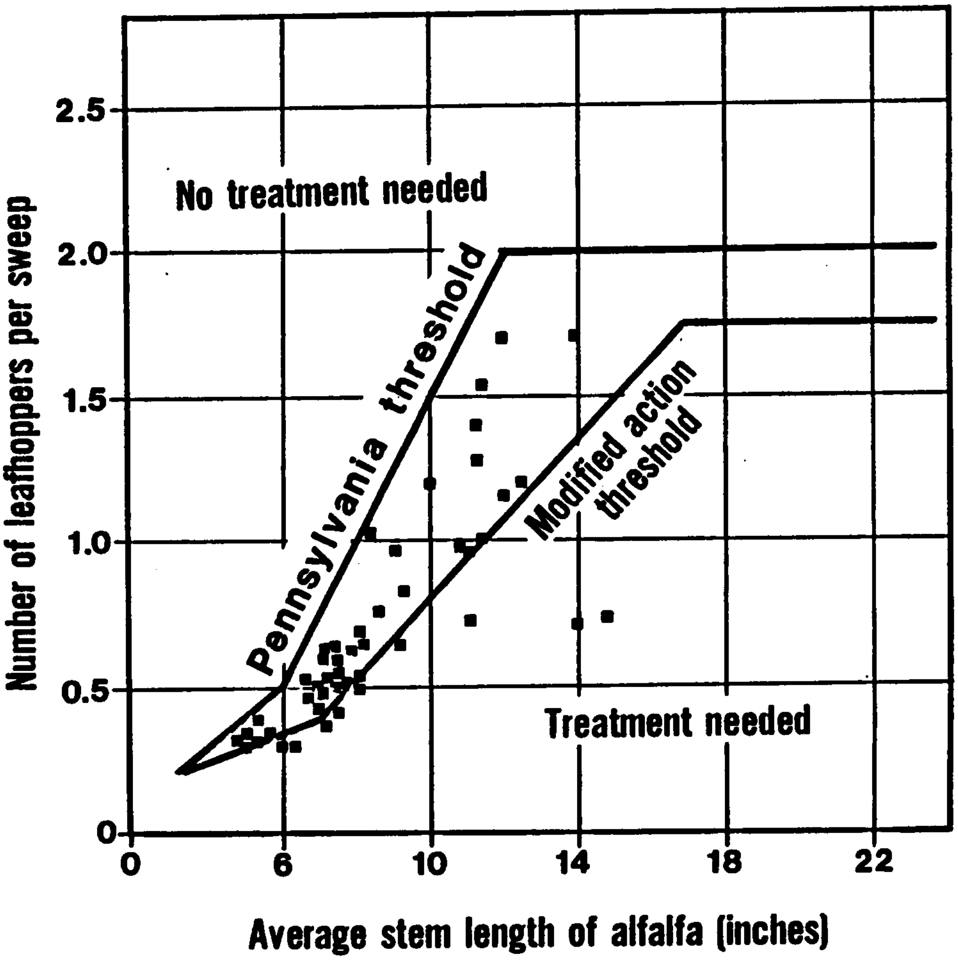


Fig. 2. Modification of the Pennsylvania decision-making chart for potato leafhopper. Plotted points are 1981 field data from fields in the IPM Scouting Program in which the Pennsylvania decision-making chart indicated no treatment was necessary, however extensive yellowing and stunting were observed at harvest.

Table 1. Summary of alfalfa scouting and control recommendations for the Alfalfa IPM Pilot Program, 1981-82.

County	No. of farmers		No. of fields		No. of acres		% of Acres insecticide recommended	
	1981	1982	1981	1982	1981	1982	1981	1982
Montgomery	2	--[1]	4	--	42	--	0	--
Rockbridge	5	19	11	46	135	516	94	100
Augusta	12	19	29	67	410	453	33	68
Rockingham	8	23	22	67	315	314	30	33
Shenandoah	--	7	--	18	--	6	--	2
Page	--	9	--	19	--	62	--	26
Totals or Ave:	27	77	66	217	902	1,351	39%	51%

[1] -- indicates county was not in the Pilot Program both years.

Program. In these counties, few economic benefits could be attributed to the IPM program, even though some benefits undoubtedly accrued from improved timing of insecticide applications. In more northern counties, such as Shenandoah and Rockingham, AW infestations were much more variable and considerable savings resulted from decreased insecticide use. Although the AW scouting program could have been continued in these counties, I believed that for the long-term success of the IPM program, there was a higher priority to conduct research on economic injury levels for AW.

Another factor in discontinuing the scouting program for AW was the difficulty in hiring and training field scouts for a very short field season (3-4 weeks) in a period of the year where the weather could be quite cold and wet. College students needing summer employment had been used quite sucessfully as field scouts in the PLH program, however this labor pool was not available for scouting alfalfa weevil in April and May. College students from Blue Ridge Community College at Weyers Cave were recruited on a part-time basis to scout fields for weevil in the pilot program, however conflicts with classwork reduced their effectiveness as field scouts.

