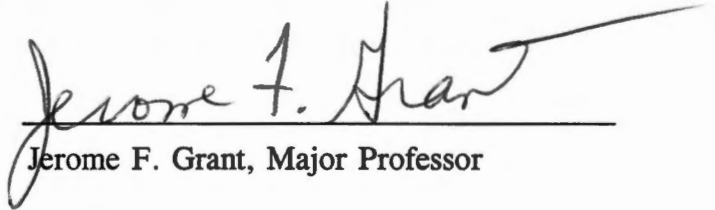
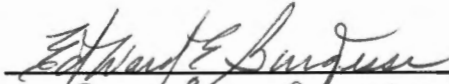
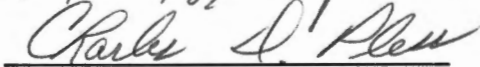


To the Graduate Council:

I am submitting herewith a thesis written by Kenneth Jeffrey Copley entitled "Distribution and Establishment of Introduced Parasitoids of the Alfalfa Weevil in Tennessee". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Entomology and Plant Pathology.


Jerome F. Grant, Major Professor

We have read this thesis and
recommend its acceptance:

Accepted for the Council:


Associate Vice Chancellor
and Dean of the Graduate
School

**DISTRIBUTION AND ESTABLISHMENT OF INTRODUCED PARASITIDS
OF THE ALFALFA WEEVIL IN TENNESSEE**

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

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ABSTRACT

The alfalfa weevil, *Hypera postica* (Gyllenhal), is the most important pest of alfalfa, *Medicago sativa* L., in North America since its introduction into Utah in 1904. By the mid-1950s, the alfalfa weevil had spread into the northeastern United States. In Tennessee, the alfalfa weevil was first detected in 1959, and within five years, the weevil had spread throughout the entire state.

In 1994, a two-year research project was initiated to study the alfalfa weevil and its biological control agents. One objective of this research was to initiate an intensive study to determine seasonality and life history of the alfalfa weevil in Tennessee. Additional objectives of this research included monitoring the establishment and distribution of introduced parasitoids of the alfalfa weevil, determining parasitism levels of the alfalfa weevil, and monitoring disease incidence of the alfalfa weevil. A state-wide survey was established to monitor the alfalfa weevil and its biological control agents in 27 alfalfa fields in nine counties. A questionnaire was developed and distributed to all agricultural extension agents in Tennessee to evaluate alfalfa production and the status of the alfalfa weevil.

Alfalfa fields in the intensified study were sampled each week from January to December in Giles and McMinn Counties. Alfalfa fields in the state-wide study were sampled twice in 1994 and twice in 1995. In Tennessee, alfalfa weevils overwintered in both the egg and adult stages. Densities of alfalfa weevil adults and larvae peaked in April during 1994 and 1995.

During this two-year study, approximately 11.39% of all field-collected larvae (n=6,215) and only about 0.43% of all field-collected adults (n=460) were parasitized. *Bathyplectes anurus* (Thomson) and *Bathyplectes curculionis* (Thomson), parasitoids of alfalfa weevil larvae, were recovered in all counties sampled. *Bathyplectes anurus* was the predominant larval parasitoid, suggesting *B. anurus* has displaced *B. curculionis* in Tennessee. Percent parasitism of alfalfa weevil larvae by *B. anurus* was 7.12% (n=6,215), and 4.12% (n=6,215) by *B. curculionis*. State-wide, *Microctonus aethiopoides* (Loan) was recovered in low numbers, suggesting poor establishment of alfalfa weevil adult parasitoids in Tennessee.

Erynia sp., a fungal pathogen of alfalfa weevil larvae, was detected from early March to late April. The number of field-collected alfalfa weevil larvae infected by *Erynia* sp. was greater in 1994 [436 infected larvae (n=2,439)] than in 1995 [45 infected larvae (n=3,320)].

As a result of the alfalfa management questionnaire, agricultural extension agents provided solid information concerning alfalfa production and the impact of the alfalfa weevil in Tennessee. The alfalfa weevil is responsible for 15% reduction in alfalfa yield, and 78% of the extension agents listed the alfalfa weevil as the major pest of alfalfa. The number one limiting factor of alfalfa production in Tennessee is expenses. Much of these expenses are attributed to insecticide applications for the alfalfa weevil. Growers in 96% of the alfalfa-producing counties applied insecticides to control the alfalfa weevil.

The absence of a successful adult weevil parasitoid allows alfalfa weevils to produce at much greater numbers, and larval parasitoids will not sufficiently reduce alfalfa weevil densities below the economic threshold level. Parasitism of alfalfa weevil adults is greater in northern states than in southern states, and the low parasitism of alfalfa weevil adults in Tennessee indicates that *M. aethiopoides* may not be adapted to the southern climate. Therefore, data from this research will provide information needed to develop and implement effective biological control methods for the alfalfa weevil in Tennessee.

