ALFALFA WEEVIL IN OKLAHOMA: THE FIRST TEN YEARS

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Alfalfa Weevil In Oklahoma: The First Ten Years[1]

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Alfalfa forage production on approximately 500,000 acres is very important to the livestock industry of Oklahoma. For the past decade, the primary insect threat to profitable alfalfa production has been the alfalfa weevil *Hypera postica* (Gyllenhal). A research project was initiated in 1971 with emphases on population ecology and development of an integrated control program for the weevil. Results of research conducted since 1971 are summarized in this publication.

Geographical Distribution

The alfalfa weevil entered Oklahoma from both east and west. The eastern strain was first collected in 1968 from counties adjoining Arkansas and Missouri. Although the western strain was not collected until 1969, we believe that it had entered the Panhandle and extreme northwestern Oklahoma 2-3 years earlier. This strain was reported in adjoining counties of Kansas as early as 1967. The distribution of the western strain apparently remained nearly static, while the eastern moved rapidly across the state from 1968-71. Based on available information on geographical distribution, we estimate that the strains met in the area of Ellis, Harper, Woods, and Woodward Counties of northwestern Oklahoma in 1971 (Berberet and Gibson, 1976). During the same year, the presence of *H. postica* was confirmed in all counties (Figure 1). Blickenstaff (1965) observed mating between members of eastern and western strains and confirmed that hybrid progeny were produced. It is possible that hybrid weevils resulting from intermating of the 2 strains were present across the northwest and Panhandle areas of Oklahoma by 1975.

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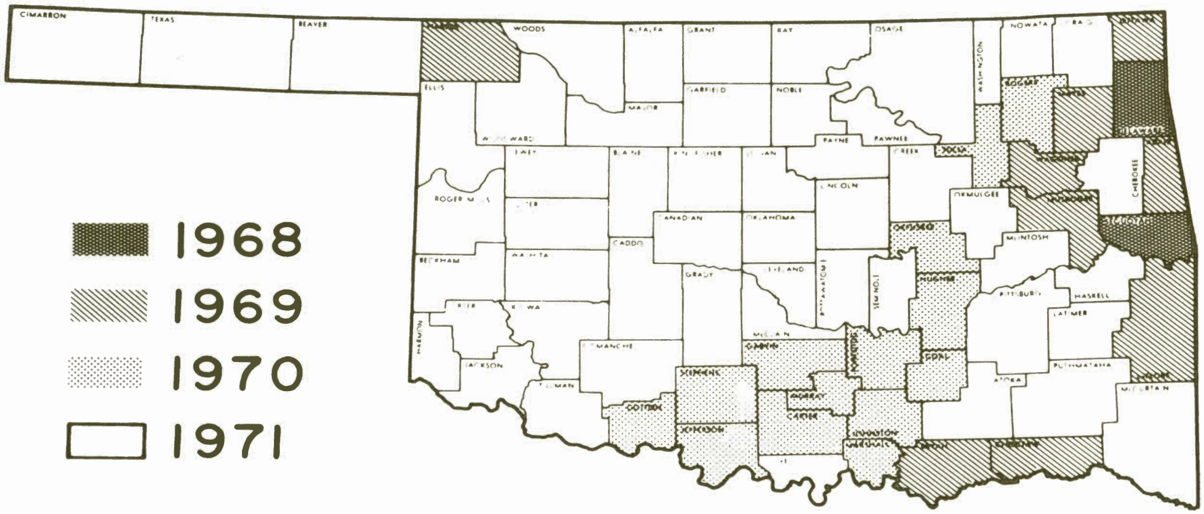

Figure 1 — Geographical distribution of the alfalfa weevil in Oklahoma from 1968 to 1971.

Seasonal Distribution

Population densities of *H. postica* have been recorded at locations in northern and southern Oklahoma since 1971. Sampling procedures involved removal of plant material from measured areas in unsprayed alfalfa stands and processing for extraction and counting of eggs and larvae. A blender technique has been used for removal of eggs from plant stems (Pass and VanMeter, 1966). Berlese funnels have served for collection of larvae from plant foliage. Insect population densities have been expressed as #/sq. ft. Dates when pupation and adult emergence were first observed have been recorded annually. Seasonal distributions for weevil egg and larval populations are presented for northern (Figure 2 - Payne Co.) and southern (Figure 3 - Stephens Co.) Oklahoma. Degree day (dd) accumulations shown in these figures were computed from the developmental threshold (48°F) for the eastern strain (Litsinger and Apple, 1973).

The highest population densities for *H. postica* were recorded during the years 1972-74. Since 1975, numbers have gradually declined. During 1979, populations were at their lowest levels observed since our research project began (Figures 2 and 3).

Egg deposition has begun during November and December of each year as adult weevils return to alfalfa fields from summer aestivation sites in vegetation along fence rows, roadsides and other uncultivated areas. Maximum temperatures have regularly exceeded the 35°F threshold for egg laying (Hsieh and Armbrust, 1974) during January and February and egg densities have generally increased throughout the winter. This pattern was interrupted by unusually cold weather until late February of 1979. Eggs laid during the fall of 1978 were rendered inviable and further oviposition was prevented by freezing weather (Figure 2 and 3). Weather conditions undoubtedly reduced weevil populations during 1979 and made the declining population trend mentioned earlier much more noticeable.

During mild winters, which are more typical in Oklahoma, degree day accumulations have been sufficient for hatching of some eggs in January and early February, particularly in southern Oklahoma (up to 40/sq.ft). Larvae seldom survive at this time

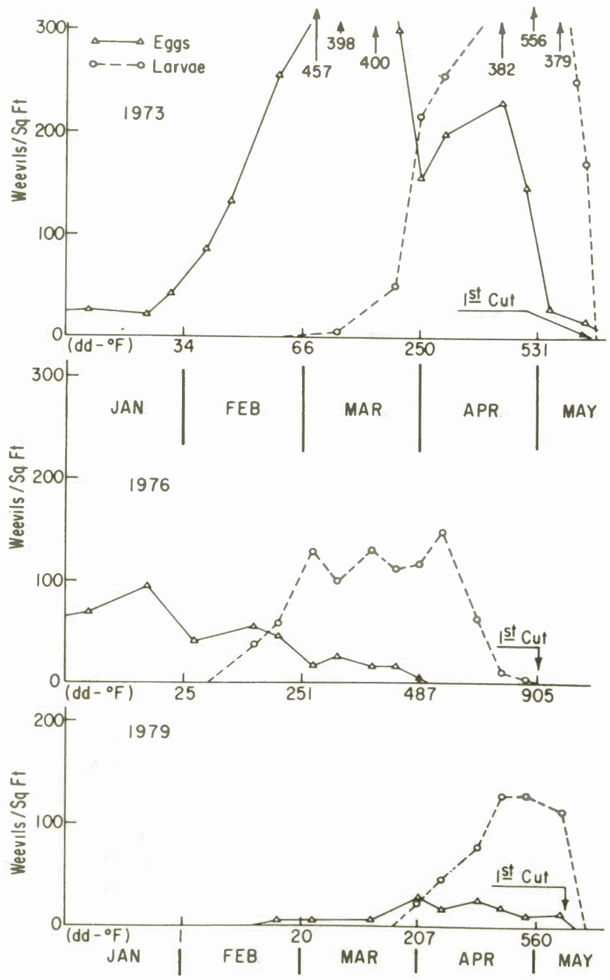

Figure 2 — Seasonal distribution of alfalfa weevil egg and larval populations in northern Oklahoma (Payne Co.). dd = degree days above threshold of 48°F.

of year due to intermittent freezing temperatures and lack of alfalfa foliage. Egg numbers decrease through March and April of each year as hatching is accelerated due to warm temperatures and reproductive capacity of adults is exhausted.

The timing of peak larval densities varies considerably by calendar date through April. According to physiological time, occurence of peak numbers is fairly consistent with accumulation of approximately 500 degree days from January 1 in the north (Figure 2) and 700 degree days in the south (Figure 3). Pupation begins from mid-March to mid-April and is usually about 2 weeks earlier in southern Oklahoma. The time interval between onset of pupation and first emergence of adults is generally about 10 days.

Effects of Weevil Damage on Alfalfa Production

Two types of studies have been conducted at the South Central Research Station, Chickasha, Okla. (Grady Co.) to determine the effects of *H. postica* infestation on productivity with susceptible alfalfa varieties.