Implementing a Grower-financed Scouting Program for PLH

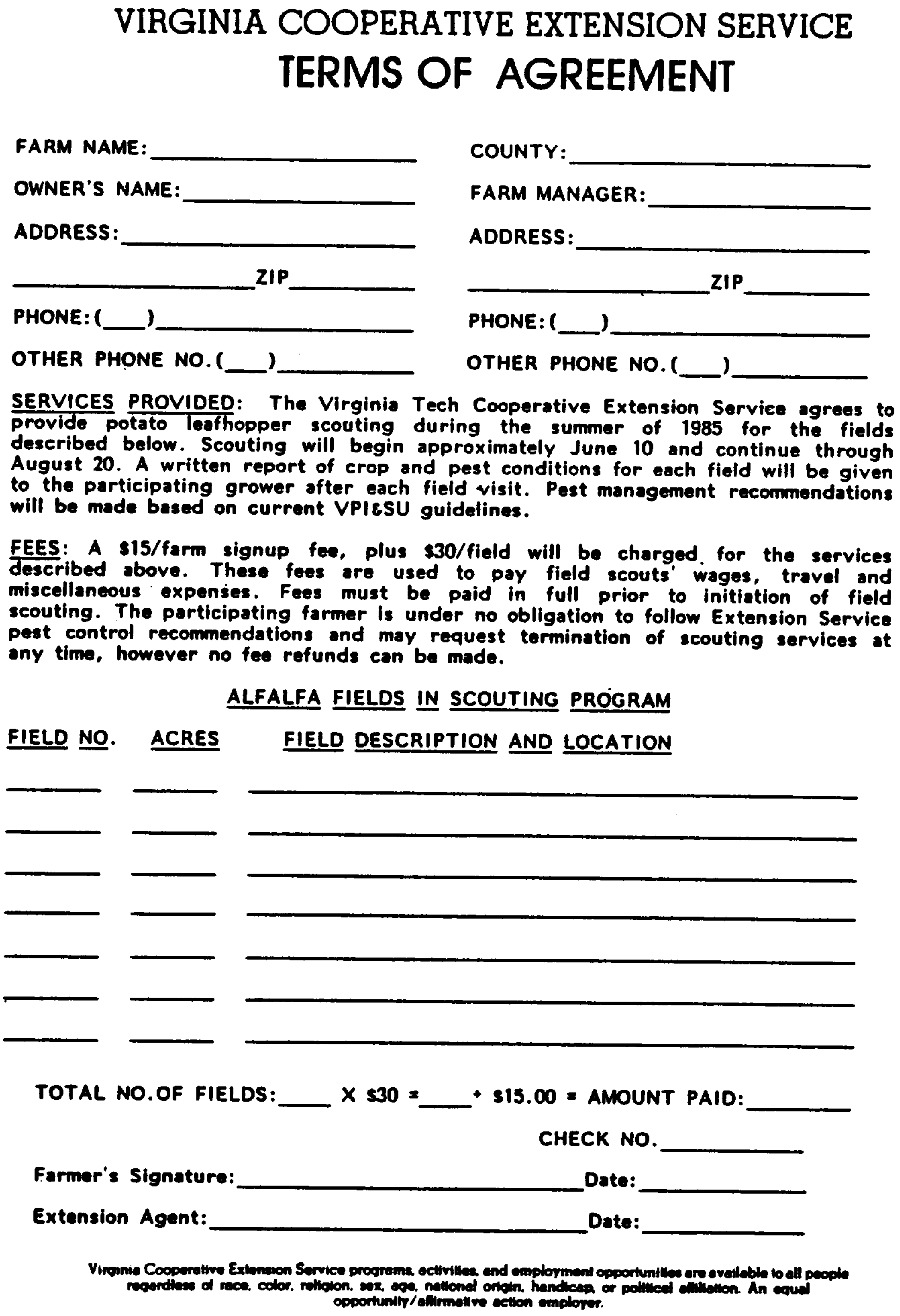
In the winter of 1983 a series of grower meetings were held in the Pilot Program counties to discuss the results of the program and to determine interest in continuing a potato leafhopper scouting program. Potato leafhopper infestations were widespread in 1982, causing extensive damage to alfalfa throughout the state, consequently there was a strong interest among Extension Agents and alfalfa producers in continuing the PLH scouting program. An Alfalfa IPM Steering Committee was formed, comprised of one Extension agent and two alfalfa producers from each county, and me. This committee developed plans to implement a fully grower-finance scouting program for the potato leafhopper.

The Virginia Tech Cooperative Extension Service agreed to administer the scouting program, and an account was established to collect and dispurse funds. Using data collected in the Pilot Program, the IPM Steering Committee developed a pricing system in which growers would be charged $15 per farm enrollment fee, plus $30 per alfalfa field. These fees would include all actual scouting costs, including wages, travel, equipment and forms. The Extension Service would provide all management and insurance for the field scouts. Although most existing IPM programs operated on a per acre fee, analysis of the leafhopper program indicated that a per field charge would be more equitable for the following reasons: field scouting is composed of several activities, including driving to the field, getting equipment out of the scout's car, actual field sampling, and report writing. Travel and report writing took a substantial part of the scouts' time and was independent of field size.

Because the number of samples taken in a field didn't depend on field size (see the development of a sequential sampling plan, Chapter 3), the only influence field size had on scouting time was the distance walked in the field. Compared to the total time involved in all activities related to scouting, this variation in time was insignificant. Thus the Steering Committee believed a fee system based on acreage alone would have unfairly benefited owners of small alfalfa fields and penalized owners of larger fields.

A "Terms of Agreement" form (Fig. 3) was developed to serve as a written contract between the Virginia Tech Cooperative Extension Service and the participating growers. Specific functions to be performed by the Extension Service were described and fields to be scouted were listed on the form.

In 1983, the first year of the grower-financed scouting program for PLH, total enrolled acreage dropped below the 1982 acreage (Fig. 4), but continued to increase in 1984 and 1985. An implementation policy was adopted to only expand the scope of the program by 3 to 4 counties per year to allow sufficient educational efforts to be focused in new participating counties. In 1985 a "Scouting Manual for the Alfalfa Pest Management Program" was written to standardize scouting procedures and assist in scout training, and the "Operator's Manual for the Virginia Alfalfa Integrated Pest



VIRGINIA COOPERATIVE EXTENSION SERVICE

TERMS OF AGREEMENT

FARM NAME:__________	COUNTY:__________
OWNER'S NAME:__________	FARM MANAGER:__________
ADDRESS:__________	ADDRESS:__________
__________ZIP__________	__________ZIP__________
PHONE:(___)__________	PHONE:(___)__________
OTHER PHONE NO.(___)__________	OTHER PHONE NO.(___)__________

SERVICES PROVIDED: The Virginia Tech Cooperative Extension Service agrees to provide potato leafhopper scouting during the summer of 1985 for the fields described below. Scouting will begin approximately June 10 and continue through August 20. A written report of crop and pest conditions for each field will be given to the participating grower after each field visit. Pest management recommendations will be made based on current VPI&SU guidelines.

FEES: A $15/farm signup fee, plus $30/field will be charged for the services described above. These fees are used to pay field scouts' wages, travel and miscellaneous expenses. Fees must be paid in full prior to initiation of field scouting. The participating farmer is under no obligation to follow Extension Service pest control recommendations and may request termination of scouting services at any time, however no fee refunds can be made.

ALFALFA FIELDS IN SCOUTING PROGRAM

FIELD NO.	ACRES	FIELD DESCRIPTION AND LOCATION
______	______	__________________
______	______	__________________
______	______	__________________
______	______	__________________
______	______	__________________
______	______	__________________
______	______	__________________

TOTAL NO.OF FIELDS:____ X $30 =____+ $15.00 = AMOUNT PAID:________

CHECK NO.__________

Farmer's Signature:____________________Date:__________

Extension Agent:____________________Date:__________

Fig. 3. Terms of Agreement form used in the potato leafhopper scouting program.