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CHAPTER I

LITERATURE REVIEW

Alfalfa, *Medicago sativa* L., was first cultivated in Iran before 700 B.C., and was carried to Arabia, the Mediterranean countries, and eventually to the New World, with the first successful attempt to grow alfalfa in Georgia in 1736 (Martin et al. 1976). It was not until 1850, when alfalfa was introduced and successfully grown in California, that alfalfa production expanded in the United States (Munir and Sailer 1984).

Alfalfa is currently the leading hay crop in the United States with approximately eight million hectares planted every year (Anonymous 1991). With its high protein content and vitamins, alfalfa is an important component of dairy operations (Christensen 1980). Alfalfa is a long-lasting legume; generally a field has a longevity of two to seven years and is usually harvested two to six times each year (Grant and Lambdin 1990). As a long-lasting legume, alfalfa is subjected to numerous types of pests throughout the growing season. The alfalfa weevil, *Hypera postica* (Gyllenhal), is the single most important pest of alfalfa in North America (Metcalf and Flint 1962, Dysart and Day 1976, Zavaleta and Ruesink 1980). As with many agricultural pests in North America, the alfalfa weevil was accidentally introduced into the United States, and each year, the alfalfa weevil costs farmers \$400 million to \$1 billion per year (Anonymous 1991).

The alfalfa weevil, native to Europe, was first detected in the United States in Utah in 1904 (Titus 1910). In Tennessee, the alfalfa weevil was first detected in 1959, and by 1964 the weevil had spread throughout the entire state (Bennett 1968). The

alfalfa weevil has been documented in all counties where alfalfa is grown in Tennessee (Burgess and Patrick 1992). Although alfalfa is successfully grown in Tennessee, where 20,000 hectares were harvested in 1993 (Anonymous 1994), the alfalfa weevil is the most destructive insect pest of alfalfa and impacts alfalfa production (Reynolds et al. 1974). With the introduction of the alfalfa weevil into Tennessee, alfalfa hectarage was drastically reduced from an all-time high of 76,113 hectares in 1958 to 20,243 hectares in 1994 (Anonymous 1995).

In alfalfa weevil-infested fields, the first cutting of alfalfa is significantly reduced, and other cuttings during the growing season are subsequently affected (Metcalf and Flint 1962, Harcourt and Guppy 1976, Wilson et al. 1979, Christensen 1980). Both larvae and adults feed on the plant, and their damage can lower the nutritional value of alfalfa hay because the greatest portion of protein is located in alfalfa leaves (Wilson et al. 1979, Anonymous 1991). In New York, a three-year-old stand of alfalfa was sampled to determine *in vitro* true digestibility (IVTD) and crude protein (CP) losses due to feeding by alfalfa weevil larvae. Losses for these components were 1.4 metric tons/hectare (IVTD) and 0.3 metric tons/hectare (CP) (Liu and Fick 1975).

Alfalfa weevil larvae inflict more extensive damage than adult weevils to alfalfa, with most larval damage occurring on the first cutting of alfalfa (Bennett 1968, Martin et al. 1976, Christensen 1980, Stark et al. 1994). In heavily-damaged fields, the foliage is consumed, the plant appears ragged and stunted, and the remaining foliage appears frosted or bleached (Metcalf and Flint 1962). Alfalfa weevil adults also damage alfalfa

by feeding on new alfalfa growth after the first cutting (Burgess and Patrick 1992). A large population of alfalfa weevil adults can delay alfalfa growth.

Alfalfa weevil larvae are present in the spring, and alfalfa weevil adults emerge from late spring to early summer (Hogg 1994). Female alfalfa weevils oviposit in green stems beginning in June and continuing into winter. Some female alfalfa weevil adults do not deposit eggs until spring. The female chews a hole in an alfalfa stem, where she then deposits 1 to 40 eggs. An individual female can lay as many as 1,000 eggs during her lifetime (Christensen 1980).

The alfalfa weevil has one generation per year, and overwinters as an adult and/or egg (Bennett 1968). The larva is light green with a black head, and has a dorsal white stripe from the head to the tip of the abdomen. The larval stage lasts about 21 to 28 days. Full-grown larvae then spin a cocoon of whitish thread-like material on the ground or attached to an alfalfa plant. Larvae pupate within the cocoons, and the pupal stage lasts about 7 to 14 days. Newly-emerged alfalfa weevil adults are approximately 4 mm long with a distinct snout and a light brown body with a dark stripe down the elytra (Bennett 1968, Metcalf and Luckmann 1982, Anonymous 1991). After emergence in the spring, adults feed for 8 to 10 weeks and then enter diapause or a state of arrested activity (Hogg 1994) and do not become active again until early fall.