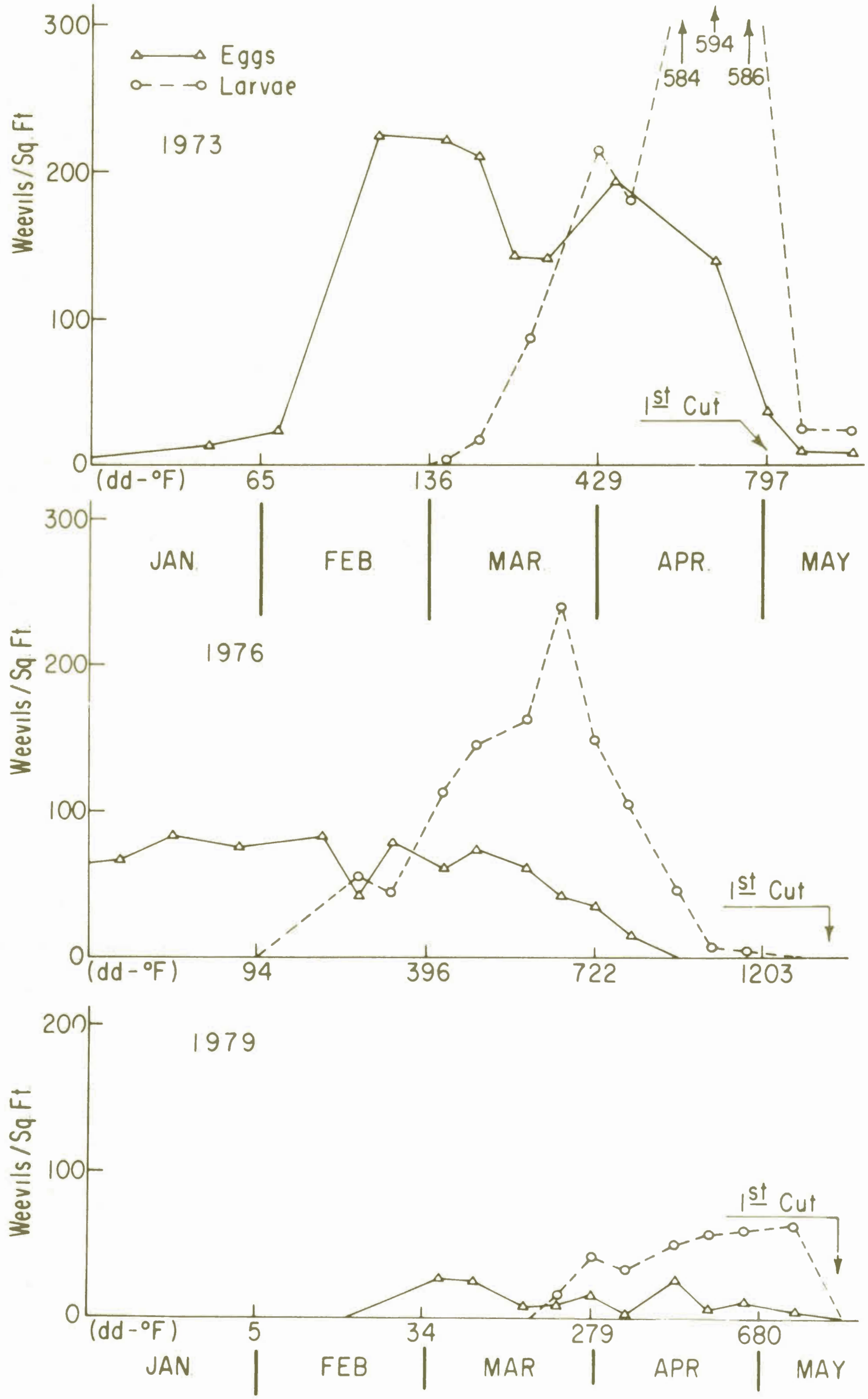

Figure 3 — Seasonal distributions of alfalfa weevil egg and larval populations in southern Oklahoma (Stephens Co). dd = degree days above threshold of 48°F.

Yield Reduction at First and Second Harvest

A series of one year experiments was designed to determine the effects of larval damage on yield of nonirrigated alfalfa in a single season. Larval numbers were adjusted in plots by application of heptachlor insecticide at several rates (Table 1). These treatments provided a gradation of population densities (from 0-10 larvae/stem) for relating weevil numbers and yield reduction at first and second harvests. Tests were conducted in full stands of alfalfa with stem densities of 30-35/sq.ft. in the first growth. Population densities were determined (larvae/stem) by pulling stem samples from plots and extracting larvae from foliage with Berlese funnels. Factors such as decreased growth, rate of maturity, and stem density were evaluated. Stem counts were made at the time of the second harvest.

Although the onset of feeding by weevil larvae varies with weather conditions from year to year, it usually corresponds closely with the start of growth by alfalfa in early spring. Peak larval densities are attained when alfalfa is 12-15 inches tall and most complete development and pupate before the first harvest is taken. Feeding by larvae is seldom observed in the second crop. However, residual effects of weevil infestation on productivity of alfalfa are apparent after the first harvest.

Yield of alfalfa in the first crop decreases approximately 170 lb/acre for each addition of one larva/stem (Figure 4). These losses are similar to average losses reported in Indiana by Hintz et al. (1976). Yield reduction is due in large part to extensive defoliation by larvae. Additional factors that contribute to losses include reduced growth (Figure 5) and delayed maturity. As a result of these factors in our tests, when undamaged plots have reached the 5-10% bloom stage and alfalfa was harvested, heavily damaged plots recovering from weevil attack were often at the pre-bud stage.

Significant losses of approximately 140 lb/acre for each addition of one larva/stem occur in the second crop of alfalfa (Figure 4). As was reported by Wilson et al. (1979), we found that decline in yield at second harvest is due primarily to reduced plant growth (Figure 5) and lower stem densities (Table 1).

Crude protein analyses were conducted on forage samples for each harvest. Due to the great variability in measurements, we were not able to show significant differences between treatments despite extensive defoliation of some plots by weevil larvae.

Table 1 — Effects of alfalfa weevil infestation on stem density at second harvest(var. - Kanza).

	1973		1975		1976	
Treatment[a]	#/stem[b]	Stems/sq.ft.[c]	#/stem	Stems/sq.ft.	#/stem	Stems/sq.ft.
1.00 lb.	0.60	35.9a	0.89	24.3a	0.18	29.0a
0.38 lb.	2.97	29.8 bc	1.75	20.1a	1.48	27.6a
0.25 lb.	4.47	31.5 b	2.67	23.0a	1.46	27.1a
0.12 lb.	5.83	32.8ab	3.95	22.6a	1.82	24.6ab
0.06 lb.	5.64	30.1 bc	4.20	22.6a	2.50	26.2ab
Untreated	8.44	26.8 c	5.74	18.0a	2.70	19.3 b

[a]Rate of heptachlor applied - AI/acre.
[b]Peak larval populations - averages for 4 replications.
[c]Values followed by the same letter are not significantly different, P = 0.10, DMRT.

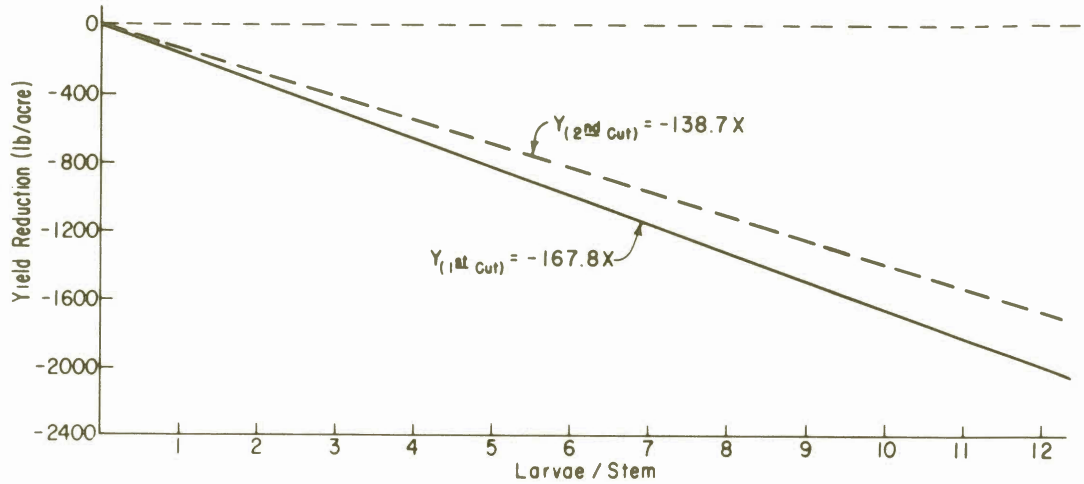

Figure 4 — Relationship of peak larval density of the alfalfa weevil vs. forage yield at first and second harvests.

The information presented in Figure 4 can serve as a guideline for alfalfa producers in making decisions on use of insecticides for weevil control. When weevil populations reach a level where the value of production which may be lost exceeds the cost of controls, a profit can be realized in utilizing control measures. Potential losses in both first and second crops must be considered in computing the value of forage production which may be lost.

Feeding damage by *H. postica* adults was not included in these studies. However, adult populations may cause serious damage to the first crop of alfalfa in early May and delay regrowth after first harvest. Damage by adults has been seen primarily with those fields where larval populations were not adequately controlled.