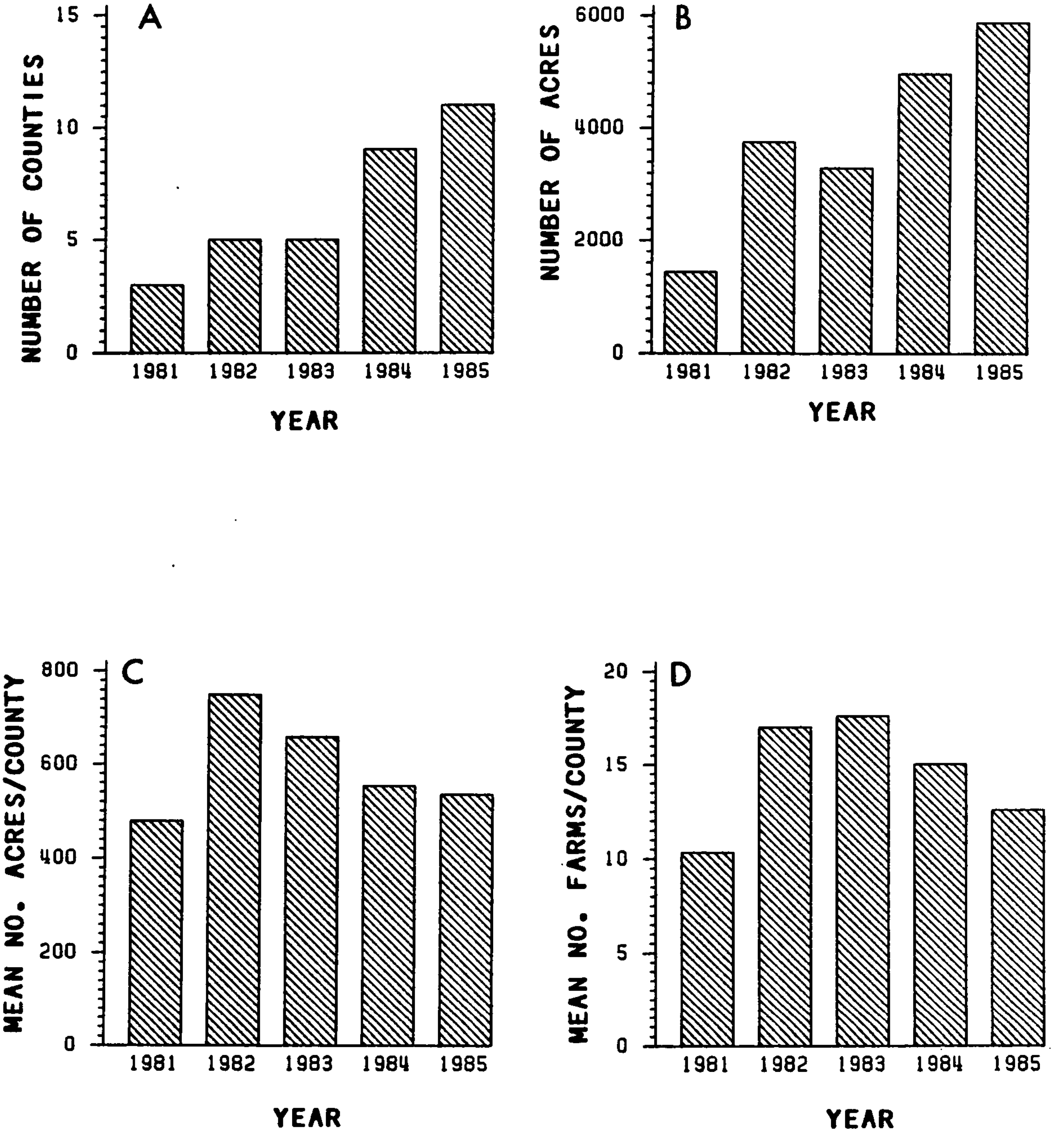


Fig. 4. Statistics associated with the potato leafhopper scouting program in Virginia, 1981-1985: (A) number of counties in program, (B) total number of acres scouted, (C) mean number of acres per county, (D) mean number of farms per county.

Management Program" was prepared to provide program operation procedures for Extension Specialists and Agents.

Development of a Computerized Data Base Management System for the Alfalfa IPM Program

IPM programs involving field scouting generate large quantities of data which have an array of potential uses. Transformation of these data into usable information for decision makers occurs at several levels of time and spatial resolution. Information concerning pest and crop states are needed by farmers implementing control strategies, and Extension agents and specialists involved in pest management recommendations. However, this information usually must be available in a near real-time mode (24 to 48 hours old) to be relevant in pest management decision-making. Information from scouting data are also useful as an historical data base for program operation evaluation, research applications, and economic impact accessment.

Computers are obvious tools for the task of developing information management systems which are fast and easy to use. Since the initiation of the Alfalfa IPM Project in 1980, a continual effort has been made to develop and implement a computer-based data acquisition and information retrieval system. This project was conducted in cooperation with Susan L. Rutherford and F. William Ravlin, and a complete discussion of the development of a data base management system (DBMS) for the Alfalfa IPM Program is included in Rutherford (1985). Rutherford developed all software assocated with this project; my role has been to define program needs and implement the DBMS in the Alfalfa pest management program. The DBMS has evolved since 1980, both in software sophistication and mechanisms of data acquisition and information delivery. The following is a brief summary of this evolution.

1980: Field data were entered onto SAS data files on the VPI & SU mainframe computer at Blackburg using CRT terminal. At the end of the field season, SAS was used to generate summary statistics of the program. This system was relatively inexpensive and problem-free, however, information was not available in near real-time.

1981: Two field scouts working in the Shenandoah Valley used a printer terminal and modem at Blue Ridge Community College to access the mainframe computer at Blacksburg. Data were entered on the computer generally on the same day collected, an error checking program verified data, and report generation programs (written in PL-1) provided near real-time information to Extension personnel. Although the turn around time for data handling was acceptable for this system, accessability to the terminal at Blue Ridge Community College was limited, and it was very inconvenient for scouts to come to the college in the evenings when the terminal was available. Telephone communication through the college switchboard also caused frequent data transmission errors.

<u>1982</u>: Portable TI-700 printer terminals (with internal 300 baud modems) were acquired, enabling scouts to enter data onto the computer directly from their homes after each day of field scouting. While this system was very convenient for the scouts to use, the printer terminals only allowed one line of text to be viewed at a time, and the data entry and error checking procedures required considerable training. Some scouts experienced great difficulty in learning the computer data entry procedures. Telephone costs for this data entry system were also prohibitively expensive. In both 1981 and 1982 Extension Agents could access a user-ID on the Va. Tech mainframe computer and print summary reports on insect and pest conditions. However most agents also only had printer terminals in their offices and communication with the Va. Tech mainframe computer was sporadic.