Alfalfa is the main food source of the alfalfa weevil, which also feeds on several other host plants, such as clovers and vetch (Bennett 1968). An alfalfa weevil can oviposit into weeds located around alfalfa fields. In a study related to alternate hosts, alfalfa weevil eggs were found more abundantly in henbit and shepherdspurse than in

alfalfa. However, larvae that hatched from eggs in nearby weeds moved to alfalfa fields to feed, and no feeding damage was observed on these weeds (Saad et al. 1969).

Chemical insecticides are the main method of control of alfalfa weevil. However, insecticides also kill the natural enemies of pest insects in the field, and prolific use of chemical pesticides may enhance development of pest resistance to pesticides (Shoemaker 1973, Armbrust 1974, Zavaleta and Ruesink 1980, Anonymous 1991, Oloumi-Sadeghi et al. 1993). Therefore, the impact of an insecticide on non-target organisms (e.g., parasitoids and predators), as well as on pest species, must be considered. Because the alfalfa weevil cannot be adequately managed with a single-factor approach (Metcalf and Luckmann 1982), chemical insecticides must be used as a management tool that is incorporated with the use of other control tactics, e.g., biological control, into a viable pest management program.

The concept of biological control in pest management is to use another living organism to reduce populations of a pest, such as the alfalfa weevil (Armbrust 1974, Dysart and Day 1976, Anonymous 1978, 1991). Biological control is generally inexpensive and not harmful to humans, plants and non-target animals (Wilson and Huffaker 1976).

Biological control cannot be expected to solve all pest problems, but it may offer an alternative solution in some instances (Wilson and Huffaker 1976). In the southeastern areas of the United States where the alfalfa weevil has limited alfalfa production, successful biological control of the alfalfa weevil may restore interest in alfalfa and increase alfalfa production (Munir and Sailer 1984). Alfalfa is a good

candidate for development of a pest management system using biological control. Because alfalfa can tolerate small amounts of damage, a sound pest management program does not need to completely eliminate insect pests. Biological control cannot be an important component if the pest is eliminated because the food source for the natural enemy also would be eliminated (Berberet et al. 1978, Metcalf and Luckmann 1982).

When the alfalfa weevil was introduced into the United States at the beginning of the twentieth century, its natural enemies were not introduced. Therefore, researchers directed attention to the use of host-specific parasitoids as a method of control of the alfalfa weevil (Chamberlin 1924, Anonymous 1991). Biological control of the alfalfa weevil was initiated in 1911, when exotic parasitoids were released into Utah (Duodu and Davis 1974). Two larval parasitoids were introduced by the United States Department of Agriculture (USDA) from Europe (Bennett 1968, Dysart and Day 1976, Grant and Lambdin 1990, Anonymous 1991, Bryan et al. 1993). Several of these introduced species of parasitoids were released against the alfalfa weevil in Tennessee (Bennett 1968, Brunson and Coles 1968, Dysart and Day 1976, Grant and Lambdin 1990, Bryan et al. 1993). Two of the most commonly released parasitoids, *Bathyplectes curculionis* (Thomson) and *Bathyplectes anurus* (Thomson), attack larvae of the alfalfa weevil (Dysart and Day 1976, Giles et al. 1994, Hogg 1994). Unlike predators that may feed on several species of prey, *B. curculionis* and *B. anurus* attack only larvae of the alfalfa weevil. The eggs, larvae, pupae and adults of *B. curculionis* and *B. anurus* are similar in appearance (Day 1970). The cocoons are slightly different, and their differences will be discussed later.

In 1911, *B. curculionis* was imported and released into the United States (Chamberlin 1924, Duodu and Davis 1974). In 1962, *B. curculionis* was released into Tennessee (Bennett 1968, Bryan et al. 1993). *Bathyplectes curculionis* has one generation in the spring, with populations peaking 7 to 14 days before the greatest density of alfalfa weevil larvae. *Bathyplectes curculionis* also has a partial second generation 7 to 21 days after the alfalfa weevil population reaches its greatest density (Dysart and Day 1976). Some parasitoid pupae from the spring generation develop and emerge as adults during the spring. These newly-emerged parasitoids must locate alfalfa weevil larvae to parasitize (Harcourt 1990, Hogg 1994). Adult *B. curculionis* emerge from overwintered cocoons in the spring. The female parasitoid deposits one egg in an early first- or second-instar alfalfa weevil larva. The wasp larva emerges from the egg and feeds internally on the alfalfa weevil larva, eventually killing the weevil after it has formed its cocoon (Hogg 1994). The full-grown parasitoid larva then spins its cocoon inside the weevil cocoon (Brunson and Coles 1968, Duodu and Davis 1974, Dysart and Day 1976, Bartell and Pass 1978a). The cocoon of *B. curculionis* is dark brown, 3 to 4 mm long and 2 mm in diameter. A distinct, non-raised cream-colored band is visible around the midsection of the cocoon (Brunson and Coles 1968, Dysart and Day 1976, Hogg 1994). Overall developmental time from oviposition to pupation of *B. curculionis* is 13 to 21 days (Bartell and Pass 1978b).