Stand Maintenance and Yield Reductions over Years

Studies were designed to determine the effects of weevil infestation over a period of several years on stand density and yield. Stem densities and yields from plots which were sprayed with heptachlor to eliminate weevil infestations were compared with those measurements from plots not sprayed. Experiments were conducted from 1973-76 (#1) and 1975-78 (#2). Dormant season applications of secumeton or terbacil herbicides were used to minimize possible competition by weed species.

Experiment #1 was begun when weevil population densities were quite high and average yield reductions for first and second harvests combined equaled nearly 1800 lb/acre (Table 2). Surprisingly, the rate of decline in stem densities (at first harvest) was similar in treated and untreated plots. However, stem counts were somewhat lower in untreated alfalfa throughout the experiment (Table 2). Herbicide applications prevented the possibility that weed competitors might contribute to stand decline in plots which were heavily damaged by the weevil.

Alfalfa in Experiment #2 was not heavily damaged after 1975. Population densities for the duration of the study averaged only 2.8 larvae/stem in untreated plots compared to 5.1 larvae/stem in Experiment #1. Correspondingly, combined yield reductions for first and second harvests were much lower (ave.=1128 lb/acre). Stem densities and yields were actually higher in the fourth year than they had been in the second (Table 3).

Yield reductions were sufficiently high throughout both experiments to warrant

Table 2 — Effects of alfalfa weevil infestation on stem densities and yield of forage in nonirrigated alfalfa (var. - Kanza), Experiment # 1, 1973-76.

Year	Population (larvae/stem)	Stems/sq.ft.[b]	Yield (lb/acre-dry wt.) 1st cut	2nd cut
1973 Treated[a]	0.6	----	3681	3653
Untreated	8.6	----	2412	1008
			(1269)[c]	(1645)[c]
1974 Treated	0.5	35.9	2688	2126
Untreated	5.2	31.9	2014	1951
			(674)	(175)
1975 Treated	0.6	25.7	3562	3577
Untreated	4.3	23.4	2218	2937
			(1344)	(640)
1976 Treated	0.1	26.2	2036	1504
Untreated	2.2	22.8	1129	1043
			(907)	(461)
Mean Treated	0.5	29.3	2992	2465
Untreated	5.1	25.9	1943	1734
			(1049)	(730)

[a]Application of heptachlor insecticide @ 1.0 lb. AI/acre when larval feeding was first noted.
[b]Stem counts taken at first harvest.
[c]Numbers in parenthesis indicate yield reduction in untreated alfalfa.

use of chemical insecticide each year. However, we learned that stand decline was not a serious problem despite the occurrence of relatively heavy weevil damage, when weed competitors were eliminated. We cannot say how the combination of weed competition and weevil damage would affect alfalfa stands.

Cultural Control

Winter Grazing of Dormant Alfalfa Stands

Four unreplicated grazing studies were conducted in Garvin and Stephens Counties during 1973-75. The purpose of these studies was to determine the effectiveness of this cultural practice for reduction of overwintering *H. postica* egg populations. Ungrazed and grazed areas from 3-25 acres in size were used. The last harvest of alfalfa was taken in early September and fall regrowth attained a height of 10-15 inches before frost. Cattle were placed on grazed plots after plant growth had been killed by freezing weather (December). Livestock were removed after these areas had been cleanly grazed to remove regrowth. (Figure 6).

Samples of plant material were taken from experimental plots from November - March and processed by the blender technique of Pass and VanMeter (1966) for extraction of weevil eggs. During March and April, samples of plant foliage were taken at weekly intervals and weevil larvae were extracted with Berlese funnels and counted. Furadan® insecticide was applied in March when needed for control of weevil larvae in ungrazed and grazed plots.

Population densities of the weevil were very high when these studies were conducted. Reductions in overwintering egg densities exceeded 60% in grazed plots

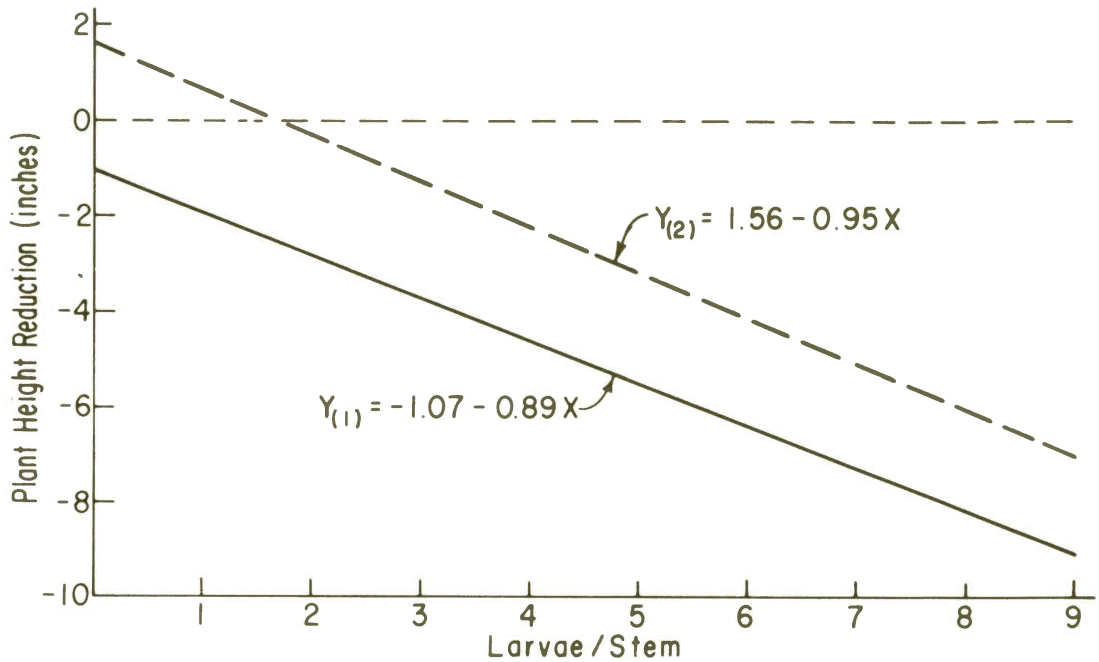

Figure 5 — Relationship of peak larval density of the alfalfa weevil vs. plant height reduction in first and second crops of alfalfa.

Table 3 — Effects of alfalfa weevil infestation on stem densities and yield of forage in nonirrigated alfalfa (var. - Kanza), Experiment # 2, 1975-78.

	Population (larvae/stem)	Stems/sq.Ft.[b]	Yield (lb/acre-dry wt.) 1st cut	2nd cut
1975 Treated[a]	0.7	----	3416	3764
Untreated	5.7	----	1829	3295
			(1587)[c]	(469)[c]
1976 Treated	0.2	21.4	3404	2550
Untreated	2.3	19.6	2688	1791
			(716)	(759)
1977 Treated	0.3	20.9	2930	2215
Untreated	1.8	17.7	2236	2483
			(694)	(+268)
1978 Treated	0.2	23.1	4196	3219
Untreated	1.3	23.7	3814	3047
			(382)	(172)
Mean Treated	0.4	21.8	3487	2937
Untreated	2.8	20.3	2642	2654
			(845)	(283)

[a]Application of heptachlor insecticide @ 1.0 lb. AI/acre when larval feeding was first noted.
[b]Stem counts taken at first harvest.
[c]Numbers in parenthesis indicate yield reduction in untreated alfalfa.

Table 4 — Effects of winter grazing on populations of the alfalfa weevil, 1973-75.[a]

Time Period	Weevils/sq. ft. Ungrazed	Grazed	% Reduction
Grazing Initiated (December)	321.3 eggs	321.3 eggs	----
Peak Population (January)	499.6 eggs	180.1 eggs*	64.0
Onset of Alfalfa Growth (February - March)	299.8 eggs	83.3 eggs*	72.2
Insecticide Application[b] (March)	211.3 larvae	99.6 larvae*	52.9
2 Weeks after application (March - April)	39.7 larvae	15.4 larvae*	61.2

[a]Values in this table are means computed from 4 grazing studies.
[b]Furadan® - 1.0 lb. AI/acre.
*Means for ungrazed vs. grazed significantly different, P = 0.01 (t-test).

(Table 4). These reductions were reflected in lower larval numbers in spring growth of alfalfa. In addition, resurgence of larval populations after insecticide application was less rapid in grazed plots. Winter grazing has excellent potential for reducing rates and perhaps numbers of chemical insecticide applications necessary for weevil control. More detailed information on grazing studies is available in the publication of Senst and Berberet (1980).

Tolerant Alfalfa Varieties

Several alfalfa varieties have been released which possess some degree of tolerance to the alfalfa weevil. Two evaluated extensively in Oklahoma are 'Team', released in 1969 (Barnes et al., 1970) and 'Arc' released in 1974 (Devine et al., 1975). Yield trials have shown that weevil tolerant varieties perform very well in comparison with other varieties adapted for production in Oklahoma (Caddel and Taliaferro, 1979).