<u>1983 - 1985</u>: Both the methods for data entry and the data base management software were totally revised in 1983. Many county Extension offices obtained CRT's and 1200 baud modems in 1983, enabling entry of scouting data from the county offices. A menu-driven system was developed which included full-screen data entry

formats resembling the scouting reports. Thus data entry and error checking became much quicker and "user friendly". A data base management system was developed on the Tech mainframe using the SPIRES data base management system developed at Stanford Univ. This system greatly enhanced the flexiblity of both data entry and information retrieval, and facilitated other uses of the alfalfa IPM data base. All data entry and error checking is still performed while on-line with the Va. Tech mainframe computer, however, and even though field scouts were only entering data into the system twice a week, telephone expenses (currently paid by Va. Tech Cooperative Extension Service) were still considered excessive. The Extension Service has recently installed IBM-PC microcomputers in the county Extension offices, and current work on the Alfalfa IPM data base management system includes development of software to allow data entry and error checking to occur off-line on the microcomputer, followed by bulk data transmission to the mainframe computer in Blacksburg. This improvement would greatly reduce telephone communication expense.

Applications for the Pest Management DBMS

Current uses for the DBMS include the following (1) generation of near on-line scouting reports (Fig. 5) which are available to Extension Agents, who use a query-driven

COUNTY	SMPL DATE	GROWER NAME	FLD NO.	BUDS	FLW	AVG STEM	PLH P SWEEP	THRES	REC
Montgo	07/25	YOUNG, ROBERT T	3	99	0	21.09	0.43	NO	N
Montgo	08/14	YOUNG, ROBERT T	3	0	0	7.60	0.32	NO	N
Montgo	06/18	YOUNG, ROBERT T	4	4	0	15.60	0.63	NO	N
Montgo	06/26	YOUNG, ROBERT T	4	0	0	4.20	0.80	YES	S
Montgo	07/16	YOUNG, ROBERT T	4	52	0	16.79	0.30	NO	N
Montgo	07/25	YOUNG, ROBERT T	4	99	0	17.70	0.33	NO	N
Montgo	08/14	YOUNG, ROBERT T	4	0	0	7.10	0.60	CLOSE	S
Montgo	06/18	YOUNG, ROBERT T	5	40	0	16.20	1.30	NO	N
Montgo	06/26	YOUNG, ROBERT T	5	0	0	4.50	1.06	YES	S
Montgo	07/16	YOUNG, ROBERT T	5	60	0	17.00	0.30	NO	N
Montgo	07/25	YOUNG, ROBERT T	5	99	0	18.70	0.30	NO	N
Montgo	08/14	YOUNG, ROBERT T	5	0	0	7.20	0.66	YES	S
Montgo	06/18	SHANKLIN, JOHN	1	99	0	23.00	0.23	NO	N
Montgo	07/05	SHANKLIN, JOHN	1	0	0	6.00	0.03	NO	N
Montgo	07/16	SHANKLIN, JOHN	1	80	0	13.10	0.26	NO	N
Montgo	07/25	SHANKLIN, JOHN	1	99	4	17.79	0.30	NO	N
Montgo	08/04	SHANKLIN, JOHN	1	99	28	27.20	1.06	NO	HM
Montgo	06/18	SHANKLIN, JOHN	2	99	0	17.39	0.56	NO	N
Montgo	07/05	SHANKLIN, JOHN	2	0	0	8.40	1.00	YES	S
Montgo	07/16	SHANKLIN, JOHN	2	68	0	12.70	0.06	NO	N
Montgo	07/25	SHANKLIN, JOHN	2	99	8	16.59	0.16	NO	N
Montgo	08/04	SHANKLIN, JOHN	2	99	40	23.39	1.10	NO	HM
Montgo	06/27	SHORTER, CHARLE	1	0	0	8.30	0.20	NO	N
Montgo	07/05	SHORTER, CHARLE	1	20	0	13.40	0.66	NO	N
Montgo	08/02	SHORTER, CHARLE	1	16	0	10.10	0.13	NO	N
Montgo	08/12	SHORTER, CHARLE	1	96	0	21.29	0.06	NO	N
Montgo	06/20	SHORTER, CHARLE	2	8	0	8.20	0.23	NO	N
Montgo	06/27	SHORTER, CHARLE	2	40	0	9.60	0.50	NO	N
Montgo	07/05	SHORTER, CHARLE	2	96	0	12.30	1.55	YES	S
Montgo	08/02	SHORTER, CHARLE	2	8	0	8.60	0.13	NO	N
Montgo	08/12	SHORTER, CHARLE	2	92	0	17.89	0.26	NO	N
Montgo	07/05	TEEL, WILLARD	1	8	0	11.30	0.33	NO	N
Montgo	07/16	TEEL, WILLARD	1	99	0	21.20	0.46	NO	N
Montgo	08/02	TEEL, WILLARD	1	0	0	7.50	0.36	NO	N
Montgo	08/13	TEEL, WILLARD	1	92	0	17.09	0.50	NO	N

Fig. 5. Example of summary of scouting reports available to county agents via computer linkage to the alfalfa data base management system. Column headings not self-explanatory: BUDS = % of alfalfa stems with buds, FLW = % of stems with flowers, AVG STEM = average stem length (inches), PLH P SWEEP = average number of potato leafhopper per sweep, THRES = whether or not populations are above the action threshold (calculated by the computer), REC = the recommendation made to the farmer by the scout.

system to define the time frame and number of counties included in the summary, (2) generating data sets for the net benefit estimation model (Chapter 7) and yearly Extension Service Narrative Accomplishment Reports, (3) generating data sets for the Cooperative National Plant Pest Survey and Detection Program, (4) printing participating grower and field information on the Terms of Agreement forms to facilitate the annual grower registration process, and (5) maintaining and printing a mailing list of participating growers. Future applications of this system include the development of annual summaries for participating farmers and graphical presentation of scouting data.

Alfalfa IPM Implementation: Current Status and Future Needs

Although the scouting program for alfalfa weevil was discontinued in 1983, the alfalfa weevil continues to be an economic pest in Virginia. Weevil populations were extremely low in 1985 (see Chapter 4), however this may have been a single year phenomenon resulting from abnormally low winter temperatures (Hilburn 1986). The research reported in Chapters III and IV enhances our understanding of crop response to AW feeding at low infestation levels, however a quantification of yield response to higher AW infestation levels (commonly encountered before the scouting program for AW was discontinued) is still necessary before an economic threshold for this insect can be implemented as part of an alfalfa IPM program.