Bathyplectes anurus was imported and released into the western United States in 1911, but did not become established (Chamberlin 1924, Bartell and Pass 1978a). In 1960, *B. anurus* was released extensively in the northeastern United States where it

became established (Dysart and Day 1976, Harcourt 1990, Parr et al. 1993). In Tennessee, *B. anurus* was released in 1967 (Bennett 1968, Bryan et al. 1993) and was not recovered until 1976 (Dysart and Bingham 1977). *Bathyplectes anurus* has one generation per year, and overwinters inside its cocoon. Like *B. curculionis*, adults emerge in the spring, and females deposit one egg inside a weevil larva. Parasitoid larvae complete their development in 18 to 21 days, and developmental time from oviposition to formation of cocoons is 21 to 25 days (Bartell and Pass 1980). Parasitism generally peaks about 7 days before the peak density of alfalfa weevil larvae in the spring (Brunson and Coles 1968, Dysart and Day 1976, Harcourt 1990). The dark-brown cocoon of *B. anurus* is 3 to 4 mm long and 2 mm in diameter, and has a narrow, raised, cream-colored band around the midsection. Unlike *B. curculionis*, the pupa of *B. anurus* moves inside the cocoon, causing the cocoon to ambulate (Brunson and Coles 1968, Day 1970, Dysart and Day 1976, Harcourt 1990, Hogg 1994).

Bathyplectes anurus is considered to be a more successful biological control agent than *B. curculionis*. It has a higher reproductive capacity (300 vs. 200 eggs), rapid searching capabilities, and the ambulation of the pupa inside the cocoon allows it to escape predators and adverse environmental conditions (Day 1970, Dowell and Horn 1977, Berberet et al. 1978, Harcourt 1990, Giles et al. 1994, Hogg 1994). Thus, *B. anurus* has gradually displaced *B. curculionis* (Dowell and Horn 1977, Day 1983, Harcourt 1990, Kingsley et al. 1993, Oloumi-Sadeghi et al. 1993, Flanders et al. 1994). In 1981 and 1982, a study conducted in eastern Ontario showed parasitism by *B. curculionis* was 8 and 10%, respectively, and parasitism by *B. anurus* was less than 2%

(Harcourt 1990). However, in 1983, parasitism by *B. anurus* increased to 15%, while parasitism by *B. curculionis* decreased to 2%. *Bathyplectes anurus* also appears to be the predominant larval parasitoid in Ohio, where larval parasitism by *B. anurus* increased from 17% in 1981 to 66% in 1988 (Kingsley et al. 1993). In 1991, in Illinois, parasitism by *B. anurus* (27.2% parasitism) was greater than *B. curculionis* (6.1% parasitism) in 27 alfalfa fields that were sampled and evaluated (Oloumi-Sadeghi et al. 1993).

The only successfully introduced parasitoid species that attacks adult alfalfa weevils is *Microctonus aethiopoides* (Loan) (Flessel and Niemczyk 1977, Grant and Lambdin 1990). *Microctonus aethiopoides* is one of the most important biological control agents of the alfalfa weevil and has the greatest potential to reduce alfalfa weevil populations (Flessel and Niemczyk 1977, Van Driesche and Gyrisco 1979, Munir and Sailer 1984, Kingsley et al. 1993). The ovipositional potential of female alfalfa weevils is greatly reduced when parasitized by *M. aethiopoides* (Flessel and Niemczyk 1977, Van Driesche and Gyrisco 1979). The reproductive organs of parasitized female alfalfa weevils do not develop normally, and the weevils cannot reproduce (Brunson and Coles 1968). Between 1948 and 1957, *M. aethiopoides* was released for the control of sweetclover weevil, *Sitona cylindricollis* (Fahr), in the United States. However, this parasitoid did not become established. In 1957, *M. aethiopoides* was reintroduced against the alfalfa weevil and became established in the northeastern United States (Radcliffe et al. 1983). *Microctonus aethiopoides* was released in Tennessee in 1967 (Bennett 1968, Brunson and Coles 1968, Bryan et al. 1993).