In conjunction with varietal evaluations, data have been taken where insecticides were not used for weevil control. In a large plot test in Grady County, several varieties were heavily damaged by the weevil from 1973-76. Peak larval populations exceeded 150/sq.ft. during each year. Data presented in Table 5 indicate the value of weevil tolerance which resulted in stand maintenance and growth in Team that exceeded other varieties in 1976. Team produced a greater yield of higher quality forage as well. Herbicides were not used in this evaluation and combined effects of weevil damage and competition by weeds on plant stand were particularly evident in Oklahoma Common. Reduced quality of forage due to presence of weeds was most notable in Oklahoma Common and 'Dawson'.

Similarly, the value of tolerance was demonstrated in a comparison of Arc and 'Kanza' varieties. Plant height measurements indicate the more rapid growth of Arc in early spring. Plants of this variety withstood moderate weevil feeding and yielded more forage than the susceptible variety (Table 6). We believe that alfalfa production with tolerant varieties can be maintained with considerably less usage of insecticides than is necessary with susceptible varieties.

Figure 6 — Comparison of plant material present in ungrazed (left) and grazed alfalfa plots, Stephens Co., 1974.

Biological Control

Geographical Distribution of *Bathyplectes curculionis* (Thomson)

This parasite of *H. postica*, first introduced into Utah in 1911 (Chamberlin, 1926), has become an important biological control agent for the alfalfa weevil throughout the United States.

Surveys were initiated in 1972 for the purpose of determining the geographical distribution of *B. curculionis* in Oklahoma. These surveys involved sweep net sampling to collect large numbers of weevil larvae from counties across the state for rearing and parasite retrieval in the laboratory.

Table 5 — Performance of alfalfa varieties after heavy weevil damage, Grady Co.[a]

Variety	Stems/ sq. ft.	Plant Height (inches)	Yield (lb/acre-dry wt.)	% Protein
Washoe	11.0	13.4	1956	18.3
Kanza	14.5	12.6	2247	18.7
Oklahoma Common	8.6	16.7	2746	12.5
Dawson	10.8	15.7	2932	15.7
Team	17.6	18.7	3777	19.1

(Planting date = September 1972)
[a]Measurements taken at first harvest, May 7, 1976.

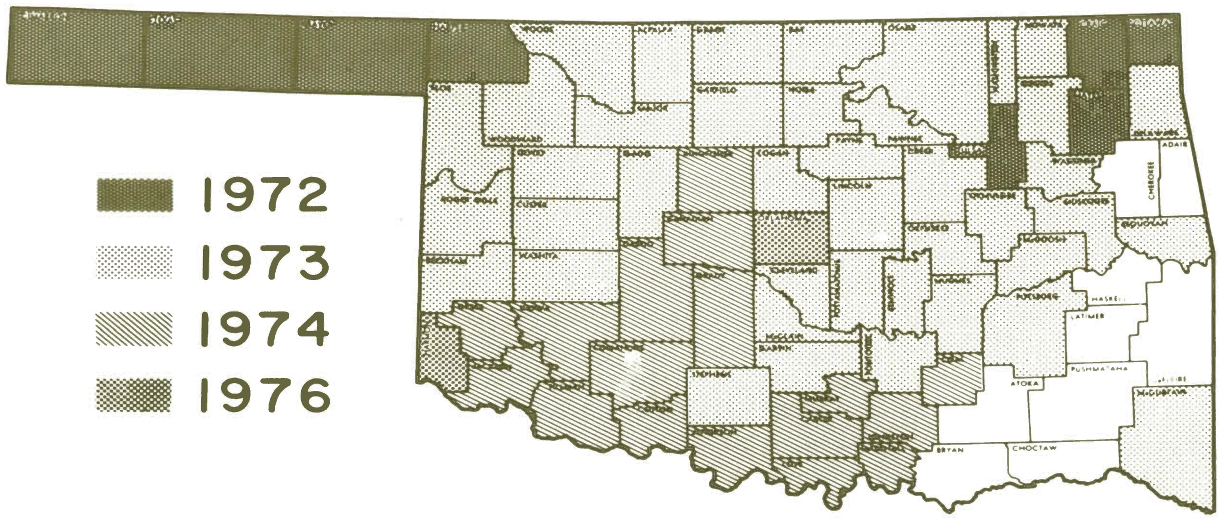

Figure 7 — Geographical distribution of *B. curculionis* in Oklahoma.

In 1972 *B. curculionis* was collected in 4 counties of northeastern Oklahoma and 4 counties in the northwest. These collections indicated spread of the parasite into the state with eastern and western strains of the weevil. It was found in 42 additional counties in 1973. Judging from the number of collections in 1973, *B. curculionis* was probably present in very low numbers in more than 8 counties during 1973, but was not detected. During 1974, the number of counties where presence of the parasite was confirmed increased to 66 and included all areas where alfalfa is an important crop (Figure 7).

Encapsulation of *B. curculionis*

Encapsulation of parasite eggs by blood cells in *H. postica* larvae was first reported by van den Bosch (1964). Embryos within fully encapsulated eggs invariably die, apparently because of interference by the capsule with respiration and nutrition (Berberet et al., 1976; Gibson and Berberet, 1974). Because of the impact of encapsulation on effective parasitism by *B. curculionis,* studies have been conducted to learn more about this defense mechanism of the weevil.

Table 6—Comparison of alfalfa weevil tolerant (Arc) and susceptible (Kanza) varieties, Payne Co.

	1974		1975		1976	
	Arc	Kanza	Arc	Kanza	Arc	Kanza
Plant Ht.[a]	---	---	12.0	10.9	10.7	7.4
Larvae/sq. ft.[b]	80	74	189	121	39	70
Tons/acre[c] (dry wt.)	1.17	1.11	1.47	1.30	1.26	1.13

(Planting date - May, 1973)
[a]Measurements (inches) taken when terminal feeding became evident.
[b]Peak larval populations.
[c]Yield at first harvest.

Weevil larvae were parasitized by *B. curculionis* in the laboratory and fixed in Duboscq and Brasil's fluid at timed intervals from 3-72 hours after parasitization. After embedding in paraffin, tissue sections were cut to observe the condition (encapsulated vs. healthy) of parasite eggs within weevils.

Results of this study show that encapsulation commences within 5-6 hours after parasitization and 40-50% of all eggs are fully encapsulated after 12-15 hours (Table 7). Deposition of melanin is observed in most fully encapsulated eggs after 18 hours. Death of parasite embryos becomes evident within 21-24 hours after parasitization.

Encapsulation results in destruction of parasite eggs at 2 time periods during embryogenesis. The first occurrence, which has just been described, begins soon after eggs are deposited in *H. postica* larvae. Renewed onset of encapsulation occurs after 24-36 hours. Embryos at this time are segmented and internal structures are becoming recognizable. Embryos within eggs encapsulated after 24 hours do not survive beyond 54 hours after parasitization (Table 7). This study, which was published in detail by Berberet et al. in 1976, has shown that encapsulation is a very effective defense reaction.

Statewide surveys have been conducted across Oklahoma since 1973 to determine the impacts of encapsulation on effective parasitism of *H. postica* by *B. curculionis* in the

Table 7—Rate of encapsulation vs. time for eggs of *B. curculionis* in alfalfa weevil larvae, and egg mortality due to encapsulation.

Time[a]	% Partially Encapsulated	% Fully Encapsulated	% Melanized	% Dead[b]
		Solitary Eggs		
6	40.0	20.0	–	–
12	8.3	50.0	14.3	–
18	7.7	15.4	66.7	–
24	6.7*	46.7	50.0	28.6
30	0.0	33.3	0.0	0.0
36	25.0*	37.5	40.0	100.
42	7.7*	30.8*	40.0	0.0
48	8.3*	58.3 (25.0*)	87.5	75.0
54	20.0*	20.0*	50.0	100.
60	0.0	28.6*	100.	100.
		Supernumerary Eggs		
6	35.8	17.9	9.5	–
12	23.7	23.7	38.9	–
18	25.8	22.7	40.6	–
24	21.9*	25.0	66.7	25.0
30	8.5*	35.2 (14.1*)	48.4	28.0
35	11.4*	40.0 (8.6*)	66.7	64.3
42	34.5*	17.2 (6.9*)	40.0	60.0
48	34.5*	27.6 (6.9*)	44.4	87.5
54	7.3*	9.8*	57.1	100.
60	2.9*	11.5*	80.0	100.

[a]Time interval between parasitization and fixation (hours).
[b]Percent fully encapsulated eggs which were inviable.
* Percent encapsulated eggs with segmented embryos.

field. These have been conducted at peak weevil population densities and again at first harvest when weevil numbers were much lower. For each survey, larvae were collected by sweep net sampling from fields in 30-35 counties. Subsamples of 100 larvae/county were dissected to determine rates of parasitism and condition (encapsulated vs. healthy) of parasite eggs. Statewide averages are given in Table 8 for actual (those weevils which contain a parasite) and effective parasitism (contain a healthy parasite) and percent reduction in numbers of weevils destroyed due to the encapsulation reaction.