Although the potato leafhopper scouting program is relatively well established in 12 counties as a fee-supported program, and 1986 plans include expansion into 3 additional counties, this program is far from institutionalized. Extension agents in participating counties perform several roles in program management and operation, including participation in the Alfalfa IPM Steering Committee, conducting educational programs about IPM, enrolling farmers and collecting fees, and recruiting scouts. In my role as Extension Specialist, I have developed the mechanics of the scouting program and provided program coordination. Specifically I have helped promote the program through participation in educational programs, provided training and supervision for the scouts, administered program finances, including paying scouts wages and travel reimbursement, prepared and printed all related forms (Terms of Agreement, Scouting Reports, and promotional brochures), and maintained the alfalfa pest management DBMS.

Although efforts have been made to place much of the responsibility of program operation with the participating county Extension agents, I believe that continued involvement by an Extension Specialist will be required for continued program maintenanace and growth. If the volume of scouted acreage were higher, which could potentially include acreage from a corn IPM program, the economies of scale might permit the hiring of seasonal scout supervisors which would relieve some of the responsibilities of the Extension Specialist. However a Specialist's involvement is essential not only to provide program coordination, scout training, and technical enhancements (i.e. improved sampling methods, action thresholds, and control strategies), but also to provide the necessary ideological impetus for the furtherance of the integrated pest management philosophy. As mentioned earlier, IPM is an accepted paradigm in the academic community, but is still an innovative concept at the farm level. Only about 6% of Virginia's alfalfa acreage was enrolled in the IPM program in 1985. Continued educational and program development efforts will be required to change prevalent attitudes among farmers concerning pest control.

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CHAPTER VII

A Net Return Analysis of the Virginia Alfalfa Pest Management Program

ABSTRACT

Growers participating in the Virginia Alfalfa Integrated Pest Management (IPM) Program during 1981-84 realized an estimated average increase in net revenue of $3.56 per acre from alfalfa weevil component of the program, according to a net return analysis. The potato leafhopper (*Empoasca fabae* Harris) component of the program increased alfalfa growers net income by an estimated average of $11.39 per acre per year. Return to investment in the potato leafhopper scouting program averaged $6.83 per $1.00 invested in scouting for the four year period.

INTRODUCTION

Economic evaluation is an essential component in the design and implementation of integrated pest management (IPM) programs. Economic analyses are necessary not only to fulfill recent Congressional funding requirements, but also to establish the utility of programs to the intended clientele, and for the successful transfer of Extension Service-sponsored programs to the private sector.

There are two classic approaches to economic evaluation of IPM programs. The first approach, called the "before and after" method, compares costs and benefits of commonly used pest control practices prior to the introduction of an IPM program with costs and benefits after implementation of the program (Carruth and Moore 1973). This approach is limited when other production technologies, such as varietal selection, irrigation scheduling, and reduced tillage systems are also being concurrently adopted along with the new pest control technologies. Also limiting this method are extremes in weather and pest populations during the comparison periods. However the before and after approach is useful when production practices have remained relatively consistent, and the time periods for comparison are kept relatively short.

A second approach to economic evaluation of IPM programs has been to compare participating IPM producers with non-IPM producers. Allen and Roberts (1974) used this approach to evaluate the economic impact of soybean scouting in Virginia; Hall (1977) compared profitability of "supervised control" with "conventional control" of cotton and citrus production in the San Joaquin Valley; and Thompson et al. (1980) compared IPM participants and nonparticipants in evaluating the New York tree fruit IPM program. Although the possibilites for statistical analysis are appealing with this approach, Frisbee et al. (1976) have pointed out that differences in soil productivities, weather patterns, varietal selections, and other cultural practices among participants and non-participants often reduce the power of this analytical approach. Also, there are often differences in managerial abilities between the two groups, since the more progressive farm managers usually tend to be the "early adopters" of new programs such as IPM.

Frisbee et al. (1976) described an improvement of this evaluation method in which criteria were used in choosing both IPM program and non-program producers. Producers must grow the same or similar varieties, use the same irrigation practices, and have the same general management capabilities. Using selection criteria such as these will certainly reduce sources of variation, but again, this technique is limited in areas where weather patterns, particularly rainfall, are highly localized, and where a wide array of production practices are utilized for a given crop.

The comparison approach also assumes that no pest management information is exchanged between IPM users and the control group, and that no other educational efforts are being conducted by the the Extension Service which influence the behavior of the non-IPM study group. However, information is commonly shared among growers, and growers in the control group are not likely to ignore successful recommendations being used the the IPM group. As Boutwell and Smith (1981) emphasized, "With intensified IPM educational programs, a point can be reached at which all producers of a given commodity or within a given geographical area have been exposed to and influenced by IPM techniques and practices. At this point, participants or cooperators are no longer characterized by the use or non-use of IPM, but instead by the percentage of available IPM practices used."

These authors proposed a system of weighted importance of IPM practices in which numerical "scores" could be obtained from grower questionairres indicating each producer's level of IPM utilization. By obtaining the producer's pest control costs and his production yield, a correlation analysis can relate insect control cost, yield, and level of IPM that the producer used. This approach may be useful, particularly where an array of pest management practices are used. However the weighted values for specific management practices are assigned by the investigator, and may not reflect the relative value of these practices in a particular year or on a particular farm.

Because of the difficulties involved in using the comparison method, particularly because of extreme variation in soil productivity, rainfall patterns, and managerial abilities of alfalfa producers in Virginia, a modification of the "before and after" evaluation technique was developed to evaluate the cost effectiveness of the Extension Alfalfa IPM Program. Also because a statewide educational effort on alfalfa IPM was being conducted, including grower meetings, Extension publications, and mass media, it was felt that obtaining unbiased samples from the control group and IPM users would be virtually impossible.

MATERIALS AND METHODS

The Virginia Alfalfa IPM Program

The Virginia Alfalfa IPM program is similar to many other IPM programs in that field scouts monitor insect pests and crop phenology on a weekly basis during the growing season and give written reports to participating growers. Two insect pests, alfalfa weevil (*Hypera postica* Gyllenhal) and potato leafhopper (*Empoasca fabae* Harris), were monitored during the pilot project phase of the program (1981-82). Sampling methods and action thresholds for these insects are described by Luna (1984) and a sequential sampling plan used for potato leafhopper decision-making by Luna et al. (1983). Several weed species were also monitored, although economic evaluation of weed monitoring and control recommendations were not considered in this study. Field scouts used computer terminals located in county Extension offices to input field data on a daily basis to a mainframe computer located in Blacksburg. A data base management system (DBMS) was used to retrieve information.

The scouting program was grant-supported during the pilot project phase (1981-1982)+, then became grower financed in 1983. Growers paid a fee of $15 per farm, plus

$30 per field, regardless of acreage. County Extension offices advertised the scouting program to all known alfalfa growers. Although educational programs in alfalfa pest managment were being conducted during the period of the pilot project and subsequent implementation phase, the following economic analysis will only apply to those growers formally enrolled in the Extension-sponsored scouting program.