Microctonus aethiopoides overwinters, in diapause, as first-instar larvae in the new brood of alfalfa weevil adults. *Microctonus aethiopoides* has two generations per year. First-generation adults parasitize overwintered weevils in the spring during alfalfa weevil oviposition. Second-generation adult *M. aethiopoides* parasitize newly-emerged alfalfa weevil adults in late spring before they reach sexual maturity (Van Driesche and Gyrisco 1979). A female *M. aethiopoides* thrusts her ovipositor into the body cavity of an alfalfa weevil and deposits one egg. After eclosion and larval development, the full-grown larva of *M. aethiopoides* emerges from the weevil and forms a white, silky cocoon in plant debris. The pupal stage lasts from 14 to 21 days. Newly-emerged adult *M. aethiopoides* search for nonparasitized adult weevils.

From 1980 to 1990, the Animal and Plant Health Inspection Service (APHIS) of the USDA released parasitoids against the alfalfa weevil in alfalfa-producing states. In an evaluation study, biological control of the alfalfa weevil by parasitoids was successful and reduced insecticide usage in Iowa, Missouri and Nebraska (Kingsley et al. 1993). In this eight-year study, less than 3% of 180 alfalfa fields were treated with a chemical insecticide for control of the alfalfa weevil. Populations of the alfalfa weevil were maintained at subeconomic injury levels, and production costs declined. These results documented the success of these introduced parasitoids in reducing populations of the alfalfa weevil in these states.

In 1973, alfalfa weevil larvae were found to be infected by a fungal entomopathogen (Harcourt et al. 1977, Millstein et al. 1982). This fungal organism was first identified as *Entomophthora phytonomi* Arthur (Harcourt et al. 1977) and was later

placed in the genus *Erynia* (Ben-Ze'ev and Kenneth 1982). This fungus was found to be an important natural mortality factor of the alfalfa weevil (Harcourt et al. 1977). All instars of the alfalfa weevil are infected by this fungus, which is most prevalent during the feeding period of alfalfa weevil larvae. The incidence of this disease is highest when weather conditions are favorable. A relationship was established with conidial discharge of *Erynia* sp. and periods of high relative humidity (Watson et al. 1981, Millstein et al. 1982). Just before death, infected larvae crawl to the undersides of the terminal leaves and appear creamy-brown (Harcourt et al. 1974, 1977). *Erynia* sp. also can affect the alfalfa weevil in the cocoon. After the larvae spin their cocoons, infected prepupae die, turn black and shrivel, and will occasionally appear flattened (Harcourt et al. 1974, 1977).

The successful use of natural enemies in alfalfa would help to reduce the use of chemical insecticides to manage the alfalfa weevil. This reduction would provide an economical and environmental benefit to alfalfa producers. Parasitoids have been released for biological control of the alfalfa weevil in Tennessee, but little information is known about the success of these releases or the abundance and spread of parasitoids in Tennessee. Therefore, research is necessary to determine the role of these introduced parasitoids in regulation of populations of the alfalfa weevil.

The objectives of this study were to :

1. determine seasonality and life history of the alfalfa weevil in Tennessee,
2. determine the establishment and distribution of introduced parasitoids of the alfalfa weevil throughout Tennessee,

3. monitor parasitism levels of the alfalfa weevil (larvae and adults),
and determine parasitoid species composition,
4. monitor disease incidence of alfalfa weevil larvae, and
5. survey county extension agents state-wide to evaluate alfalfa production in
Tennessee and the economic benefit of parasitoids in controlling the
alfalfa weevil.

CHAPTER II

LIFE HISTORY AND BIOLOGICAL CONTROL AGENTS OF THE ALFALFA WEEVIL IN EASTERN AND MIDDLE TENNESSEE

i. Introduction

Alfalfa, *Medicago sativa* L., was first grown in the United States in Georgia in 1736 (Martin et al. 1976). In California, in 1850, the production of alfalfa was expanded when it was introduced into the western United States (Munir and Sailer 1984). Alfalfa is currently the leading hay crop, with approximately eight million hectares planted annually (Anonymous 1991). Because of its high protein content and vitamins, alfalfa is an important legume in dairy operations (Christensen 1980).

The alfalfa weevil, *Hypera postica* (Gyllenhal), accidentally introduced into the United States from Europe, has become the most important pest of alfalfa, costing farmers from \$400 million to \$1 billion in control costs and losses per year (Metcalf and Flint 1962, Dysart and Day 1976, Zavaleta and Ruesink 1980, Anonymous 1991). This pest was first detected in the United States in 1904 in Salt Lake City, Utah (Titus 1910), and has since spread to all 48 contiguous states (Dysart and Day 1976). The alfalfa weevil was first discovered in Tennessee in 1959, and within six years, this pest species had spread throughout the entire state (Bennett 1968).