Rates of parasitism increased greatly as *B. curculionis* became well established. Actual parasitism at peak weevil density increased from 2.9% in 1973 to 50.4% in 1977. This measure of parasite activity increased from 24.3% to 88.6% in the late weevil population during these years (Table 8). For the past 2 years, we have observed declining rates of parasitism. We have no explanation for this decreasing incidence of parasitism.

Some definite trends in encapsulation of *B. curculionis* eggs have persisted during surveys. Encapsulation of supernumerary parasites (2 or more/host) is more common than in solitary parasitism. However, percent reduction in effective parasitism is greater for solitary parasites. Weevils are limited in ability to encapsulate more than one egg and a parasite generally survives when 2 or more are present per host (Table 9). Percent encapsulation of both solitary and supernumerary parasites is consistently higher at peak weevil densities.

Table 8 — Impact of encapsulation on effective parasitism of the alfalfa weevil by *B. curculionis*, 1973-79.

Year		Actual Para.[a]		Effective Para.[b]		% Reduction[c]
		%	#/Sq. Ft.	%	#/Sq. Ft.	
'73	P[d]	2.9	5.8	2.1	4.2	27.6
	L[e]	24.3	2.4	21.0	2.1	13.6
'74	P	8.6	17.2	5.4	10.8	37.2
	L	57.9	5.8	52.4	5.2	9.5
'75	P	10.0	20.0	7.2	14.4	28.0
	L	56.9	5.7	51.3	5.1	9.8
'76	P	18.2	36.4	14.8	29.6	18.7
	L	74.9	7.5	70.5	7.1	5.9
'77	P	50.4	100.8	42.7	85.4	15.3
	L	88.6	8.9	86.6	8.7	2.3
'78	P	37.6	75.2	30.4	60.8	19.1
	L	88.3	8.8	84.8	8.5	4.0
'79	P	31.3	62.6	25.6	51.2	18.2
	L	85.5	8.6	81.5	8.2	4.7
Mean	P	22.7	45.4	18.3	36.6	23.4
	L	68.1	6.8	64.0	6.4	7.1

[a] Weevil larvae which contain *B. curculionis*.
[b] Weevil larvae which contain one or more healthy *B. curculionis*.
[c] Reduction in effective parasitism due to encapsulation.
[d] Peak weevil population (avg.= 200 larvae/sq. ft.).
[e] Late weevil population remaining at first harvest (avg.= 10 larvae/sq. ft.).

Table 9 — Encapsulation of *B. curculionis* eggs by alfalfa weevil larvae.[a]

Population level	Solitary parasites	Supernumerary parasites	Total
		% Encapsulation	
Peak Weevil Population	25.3	39.9	28.1
Late Weevil Population	9.0	21.4	15.4
		% Reduction[b]	
Peak Weevil Population	25.3	8.8	23.4
Late Weevil Population	9.0	2.9	7.1

[a] Values in tables are averages for 7 years (1973-79).
[b] Reduction in effective parasitism due to encapsulation.

Hyperparasitism of *B. curculionis*

Numerous species of hyperparasites have been identified which attack *B. curculionis* in the United States (Pike and Burkhardt, 1974; Puttler, 1966). It is the opinion of some researchers that destruction of *B. curculionis* by these species poses a serious threat to effectiveness of biological control of the alfalfa weevil (Pike and Burkhardt, 1974; Simpson et al., 1979). Two species of hyperparasites have been found in Oklahoma, *Eupteromalus tachinae* (Gahan) and an Encyrtidae (unidentified) (Nuss, 1976). Additional studies are needed to determine the full range of hyperparasite species which may exist in this region and their impact on populations of *B. curculionis*.

Seasonal Distribution of *B. curculionis*

From 1975-79, samples of 100 weevil larvae from unsprayed sampling areas in northern and southern Oklahoma were dissected each week from mid-March until May. Weevil population densities in these areas were determined by collection of larvae from samples of foliage with Berlese funnels. Rates of parasitism and encapsulation, as well as percent reduction in effective parasitism due to encapsulation were determined. In addition, *B. curculionis* were reared from samples of weevils and observed for emergence of second generation (nondiapausing) adults.

B. curculionis overwinter as diapausing larvae in cocoons. In February these larvae pupate and emergence of first generation adults begins in March or early April (Berberet et al., 1978). Parasitism by first generation *B. curculionis* occurs at peak weevil densities and percentages, particularly of superparasitism, are fairly low (Table 10, weeks 1-3). Reduction in effective parasitism due to encapsulation is relatively great due to destruction of solitary parasites during this period. Little increase in parasitism is observed as first generation adults die in weeks 3-4 (northern) or 2-3 (southern).

Rates increase once again as second generation (nondiapausing) adults begin to emerge from cocoons (Table 10). Nondiapausing parasites comprise up to 30-50% of the total. The remainder stay in cocoons as diapausing larvae until the following year. Second generation parasites become numerous as weevil populations decline in late April and May. As a result, solitary and superparasitism rise considerably. Percent encapsulation and reduction in effective parasitism decline greatly in weeks 6 and 7 (Table 10).

Establishment of Imported Parasites

A number of parasite species have been obtained from the Introduced Beneficial Insects Laboratory, USDA, for release in Oklahoma. Release sites were located in

Table 10 - Seasonal performance of *B. curculionis*.[a]

Week	Larvae/ sq. ft.[b]	% Parasitism Solitary	Super-	Total	% Encapsulation	% Reduction[c]	% Non-diapausing[d]
				Northern Oklahoma			
1	117	16.0	2.0	18.0	22.1	22.0	31.2
2	160	25.6	4.4	30.0	30.5	28.7	50.6
3	160	32.4	8.8	41.2	23.0	18.5	44.2
4	107	33.4	9.0	42.4	17.4	12.5	46.9
5	80	39.8	8.8	48.6	24.8	17.7	26.1
6	15	40.6	22.4	63.0	16.8	12.0	9.3
7	11	51.6	31.4	83.0	14.6	5.1	8.9
Mean	93	34.2	12.4	46.6	21.3	16.6	31.0
				Southern Oklahoma			
1	70	5.7	0.0	5.7	37.6	37.5	3.5
2	115	10.5	3.0	13.5	30.4	32.4	15.4
3	92	9.8	1.4	11.2	62.8	56.8	29.7
4	92	21.6	3.6	25.2	35.6	35.0	41.1
5	42	26.6	9.0	35.6	28.0	22.2	33.0
6	11	39.0	22.6	61.6	19.8	11.4	24.9
7	2	48.0	45.8	93.8	11.4	3.1	14.1
Mean	61	23.0	12.2	35.2	32.2	28.4	23.1

[a] Values in table are averages for 5 years (1975-79).
[b] Population density of alfalfa weevil.
[c] Reduction in effective parasitism due to encapsulation.
[d] Nondiapausing parasites in cocoons of first generation.

several counties and maintained in alfalfa production without use of insecticides for a minimum of 2-3 years to allow sufficient opportunity for establishment of parasites. Of the 4 species liberated, only *Bathyplectes anurus* (Thomson) was recovered after one year (Table 11).

Parasitism of H. postica by *B. anurus* and *B. curculionis* was studied from 1974-77 at locations in northern (Payne Co.) and southern (Stephens Co.) Oklahoma. No insecticides were utilized in experimental areas for the duration of the study. Weevil population densities were determined by collecting larvae from samples of plant foliage with Berlese funnels. Rate of parasitism by each species was determined from sweep samples of weevil larvae which were reared in the laboratory for parasite retrieval.

Both species begin to parasitize weevil larvae at approximately the same time in early spring. The single generation completed by *B. anurus* each year is well synchronized with peak weevil populations. However, *B. curculionis* has provided much more effective control (Table 12) and has demonstrated ability to spread rapidly into new geographical regions. By contrast, our findings support those of Dowell and Horn (1977) who estimate the rate of dispersal of *B. anurus* at less than 10 miles/year. During the 7 years that this species has been established in Oklahoma, it has not been found more than 5-10 miles from initial release points.

B. curculionis is distributed throughout alfalfa growing areas of the state and has become an important control agent for *H. postica* (Berberet and Gibson, 1976; Berberet et al., 1978). *B. anurus* has not shown a great deal of potential as a control agent, thusfar.

Table 11 — Release and recovery of imported parasites of the alfalfa weevil.

Species	Host life Stage[a]	Year Released	County	Year Recovered
Bathyplectes anurus	larva	1972	Payne	1973
		1972	Stephens	1973
		1974	Texas	– –
		1975	Grady	1976
		1975	Kiowa	– –
		1975	Payne	1976
		1975	Washita	1976
Microctonus aethiopoides	adult	1973	Payne	– –
		1973	Stephens	– –
		1976	Stephens	– –
Peridesmia discus	egg	1972	Stephens	– –
Tetrastichus incertus	larva	1972	Stephens	– –

[a]Life stage of *H. postica* which is parasitized.