Economic Evaluation Procedures

Prior to the implementation of the alfalfa IPM program in Virginia, a written survey of alfalfa production and pest management practices was conducted in 44 western Virginia counties. Of the 1,100 surveys mailed, 204 were returned. This survey (Luna 1982) provides baseline data from which to measure changes in grower attitudes and practices during the period of IPM program implementation. This survey indicated that 89% of the alfalfa growers routinely applied insecticide every year for alfalfa weevil control, and less than 5% of the growers used either chemical or cultural control (early harvest) for potato leafhopper. None of the respondants said they used sampling methods or action thresholds to make pest control decisions.

A fundamental assumption is made in the following analysis: During the relatively short time frame (four years) of this program, growers would have continued to use the same pest control and other crop management practices indicated in the pre-IPM program survey had not the Alfalfa IPM program been initiated. This assumption permits estimation of changes in yields and pest control costs as a result of the IPM scouting program.

Two additional assumptions are made in this analysis. First, the action threshold is used to estimate yield loss from pest infestations. If pest densities surpass the threshold, a single rate of yield and quality loss is used. Conversely, if densities are below the action threshold, it is assumed that no yield loss occurs. In reality, however, yield loss is probably a continuous function of pest density, soil fertility, weather conditions and other variables (Poston et al. 1983). A second assumption is that fields are sprayed within 3 days after treatment recommendations are made, insect control is absolute and no measureable yield loss occurs. This is a fairly realistic assumption, given the efficacy of recommended materials, and by the observed response of the growers in following spray recommendations.

Estimating costs and benefits

In this partial budget analysis, all costs and benefits are computed initially on a individual county basis. County estimates are then averaged to estimate total annual program benefits. Only two costs are associated with pest management, scouting and insecticide application. Early harvest is also used as a management tactic for leafhopper control, however this operation would have occured regardless of pest management considerations. Scouting costs include wages, supplies and travel, and these data were obtained from financial records. Average insecticide and application costs were estimated each year from telephone interviews with farm supply dealers and applicators in the project area. External costs associated with insecticide use, such as environmental contamination, health risk, regulatory costs, and others are not included in this analysis. Similarly, external benefits are not considered.

In the alfalfa weevil program, economic benefits are derived primarily from reducing unnecessary insecticide application, since 90% of the growers were applying sprays routinely regardless of pest control need prior to the IPM program. Average savings in control costs were calculated by multiplying the total number of acres which were not sprayed by the average cost of chemical control. Since 10% of the acreage would not have been sprayed regardless of the IPM program, 10% of the total acreage in the program was subtracted from the unsprayed acreage prior to calculations. Average scouting costs were then subtracted from average savings to derive average net benefit.

With the potato leafhopper, however, much of the benefit of the IPM program resulted from an increased use of insecticides. Although the potato leafhopper is a well recognized pest of alfalfa in the United States and Canada, fewer than 5% of the alfalfa producers in Virginia were spraying for this pest prior to initiation of the IPM project. Also most of these growers were spraying too late to prevent crop damage. Because of the insect's small size, behavior, and type of damage produced in alfalfa, most growers and Extension agents had previously misidentified potato leafhopper damage as boron deficiency, poor root nodulation, or drought stress.

Early harvest is another management tactic used in the alfalfa IPM program to reduce quality loss (Luna 1984). This practice not only prevents further damage from occuring within a cutting, but also allows more growing time for subsequent cuttings, thus increasing total seasonal hay yield. However, none of the 204 alfalfa growers responding to the pre-IPM survey used this tactic for leafhopper management.

Therefore, because of the lack of pest management practices for potato leafhopper prior to the introduction of the IPM program, all benefits derived from timely pest management practices can be directly attributed to the Extension IPM program. The following equation gives an estimate of the increase in average net return per acre (<u>on a per county basis</u>) for growers participating in the potato leafhopper scouting program:

$$R = ((YV\ (r_iS + r_hH)) - (SC_i + C_s))\ /\ N \qquad (1)$$

where:

R = Average net benefit per acre (per county),

Y = Average yield per acre per cutting in tons for second and third cuttings, obtained at the end of each growing season from interviews with Extension agents and growers in the project counties,

V = Average dollar value of hay per ton. Since most alfalfa is used on-farm and not sold in a cash market, hay value was estimated from both comparable feed replacement costs and from known prices paid at hay markets. Again interviews with Extension agents in the project counties were used to derive average hay value estimates,

S = Total number of acres treated with insecticide, derived from scouting data entered in the Alfalfa DBMS,

H = Total number of acres harvested early for leafhopper control, derived from the DBMS,

r_i = Yield reduction parameter for fields with leafhopper populations surpassing the action threshold for insecticide application, Estimated from (Kindler et al. 1973; Luna and Allen 1981; Ives et al. 1985) and from interviews with Extension Agents. This parameter incorporates associated loss of protein from leafhopper damage. For this analysis, r_i is set at 0.25.

r_h = Yield reduction parameter for fields with leafhopper populations surpassing the action threshold for early harvest. By removing a leafhopper-damaged crop, further quality (protein) losses are minimized for that particular cutting. Usually when leafhopper population levels have surpassed the harvest action threshold, there is little subsequent yield accumulation because of the insect damage. Thus by early harvest, the length of the growing season for the subsequent cuttings is longer than if the leafhopper-damaged crop had been allowed to continue standing in the field. This "lengthening" is estimated to be about one week. A six week growth/harvest cycle for late season alfalfa translates to a r_h parameter of 0.17.

C_i = Average insecticide costs per acre, including application, described earlier,

C_s = Total scouting costs,

N = Total number of acres in the IPM program, derived from the DBMS.

Equation (1) estimates the average increase in net return per acre on a per county basis, and cannot be used to compute the change in net return for an individual grower. An estimate of the average increase in net return for all growers in the IPM program is obtained by averaging all county values.

Response of benefit estimation model to changes in parameter values

To evaluate the response of the benefit estimation model (Equation 1) to changes in key parameter values, data from the 1984 scouting program were entered into an electronic spreadsheet (SuperCalc3) on an individual county basis. A series of simulations were conducted holding the yield loss parameter, r_i, constant and incrementally changing the hay value parameter, V. The yield loss parameter was then increased incrementally and the same series of simulations conducted with changes in hay value.

Grower Survey Approach to Benefit Estimation

Another approach to estimation of program benefits is to survey participating growers at the end of each scouting season. In 1982 and 1983 written surveys were conducted of all participating growers asking for estimates of the net value per acre of the program. Rather than generating actual net benefit values, since most growers do not apply strict economic evaluation criteria to obtain their estimates, this approach generates estimates of the growers' *perceived* value of the program.