The biology and life history of this insect have been documented by numerous researchers (Bennett 1968, Harcourt et al. 1977, Metcalf and Luckmann 1982). The alfalfa weevil has one generation per year and overwinters in the adult and/or egg stage (Bennett 1968). A newly-hatched larva is cream-colored and becomes light-green as it develops. A larva is easily recognized by its black head and a white stripe down the dorsal surface of the body. A full-grown larva (approximately 9 mm long) spins a silken cocoon on the ground or attached to an alfalfa plant; the larva pupates inside the cocoon, where it transforms to an adult within 1-2 weeks. Alfalfa weevil adults emerge in the spring, feed for a few weeks, and enter diapause or a state of arrested activity (Hogg 1994). The alfalfa weevil adult (approximately 4 mm long) has a distinct snout and a light brown body with a dark stripe down the middle of the elytra (Bennett 1968, Metcalf and Luckmann 1982, Anonymous 1991).

Alfalfa is an ideal crop for an integrated pest management system because it can tolerate small amounts of damage. Biological control, or the use of another living organism to reduce populations of pests, has been incorporated into management programs for the alfalfa weevil (Armbrust 1974, Dysart and Day 1976, Anonymous 1978, 1991). Several introduced parasitoid species have been released to help reduce populations of the alfalfa weevil in Tennessee (Bennett 1968, Brunson and Coles 1968, Dysart and Day 1976, Grant and Lambdin 1990, Bryan et al. 1993). For example, two parasitoids of alfalfa weevil larvae [*Bathyplectes curculionis* (Thomson) and *Bathyplectes anurus* (Thomson) (Dysart and Day 1976, Giles et al. 1994, Hogg 1994)] and one

parasitoid [*Microctonus aethiopoides* (Loan)] of alfalfa weevil adults have been released in many locations in Tennessee (Flessel and Niemczyk 1977, Grant and Lambdin 1990).

The life cycle of the alfalfa weevil and its parasitoids must be fully understood before appropriate integrated pest management programs can be developed and implemented. This biological information will enable researchers to better predict emergence patterns of the alfalfa weevil and allow alfalfa producers to target insecticide applications so parasitoids and other beneficial insects are not eliminated.

Little published information is available on the composition of parasitoid species and parasitism levels of the alfalfa weevil in alfalfa fields in Tennessee. Although numerous parasitoids have been released in Tennessee, few follow-up studies have been conducted to determine establishment and success. Thus, the objectives of this two-year research program were to:

1. define the life cycle of the alfalfa weevil under field conditions,
2. determine composition of parasitoid species of the alfalfa weevil and assess levels of parasitism,
3. monitor other pest and beneficial insects that are active in alfalfa fields, and
4. monitor disease incidence of the alfalfa weevil.

ii. Materials and Methods

In 1994 and 1995, an intensified study was conducted in one alfalfa field in Giles County (Middle TN) and in one field in McMinn County (East TN) to evaluate the life

cycle of the alfalfa weevil and its parasitoids (Figure 1). In 1994, both fields were sampled each week from the beginning of the growing season (April 7) through November 25. In 1995, sampling in both fields began early in the growing season (February 22). The field in Giles County was sampled each week until July 31. However, sampling in McMinn County ended on April 10 because the field was cultivated by the grower. These two counties were selected for intensive sampling because several species of introduced parasitoids had been released in those areas (Bryan et al. 1993).

Fields were selected in cooperation with agricultural extension agents in both counties. The fields represented typical alfalfa production in Tennessee, and had well established populations of the alfalfa weevil.

The alfalfa field (ca. 4 hectares) in McMinn County was treated with Furadan 2E (carbofuran) at 0.946 liter/hectare for control of the alfalfa weevil in 1994; a corner of the field was flagged (22.78 x 7.62 m) prior to treatment to provide an untreated alfalfa area to sample. Larvae were collected from this smaller, unsprayed part of the field. The alfalfa field (ca. 4 hectares) in Giles County was not treated with an insecticide during 1994 and 1995.

In McMinn County, the alfalfa (variety Alfagraze) stand was four-years old, and the previous crop was fescue pasture. In Giles County, the alfalfa (variety Buffalo) stand was two-years old, and the previous crop was Sudangrass.