Table 12 — Parasitism of the alfalfa weevil by *Bathyplectes* spp., 1974-77[a].

Date	Larvae/ sq. ft.	% Parasitism		
		B. curculionis	*B. anurus*	Total
		Northern Oklahoma		
Mar. 17	134.9	3.6	0.0	3.6
24	95.5	12.6	0.3	12.9
31	135.2	12.4	0.8	13.2
Apr. 7	158.0	22.2	2.2	24.4
14	159.7	20.7	1.8	22.5
21	133.2	23.4	1.4	24.8
28	73.4	42.2	1.3	43.5
May 5	70.6	37.5	1.6	39.1
12	18.6	38.0	2.2	40.2
		Southern Oklahoma		
Mar. 17	82.0	2.8	0.6	3.4
24	68.7	11.4	4.7	16.1
31	89.2	6.4	1.0	7.4
Apr. 7	67.8	8.4	0.8	9.2
14	68.0	8.9	0.1	9.0
21	46.4	29.4	0.2	29.6
28	29.5	33.3	0.1	33.4
May 5	14.9	47.2	0.0	47.2
12	1.2	36.8	0.0	36.8

[a]Values in table are 4 year averages.
[b]Population density of alfalfa weevil.

Chemical Control

Efficacy of Registered Insecticides

Chemical insecticides provide an essential means for reducing *H. postica* larval populations, particularly at peak densities. If this method of control was not available, severe losses in forage production often could not be avoided (Berberet and Pinkston, 1976). Numerous studies have been conducted to identify those insecticides which provide the most effective weevil control (Armbrust et al., 1968; DePew, 1969; Summers, 1975). Compounds which gave the best control in these evaluations include Furadan®, methyl parathion, and Supracide®.

Sampling procedures and guidelines for decision-making regarding chemical applications for weevil control have been developed in the Midwest (Wedberg and Ruesink, 1977). The procedures and recommendations have been modified for use in the Southern Plains (Berberet and Sholar, 1980). Use of this sampling system reduces unnecessary insecticide usage and allows maximum return to producers from investments in chemical control.

Two unreplicated large plot (0.25 acre) tests were conducted in Stephens County during 1973 to evaluate alfalfa weevil control with several registered insecticides. Materials in the tests included Furadan®, Supracide®, Imidan®, and Guthion®. Sprays were applied with ground equipment using a total volume of 20 gal./acre @ 25 psi. Three - 25 stem samples were taken from each plot at 2, 7, 14, and 21 days after treatment. Larvae were separated from plant foliage with Berlese funnels and counted. Results from treated plots were compared with untreated to determine percent control. Yield estimates were calculated from 2-225 sq. ft. samples taken in each plot.

Furadan® and Supracide® provided the most effective initial and residual control. Forage yields returned by application of these insecticides averaged approximately 0.5 tons/acre. Imidan® and Guthion® gave good control initially, however, averages for these compounds over the 3 week evaluation period were only 70-80% control. With very heavy weevil populations, this level of control is not sufficient to prevent serious damage. Increased yields of forage over the untreated plots were not nearly as great as those recorded for Furadan® or Supracide® (Table 13).

Importance of Spray Volume in Aerial Application

Two experiments have been conducted to determine the effects of spray volume on alfalfa weevil control with fixed wing aircraft. The first of these was applied on March 26, 1973, using 2 acre unreplicated plots. The second was sprayed on April 1, 1975,

Table 13 — Alfalfa weevil control with registered insecticides, Stephens Co., 1973.

Treatment	Rate (lbA.I./acre)	% Control[a]	Return over untreated lb/acre(dry wt.)	Return over untreated $/acre[b]
Furadan 4F	1.0	91.7	1167	37.93
Furadan 4F	0.5	88.6	1246	40.50
Supracide 2E	0.75	91.1	801	26.03
Imidan 50W	1.0	81.2	632	20.54
Imidan 50W	0.5	73.6	369	11.99
Guthion 2L	0.5	72.2	193	6.27

[a] Averages of samples taken 2, 7, 14 and 21 days after treatment.
[b] Computed @ $65/ton, - cost of insecticides not subtracted.

with plots 1.5 acres in size arranged in a randomized complete block design with 3 replications. Methodology for the 2 experiments was similar.

Methyl parathion was applied at the rate of 0.5 lb. AI/acre with total spray volumes of 0.5, 1.0, 2.0, and 4.0 gal./acre and 30 psi pressure. Nozzle tips were changed between treatments so that spray volume could be adjusted without changing pressure. Each swath over which material was applied was measured and flagged to insure uniform coverage. Weather conditions were excellent for each application with wind speed less than 5 mph and temperatures of 50-60°F. Height of alfalfa ranged from 8-12 inches.

Three-25 stem samples were taken from each plot at 3-7 day intervals after treatment and examined to determine percent infestation. Larvae were separated from foliage in Berlese funnels and counted. These data were used along with stand counts in experimental areas to calculate population densities (larvae/sq.ft.). For the 1975 test, a damage rating system (1 = undamaged, 9 = defoliated) was utilized to further delineate differences between treatments.

The 1973 experiment showed that increased spray volume enhanced performance of methyl parathion for weevil control (Table 14, Figure 8). All treatments greatly suppressed larval populations which in unsprayed plots increased rapidly in April to a density exceeding 600/sq.ft. However, volumes of 2.0 and 4.0 gallons were much more effective than lesser amounts due to better coverage obtained. The 0.5 gallon treatment did not reduce larval numbers sufficiently to prevent serious damage for even a short time (Table 14).

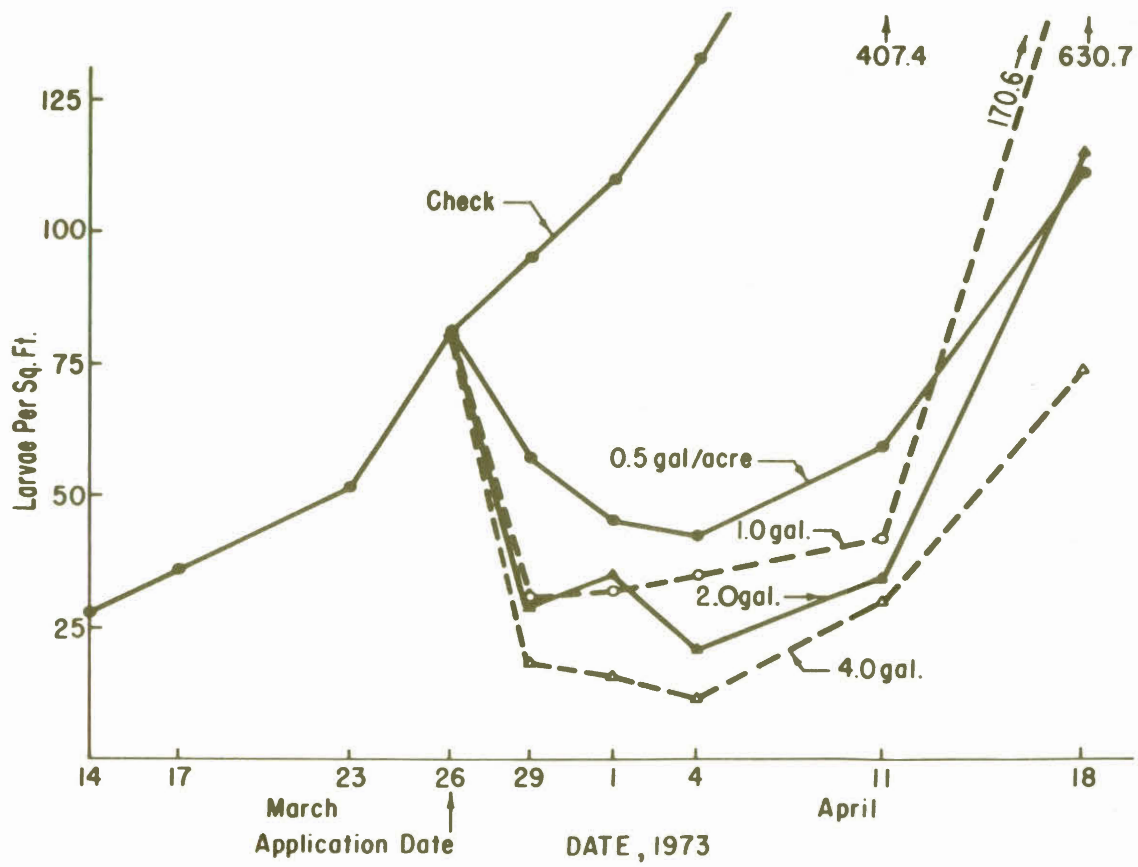

Figure 8 — Comparison of alfalfa weevil control attained using methyl parathion at spray volumes for 0.5-4.0 GPA, Stephens Co., 1973.

Table 14 — Effect of spray volume on control of the alfalfa weevil by aerial application, Grady Co., 1973.