RESULTS AND DISCUSSION

Alfalfa Weevil Program

Five counties in the Shenandoah Valley region of western Virginia were involved in the 1981-82 pilot project for 1981-82. Compared to the 90% routine annual insecticide application for weevil control prior to program implementation, the IPM program clearly reduced the amount of insecticide being applied in both years (Table 1). In both years growers enrolled in the program realized an average increase in net return over their previous pest control practices. Although the weevil scouting program generated an average net benefit to participating growers, the program was discontinued in 1983 for several reasons:

(1) Average benefits varied considerably along the length of the Shenandoah Valley, with greatest benefits occuring in the northern most county (Shenandoah) and net losses occuring in the southernmost county (Rockbridge). The economic impact of the scouting program was directly related to pest infestation levels, with very low levels occuring in the north and practically all fields needing treatment in the south. Since most growers in Rockbridge County were spraying for weevil prior to introduction of IPM practices, the scouting program merely increased the cost of production. The assumption is made here that insecticides were being applied at optimum rates and

Table 1. Average costs and estimated benefits for the Alfalfa Weevil Scouting Program (on a per hectare basis).

Year	Number of counties	Number of farmers	Total hectares	% of total hectares requiring treatment	Savings in control costs	Average scouting costs	Average increase in net return per hectare
1981	4	20	291	32%	\$11.53[a]	\$1.97	\$9.54
1982	5	71	1,072	51%	\$10.87[b]	\$2.81	\$8.08
Average:				41.5%			\$8.80

[a] Based on average control costs of \$19.75/hectare.

[b] Based on average control costs of \$22.23/hectare.

times prior to the introduction of the IPM program, although in fact this was probably not the case.

(2) The action threshold being used for alfalfa weevil in the pilot project was adapted from the Pennnsylvania IPM Program for alfalfa (Gesell 1978) and did not appear responsive to the variations in soil type and moisture regimes encountered in Virginia. During excessively dry or moist soil conditions, the action threshold appeared to respectively under and over-treat for weevil control, according to visual observations of resulting defoliation. A research program was initiated in 1983 to develop action thresholds more appropriate to Virginia conditions.

The Potato Leafhopper Program

A four-year summary of the potato leafhopper IPM program is shown in Table 2. Apparent from these data is the variability of pest infestation levels from year to year, with 36% to 98% of the acreage needing treatment. This variability is also reflected in the estimated net returns from scouting, shown in Table 3. Estimated net returns are considerably lower in 1983 than in the previous two years, and this reduction can be attributed to two factors: (1) reduced potato leafhopper levels, and (2) drought-induced yield reductions in the 3rd and 4th cuttings which reduced the economic value of insecticide applications. Leafhopper infestations in 1984 were similar to 1983, however above

Table 2. Four-year summary of the Virginia Potato Leafhopper Scouting Program.

Year	Number of counties	Number of farmers	Number of fields	Hectares	Per cent hectares needing treatment	Per cent hectares needing early harvest
1981	4	31	99	581	36%	52%
1982	5	85	257	1,515	98%	38%
1983	5	88	227	1,330	51%	25%
1984	10	135	329	2,013	51%	21%
Averages:					59%	34%

Table 3. Average costs and estimated benefits for the Potato Leafhopper Scouting Program (on a per hectare basis).

	A	B	C (A+B)	D	E	F (C-D-E)	G (C-D)/E
Year	Crop savings from spraying[a]	Crop savings from early harvest[b]	Total savings	Average cost of chemical control[c]	Average scouting costs	Average net return per hectare	Average return per dollar invested in scouting
1981	$16.14	$17.29	$33.43	$ 4.94	$3.95	$24.58	$ 7.21
1982	48.61	15.76	64.37	17.02	4.49	42.85	10.55
1983	18.94	6.27	25.21	8.84	6.10	10.28	2.68
1984	38.06	11.61	49.67	8.87	5.90	34.90	6.91
Averages:	$30.44	$12.72	$43.18	$ 9.90	$5.11	$28.13	$ 6.83

[a] Based on an estimated loss of $74/hectare in hay value if not treated when leafhopper populations are above the action threshold.

[b] Based on an estimated savings of $50.39/hectare in hay value if harvested early when potato leafhopper levels are above the action threshold.

[c] Based on an average cost of $17.29/hectare for insecticide and application.

average rainfall in 1984 increased the yield potential of the crop, resulting in more economic benefit from timely insect control.

A additional benefit parameter, "average return per dollar invested in scouting," is also shown in Table 3. This is calculated by subtracting the average cost of chemical control (Column D) from total savings (Column C) , the quantity dividied by the average scouting costs (Column E).

Response of benefit estimation model to changes in parameter values

The response of the net benefit estimation model to changes in key parameter values is shown in Table 4. Setting the yield reduction parameter at 0.15 and changing the hay value incrementally by $10 per ton produced an constant rate of change in net benefit estimate of $1.16. As the yield loss parameter was increased by 0.01, the rate of change in net return increased linearly, with the rate of change increasing approximately $.05 for each 0.01 increase in r_i. Because of this linear relationship, results of only a few of the simulations are shown in Table 4.

Robustness of the model is limited by inadequate knowledge of the quantitative relationship between leafhopper densities and alfalfa yield reductions under varying crop growth environments. Replacement of the yield reduction parameter, r_i, with a dynamic yield loss function

Table 4. Response of the net-benefit estimation model to changes in parameter values.

Parameters		Model estimate of increase in net return	Average change[c]
R_i[a]	V[b]		
.15	$ 90	$11.06	
	100	13.93	
	110	16.80	$2.87
	120	19.68	
.16	90	12.20	
	100	15.19	
	110	18.20	2.99
	120	21.19	
.17	90	13.34	
	100	16.47	
	110	19.59	3.14
	120	22.72	
⋮	⋮	⋮	
.25	90	22.48	
	100	26.63	
	110	30.75	4.15
	120	34.90	

[a] Yield reduction parameter

[b] Hay value parameter in dollars per ton.

[c] Average change in estimated net return per $10 change in hay value.

would undoubtedly improve the accuracy of the benefit estimates.

Grower evaluation of program benefits

Grower estimates of net benefit per acre of the potato leafhopper scouting program are shown in Table 5. Forty one percent of the respondents gave a dollar estimate of net benefits in 1982 and 54% estimated net benefits in 1983. Estimates ranged from $1.00 to $50.00 per acre, with a similar mean estimate of about $19.90 both years. These estimates are very close to the calculated estimates (Table 4) of $17.35 for 1982, but considerably different from the calculated $4.16 per acre benefit in 1983.