On each sampling date, alfalfa height (cm) was randomly measured at five locations, and average plant height was recorded. Temperature (C°) and

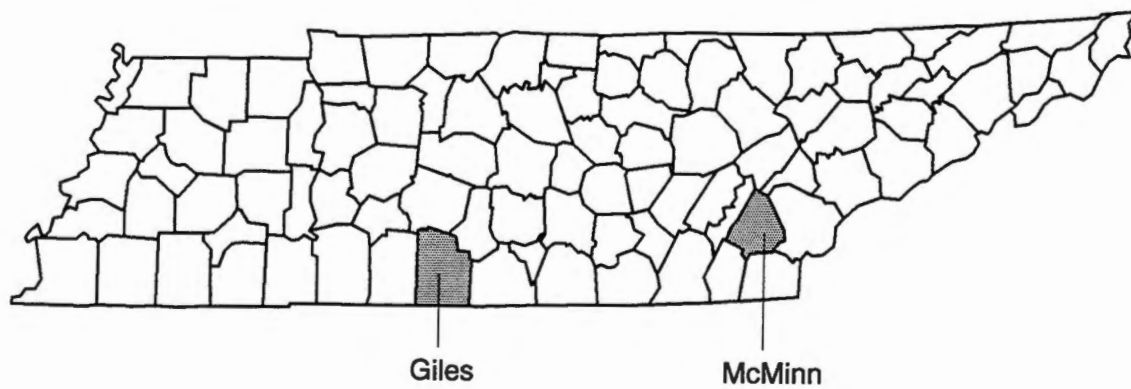


Figure 1. Location of alfalfa weevil intensive sampling sites in Tennessee, 1994-1995.

environmental conditions also were recorded. Two-hundred sweep-net (15-cm diameter) samples were randomly taken in each field. Sweep-net samples were collected in eight sets of 25 sweeps each. The contents of each set of sweeps were emptied into a labeled paper bag (35 x 17 cm), taken to the laboratory, and processed.

In the laboratory, four sets of 25 sweeps were emptied into a plastic pan (32 x 26 cm) and examined for alfalfa weevil larvae and adults. Alfalfa weevil adults were removed and placed into 27 petri dishes (100 x 15 mm). The number of adult weevils reared in petri dishes varied with each collection date, ranging from 1 to 30 adults per petri dish. Larvae were separated by size (small, medium and large), and 10 larvae of each size grouping were placed into 126 petri dishes (100 x 15 mm) and provided foliage. Adults and larvae were held at room temperature and monitored daily until death, adult emergence, or emergence of parasitoids.

The remaining four sets of 25 sweeps each were frozen (-17°C) and processed at a later date. In the laboratory, each set was emptied into a plastic pan (32 x 26 cm) and the contents were observed under a microscope. Beneficial insects and pests of alfalfa in each sample were separated and counted to determine insect numbers and insect diversity within alfalfa fields throughout the growing season.

Fifty alfalfa stems were selected randomly from each field on weekly sampling periods. In the laboratory, each stem length (cm) was measured and recorded. Each stem was then dissected lengthwise and examined for eggs of alfalfa weevil. The number of eggs per stem was recorded. This information will be used to define the optimum time for oviposition by alfalfa weevil during the growing season.

Percent parasitism and percent diseased larvae were log transformed and analyzed using a factorial analysis of variance (General Linear Models). Significant differences were compared using Least Square Means comparisons ($P \leq 0.05$). Other means were separated using Duncan's Multiple Range Test ($P \leq 0.05$) (SAS 1989).

iii. Results and Discussion

General Seasonality of the Alfalfa Weevil

During this two-year study, the alfalfa weevil overwintered in both the egg and adult stages in Giles and McMinn Counties (Figure 2). By combining and evaluating data from both locations, a general overview of seasonality of the alfalfa weevil was developed. Overwintering eggs were detected as early as late October to late June. Larvae were present from early February to late July, and pupae were found from mid-April through early June. Late-season larvae may have been destroyed by alfalfa harvesting before pupation as no pupae were found after early June although larvae were present in the field. Alfalfa weevil adults were present in the field throughout most of the year, but densities were greatest in April. However, adults left the field to aestivate during the summer months, and no adults were collected from alfalfa during August.

Averaged across all sampling dates, significantly greater numbers of eggs were found in Giles County than in McMinn County (0.61 and 0.19 eggs/stem, respectively). In Giles County, egg densities were monitored from November to April, and densities of alfalfa weevil eggs were significantly greater in November (1.33 eggs/stem) than on