Volume	March 29		April 1		April 4		April 11	
(gal/acre)	%[a]	#/sq.ft.[b]	%	#/sq.ft.	%	#/sq.ft.	%	#/sq.ft.
4.0	41.3	23.9	45.3	20.9	17.3	11.0	29.3	31.9
2.0	37.3	29.4	42.7	34.9	26.7	20.2	41.3	34.4
1.0	53.3	30.7	41.3	31.3	26.7	34.9	45.3	41.7
0.5	49.3	57.7	38.7	46.6	36.0	42.9	62.7	58.9
Untreated	---	95.0	---	110.0	82.7	113.7	94.7	407.4

(application date = March 26)
[a] Percent plant terminals infested.
[b] Number of larvae/sq. ft.

Results of the 1975 experiment were similar to those of 1973. Percent of terminals infested and larval numbers remained consistently lower as spray volume was increased. The amount of defoliation as indicated by the damage rating scale was significantly greater (P=0.10) at 0.5 gallons/acre than for any other spray volume after 2 weeks (Table 15). We are in agreement with Wilson and Armbrust (1968) that increases in spray volume reduce problems with spray drift and improve penetration of foliage resulting in greater contact with weevil larvae by the insecticide.

Integrated Control Program

We have initiated research to determine how components of an integrated control program interrelate and identify possible deleterious effects that each component may exert on others.

Impact of Grazing on Survival of Overwintering *B. curculionis*

Two experiments were conducted in Stephens County during 1976-78 to learn what extent of mortality may result in overwintering *B. curculionis* within cocoons on the soil surface due to trampling by grazing cattle. Laboratory reared parasites in cocoons were placed about alfalfa crowns in sampling sites in ungrazed and soon to be grazed plots of alfalfa during October of 1976 and 1977. This timing for field placement was chosen to avoid hyperparasitism and predation as much as possible, but still permit diapausing larvae to become acclimatized to cool weather.

Cocoons were collected from ungrazed and grazed plots at 1-2 week intervals during January through March of 1977 and 1978. Numbers of cocoons which had been crushed by livestock or chewed apart by predators were recorded. Intact cocoons were dissected to determine mortality rates and identify instances of hyperparasitism.

We found that trampling by livestock in grazed alfalfa stands can definitely be expected to cause some mortality of *B. curculionis*. In 1977 however, higher rates of predation, hyperparasitism, and mortality of parasites in intact cocoons in ungrazed alfalfa outweighed the 12.2% mortality due to crushing in the grazed area. Total mortality was slightly higher in ungrazed alfalfa (Table 16). In 1978 total percent mortality was higher in the grazed plot although only 2.5% of the cocoons were crushed. Impacts of trampling by cattle utilized in winter grazing appear to be quite variable and are probably not of major importance in a control program. Considering the beneficial effects of grazing in reducing weevil populations as mentioned in this publication and reported by Senst and Berberet (1980), parasite mortality associated with this cultural practice can be tolerated in an integrated control program.

Table 15 — Effect of spray volume on control of the alfalfa weevil by aerial application, Muskogee Co., 1975.

Volume	April 4			April 9			April 16		
(gal/acre)	%[a]	#/sq.ft.[b]	Dr.[c]	%	#/sq.ft.	Dr.	%	#/sq.ft.	Dr.
4.0	44.9[a]	23.2[a]	3.6[a]	44.4[a]	38.2[a]	3.6[a]	54.2[a]	80.9[a]	3.4[a]
2.0	45.3[a]	27.1[a]	3.6[a]	46.2[a]	44.3[a]	2.9[a]	68.0 [b]	106.7[a]	4.3[a]
1.0	59.6[a]	31.2[a]	4.1[a]	60.0[ab]	51.3[a]	3.6[a]	73.3 [bc]	89.0[a]	4.3 [b]
0.5	60.6[a]	35.2[a]	3.7[a]	56.4[ab]	50.6[a]	3.9[a]	81.8 [c]	122.4[ab]	4.9 [bc]
Untreated	95.6 [b]	84.7 [b]	4.0[a]	77.3 [b]	113.4 [b]	3.7[a]	94.7 [c]	184.4 [b]	5.1 [c]

(application date = April 1)
[a] Percent plant terminals infested.
[b] Number of larvae/sq. ft.
[c] Damage rating (1 = undamaged; 9 = defoliated).
Means followed by same letters are not significantly different, P = 0.10, DMRT.

Table 16 — Mortality of overwintering *B. curculionis* in ungrazed and grazed alfalfa stands.[a]

	1977		1978	
	Ungrazed	Grazed	Ungrazed	Grazed
# Cocoons Recovered	67	74 (NS)	175	183 (NS)
% Predation and Hyperparasitism	8.2	2.7 (NS)	5.5	11.1*
% Crushed[b]	0.0	12.2*	0.0	2.5*
% Total Mortality[c]	34.0	32.6 (NS)	13.4	27.3*

[a] Means computed for 8 sampling dates/yr.
[b] Percentage of cocoons crushed by grazing livestock (parasites inviable).
[c] Includes inviable parasites dissected from intact cocoons.
* Means within years significantly different, P = 0.05, (t - test).

Integration of Grazing with Chemical and Biological Controls

During 1978-79, rates of parasitism of *H. postica* by *B. curculionis* were determined in ungrazed and grazed plots (size = 12 acres) from March to early May. Sweep samples of 100-500 larvae were collected weekly and reared to pupation in the laboratory. Percent parasitism was computed from numbers of weevil pupae and parasite cocoons counted in samples. Larval population densities of the weevil were determined from 10-1 sq.ft. samples/plot processed in Berlese funnels each week. Numbers of weevils parasitized by *B. curculionis* which are given in Figures 9 and 10 were obtained by multiplying larvae/sq. ft. X percent parasitism.

Chemical insecticides were applied only when *H. postica* populations threatened serious damage to the alfalfa. Numbers of applications and rates utilized were held to a minimum to prevent destruction of *B. curculionis*. Larval numbers were reduced in both

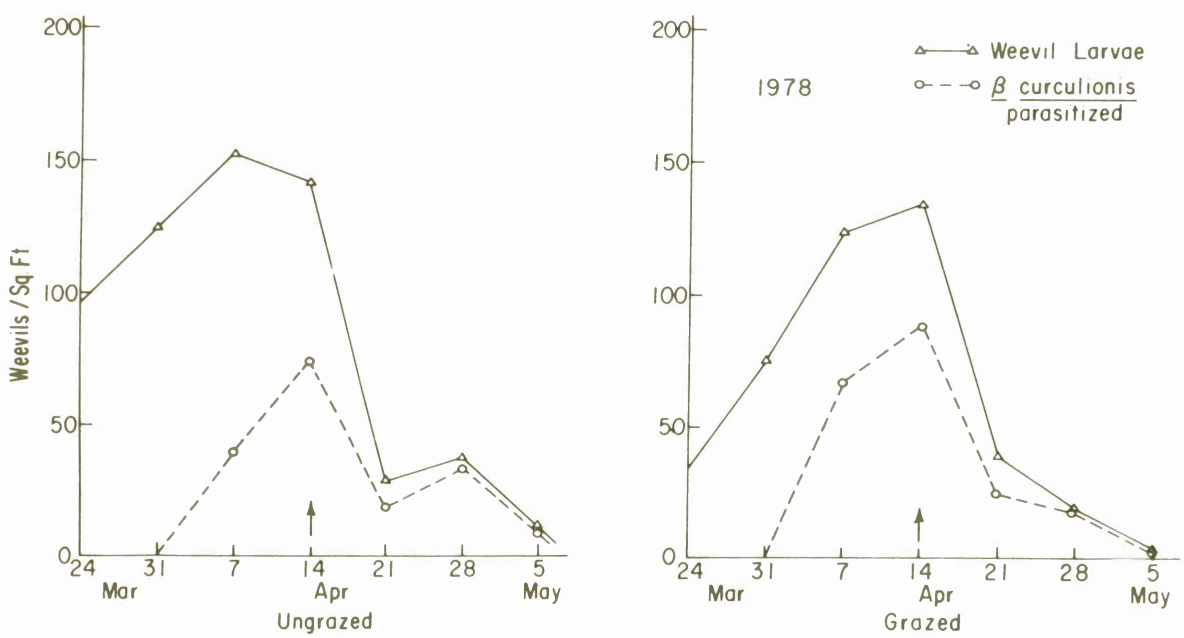

Figure 9 — Parasitism of the alfalfa weevil by *B. curculionis* in ungrazed and grazed alfalfa stands, Stephens Co., 1978. (arrows indicate date of insecticide application - methyl parathion @ 0.5 lb. AI/acre.)

ungrazed and grazed plots with methyl parathion (0.5 lb. AI/acre) on April 14, 1978. Ungrazed alfalfa was sprayed in 1979 on March 31 with Furadan® (1.0 lb. AI/acre) and again on April 22 with methyl parathion (0.5 lb. AI/acre). A single application of Furadan ® (0.5 lb. AI/acre) was made on the grazed plot on April 7. The first harvest was taken on May 9, in 1978 and in 1979 on May 10.