Although average net benefits estimated from this cost/benefit analysis are substantial across the four years of the Alfalfa IPM Program, it should be stressed that these are average benefit estimates. Individual growers who had particularly high leafhopper infestations experienced far greater benefits from the scouting program. Conversely growers who did not need to treat for leafhoppers incurred a net loss (i.e., the cost of scouting) . In one sense, the leafhopper scouting program represents a type of disaster avoidance program, similar in rationale to prophalactic insecticide use. In epidemic leafhopper years, like 1982, timely control of potato leafhopper can mean the difference between good hay yields and total crop failure, including occassional stand loss. Benefits of the scouting program in

Table 5. Grower estimates of net benefit per hectare of potato leafhopper scouting (1982-1983).

Year	No. of farmers in program	No. of respondants to survey	No. giving net benefit estimate	Mean estimated net benefit	Standard error
1982	85	22	9	$49.13	13.72
1983	88	33	18	$49.20	7.95

such years should be amortized over years of low leafhopper infestations. Although the scouting program for the alfalfa weevil was discontinued in 1983, the cost/benefit analysis of the Pilot Project indicates a clear profitability to the growers in using IPM approach.

Like the agroecosystems they attempt to manage, IPM programs are unique socio-economic phenomenon. Procedures for economic impact evaluation must be tailored to fit the unique aspects of each program. The evaluation approach described here has been developed specifically for the Virginia Alfalfa IPM Program, however this approach can be adapted to other crop and state IPM programs.

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APPENDIX A

SURVEY REVEALS VIRGINIA ALFALFA PRODUCTION AND PEST MANAGEMENT PRACTICES[1]

John M. Luna
Extension Entomologist

The "average" alfalfa producer in Western Virginia farms 40.2 acres of alfalfa, estimates his yearly alfalfa production in the alfalfa to be worth $320.87/acre and is planning to plant 27.9 more acres of alfalfa within the next 3 years. Seventy-seven percent of Virginia's alfalfa growers use insecticides for alfalfa weevil control, spending an average of $7.84/acre for control. Although 34.7% of the growers have observed potato leafhopper damage in the past, only 9.3% have used insecticidal control for leafhopper.

These statistics are derived from a survey conducted of Virginia alfalfa producers during the spring of 1981 by the Va. Tech. Cooperative Extension Service. The purpose of the survey was to assess current alfalfa production and pest management practices. Questionnaires were mailed to extension agents in 44 Western Virginia counties, who in turn forwarded them to alfalfa producers within their counties. Of 1,100 questionnaires mailed, 204 were completed and returned. Not all respondents answered all questions.

Other information drawn from the survey include the following:

> 51% of the alfalfa is grown for dairy feed, 25% for beef, 12% for cash crop, 7% for horses, and 5% for sheep.
>
> Growers expect 6 years of production from their stands and expect to produce 6.2 tons of hay/acre each year.
>
> 66% of the alfalfa acreage is grown in pure stands; 34% is mixed with grass.
>
> Of the growers who treat for alfalfa weevil, 88% treat every year; 6.5% treat every second year; 5% treat less frequently.

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[1] Published in Agronomy Tips 4: 9-11 (Agron. Dept., VPI & SU).

Furadan was the most commonly used insecticide for alfalfa weevil control, being used by 60% of the growers who treated for weevil. Other insecticides and the frequency of use included Supracide, 18%; Imidan, 10%; Parathion, 4%.

35% of the respondants use herbicide for weed control, spending $5.25/acre.

Although the survey data also were analyzed separately for each county, data were pooled across counties to examine pest management practices in three fairly distinct climatic regions. The regions, shown in Fig. 1, are (1) East of the Blue Ridge Mountains, (2) Central Valley, comprising the Shenandoah and Roanoke Valleys, and (3) Mountains, comprising the Appalachian Mountains and Southwestern Virginia counties. Results of these pooled analyses are shown in Tables 1 and 2.

TABLE 1. Alfalfa Pest Management Survey Results, pooled by geographic region.

	% of respondents answering yes		
Question	CV[1]	EBR	MT
Do you use insecticides for weevil control?	89	100	34
Have you observed potato leafhopper damage in your alfalfa?	40	34	24
Do you use insecticides for potato leafhopper control in alfalfa?	13	4	6
Do you use herbicides for weed control in alfalfa?	39	45	20

	Average Values		
How many acres are in pure alfalfa?	23	44	18
How many acres in alfalfa/ grass mixtures?	11	20	15
How many acres of alfalfa expected to plant in the next 3 years?	19	45	14
How much per acre do you spend on weevil control?	$7.56	$9.04	$3.65

[1] CV = Central Valley counties between Blue Ridge & Appalachian Mountains; EBR = Counties east of the Blue Ridge Mountains; MT = Counties in the Appalachian Mountains and Southwestern Virginia.

Some differences among regions can be seen from Table 1. Clearly the alfalfa weevil is perceived as a greater threat to production in the Central Valley and east of the Blue Ridge counties than in the mountain counties. This difference in weevil pressure probably results from differences in winter egg laying and survival among the regions. A somewhat higher incidence of treatment for potato leafhopper in the Central Valley area may be a result of greater educational effort by the Cooperative Extension Service to inform producers of the leafhopper as an alfalfa pest. The higher use of herbicides in the Central Valley and east of Blue Ridge counties compared to the mountain counties is probably related to the higher proportion of pure alfalfa compared to alfalfa/grass mixtures grown in these areas. Differences observed in control costs for weevil may be due to a higher proportion of growers hiring custom spraying in the Central Valley (36%) and east of the Blue Ridge counties (38%) compared to the mountain counties (0%).

Insecticide usage for weevil control was also analyzed for each region, and these results are shown in Table 2.

TABLE 2. Insecticide use patterns, pooled by region.

Insecticide used	% of growers using insecticide CV	 EBR	 MT
Alfatox	1.2	2.4	0
Dyfonate	1.2	0	0
Furadan	51.9	82.9	41.2
[illegible]uthion	1.2	0	0
Imidan	13.6	7.3	0
Malathion	2.5	0	17.6
Parathion	7.4	0	0
Supracide	21.0	7.3	35.3
Sevin	0	0	5.9

Furadan is clearly the most commonly used insecticide for weevil control inall regions, with Imidan, Supracide, and Malathion being other commonly used materials. The higher incidence of Malathion usage in the mountain region is probably due to a higher incidence of stubble spraying after the first cutting.

This survey has generated valuable informaiton for the developmentof a state-wide Integrated Pest Management (IPM) program for Virginia alfalfa producers and will serve as a benchmark to measure changes in pest management practices as a result of the Extension IPM program.