Grazing of dormant alfalfa had no apparent deleterious effects on parasitism by *B. curculionis* (Figures 9 and 10). Although rates were much higher in 1978, parasitism was similar in ungrazed and grazed areas during both years.

Population densities of *H. postica* larvae increased more rapidly during early spring in ungrazed alfalfa. For example, nearly 150 larvae/sq.ft. were found in ungrazed alfalfa on March 24, 1979 compared to a population of 65/sq.ft. in the grazed plot. However, a single application of methyl parathion (Figure 9) was sufficient to prevent serious damage to alfalfa in both ungrazed and grazed plots in 1978. Furadan® was applied in ungrazed alfalfa one week earlier and at twice the rate used in the grazed to prevent serious damage in 1979 (Figure 10). A second application was required to suppress heavy populations in the ungrazed plot. Weevil numbers declined rapidly in the grazed area from April 21 to May 5 without additional spraying. We believe that winter grazing can be beneficial as an aid in reducing reliance on insecticides for weevil control.

One objective of the integrated control program for *H. postica* in Oklahoma is reduction of insecticide usage in order to lower production costs and improve effectiveness of biological agents such as *B. curculionis*. Davis (1970) and Wilson and Armbrust (1970) have found that, with proper timing of applications, the use of insecticides appears to be compatible with survival of *B. curculionis*. We are attempting to introduce alternative means of control for the alfalfa weevil in Oklahoma so that insecticides may be applied at relatively low dosages only at peak population densities. We wish particularly to avoid applications that destroy second generation *B. curculionis* parasitizing residual weevil populations within 2-3 weeks of first harvest.

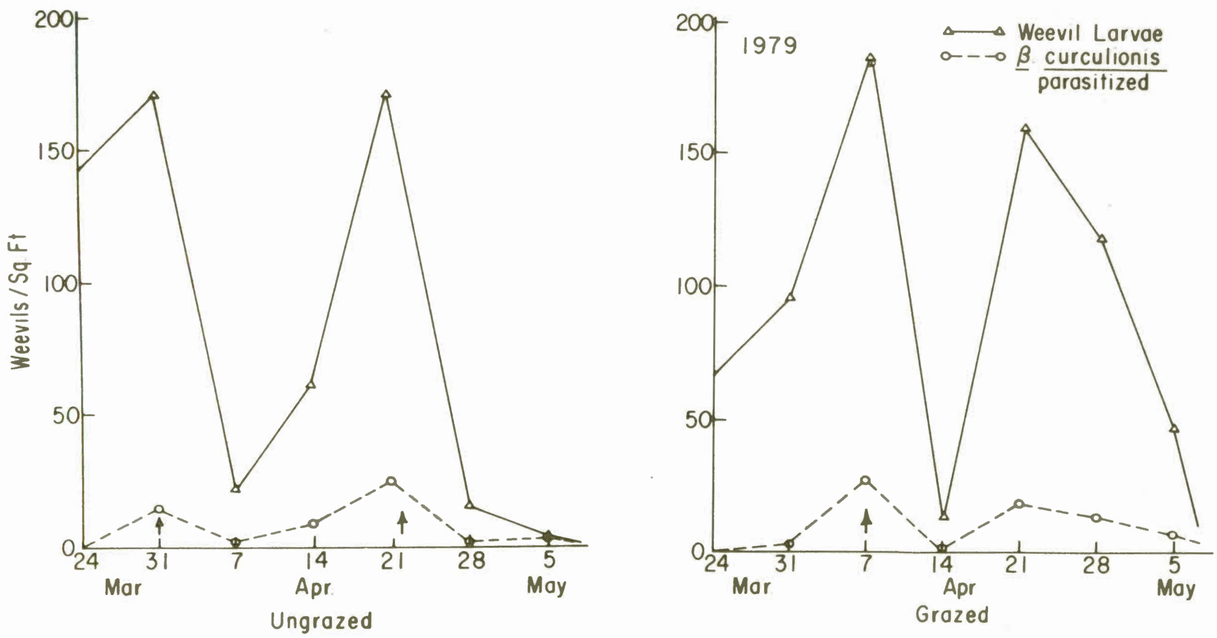

Figure 10 — Parasitism of the alfalfa weevil B. curculionis in ungrazed and grazed alfalfa stands, Stephens Co., 1979. (arrows indicate dates of insecticide applications).

Additional research projects have been initiated to evaluate tolerant alfalfa varieties along with other means of weevil control in the integrated program. These projects are also designed to study the relationship of the weevil control program with other pest complexes including insects, pathogens, and weeds which infest alfalfa stands.

Summary

Four types of controls (winter grazing, tolerant varieties, chemical insecticides, and biological agents) are being combined to implement an integrated program for suppression of *H. postica* in Oklahoma. Development of high population densities and the start of serious weevil damage in spring is being delayed by winter grazing for destruction of overwintering egg populations. Use of tolerant varieties further reduces the impact of feeding by weevils. Although these measures have considerable importance in reducing the need for insecticides, chemical control is essential for prevention of serious losses when larval populations exceed 1.5-2.0 larvae/stem (40-50 larvae/sq.ft.). Population densities of this magnitude or greater are very common in Oklahoma.

The biological agent, *B. curculionis*, destroys most larvae which survive insecticide applications and regularly parasitizes 80-90% of those present during late April and May. The result of parasitism by *B. curculionis* is that fewer weevils survive to the adult stage and contribute to populations during the following year.

It is the intent of this integrated program to provide effective means for regulating alfalfa weevil populations at the least possible cost to producers.

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OKLAHOMA

Agricultural Experiment Station

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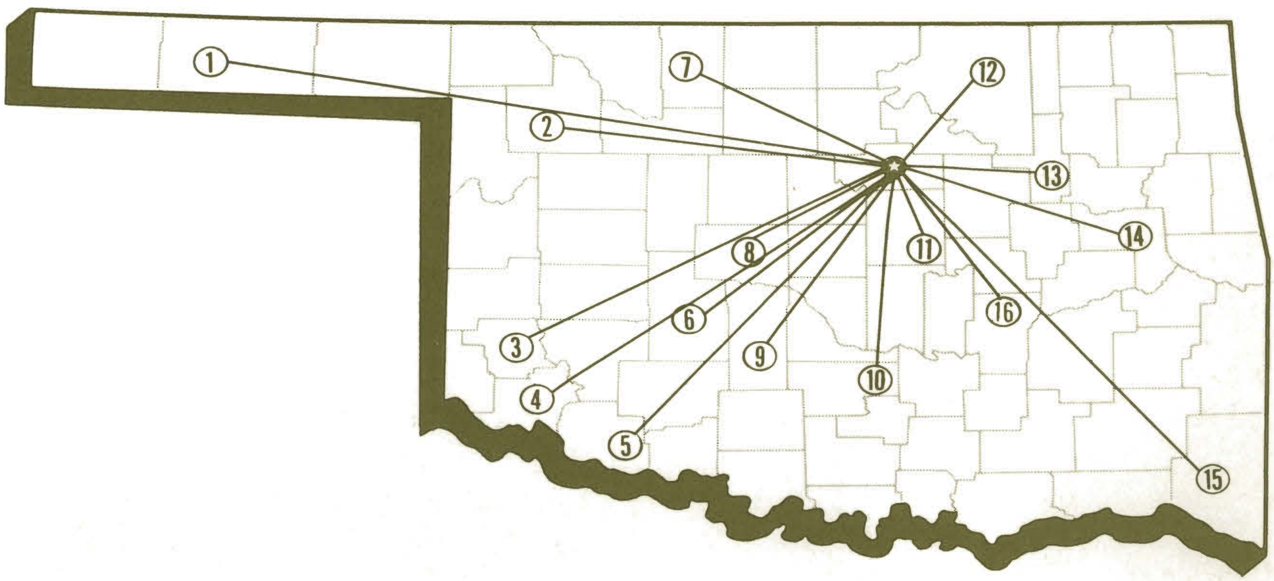

Main Station — *Stillwater, Perkins and Lake Carl Blackwell*

1. **Panhandle Research Station — *Goodwell***
2. **Southern Great Plains Field Station — *Woodward***
3. **Sandyland Research Station — *Mangum***
4. **Irrigation Research Station — *Altus***
5. **Southwest Agronomy Research Station — *Tipton***
6. **Caddo Research Station — *Ft. Cobb***
7. **North Central Research Station — *Lahoma***
8. **Southwestern Livestock and Forage Research Station — *El Reno***
9. **South Central Research Station — *Chickasha***
10. **Agronomy Research Station — *Stratford***
11. **Pecan Research Station — *Sparks***
12. **Veterinary Research Station — *Pawhuska***
13. **Vegetable Research Station — *Bixby***
14. **Eastern Research Station — *Haskell***
15. **Kiamichi Field Station — *Idabel***
16. **Sarkeys Research and Demonstration Project — *Lamar***