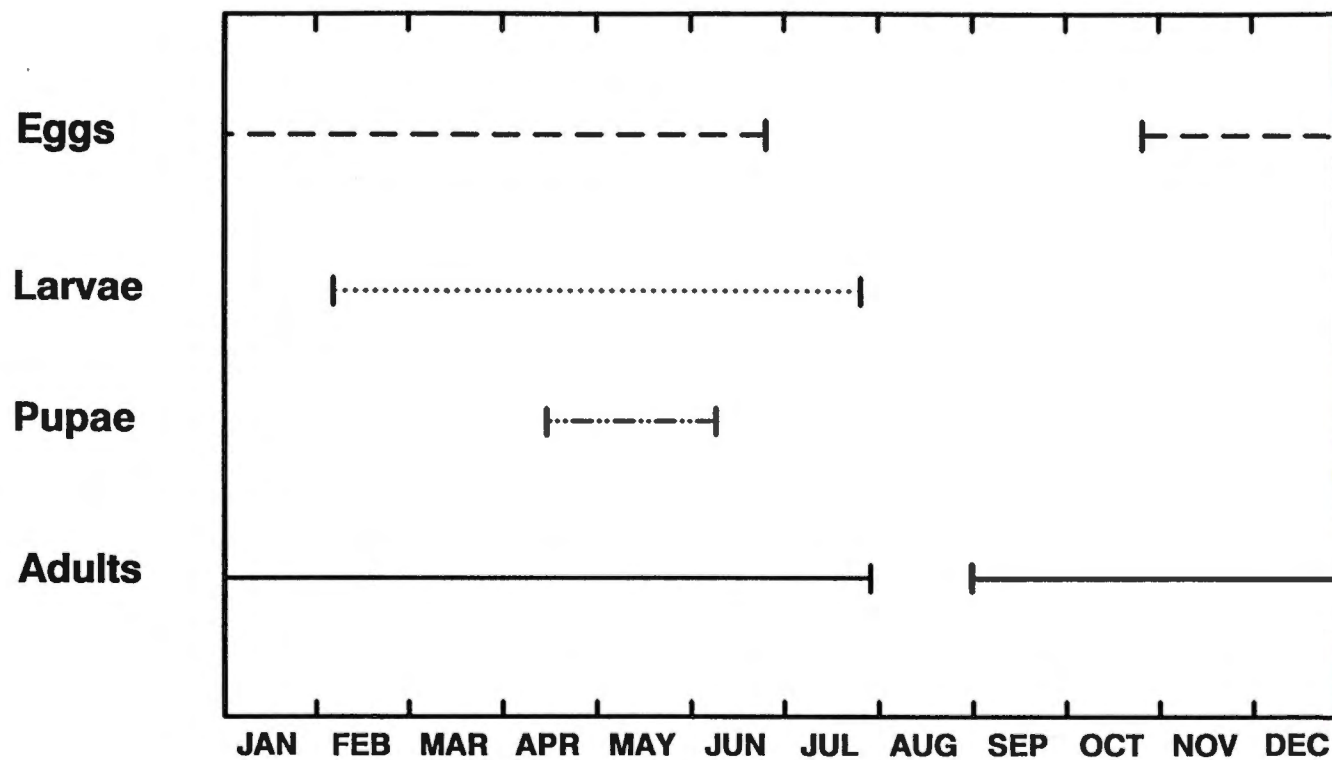


Figure 2. Seasonality of the alfalfa weevil in Giles and McMinn Counties in Tennessee.

any other sampling date (Table 1). This greater egg density can be partially attributed to alfalfa weevil adults returning to alfalfa fields in the fall to deposit eggs in uncut alfalfa stems. Alfalfa stems should be mowed in the fall to reduce the numbers of alfalfa weevil eggs that overwinter, thereby reducing the number of larvae in spring.

Alfalfa weevil larvae were detected in April in McMinn County and as early as March in Giles County (Figure 3). The warmer climate in Giles County may have enhanced egg development and hatch. Alfalfa weevil larval populations were much greater (about 4 1/2 times) in Giles County than in McMinn County. For example, larval densities peaked in both counties during April; however, densities peaked in McMinn County at 151.10 larvae/100 sweeps while those in Giles County peaked at 692.00 larvae/100 sweeps (Figure 3).

Densities of alfalfa weevil adults peaked in April in both counties (Figure 4). Surprisingly, peak densities of adults were similar among counties (23 adults/100 sweeps and 25 adults/100 sweeps in McMinn and Giles Counties, respectively), even though larval densities were much greater in Giles County. The impact of natural enemies on alfalfa weevil larvae may have been greater in Giles County. The late cuttings of alfalfa in McMinn County in 1994 may have allowed more time for pupation and enhanced survival of alfalfa weevils. The first cutting of alfalfa occurred in June in McMinn County, and in late April in Giles County. Environmental conditions also may have been more favorable during the pupal stage in McMinn County than in Giles County. In Giles County, there were slightly more alfalfa weevil adults in 1994 (2.50 adults/100 sweeps) than in 1995 (2.47 adults/100 sweeps).

Table 1. Mean number of alfalfa weevil eggs/stem in alfalfa in Giles County, 1994 and 1995.

Sampling Date	Mean/50 Stems
November 25	1.33 a*
February 24	0.45 b
March 24	0.11 b
April 7	0.11 b
April 14	0.00 b

* Means with the same letter are not significantly different ($p > 0.05$) (Duncan's multiple range test).

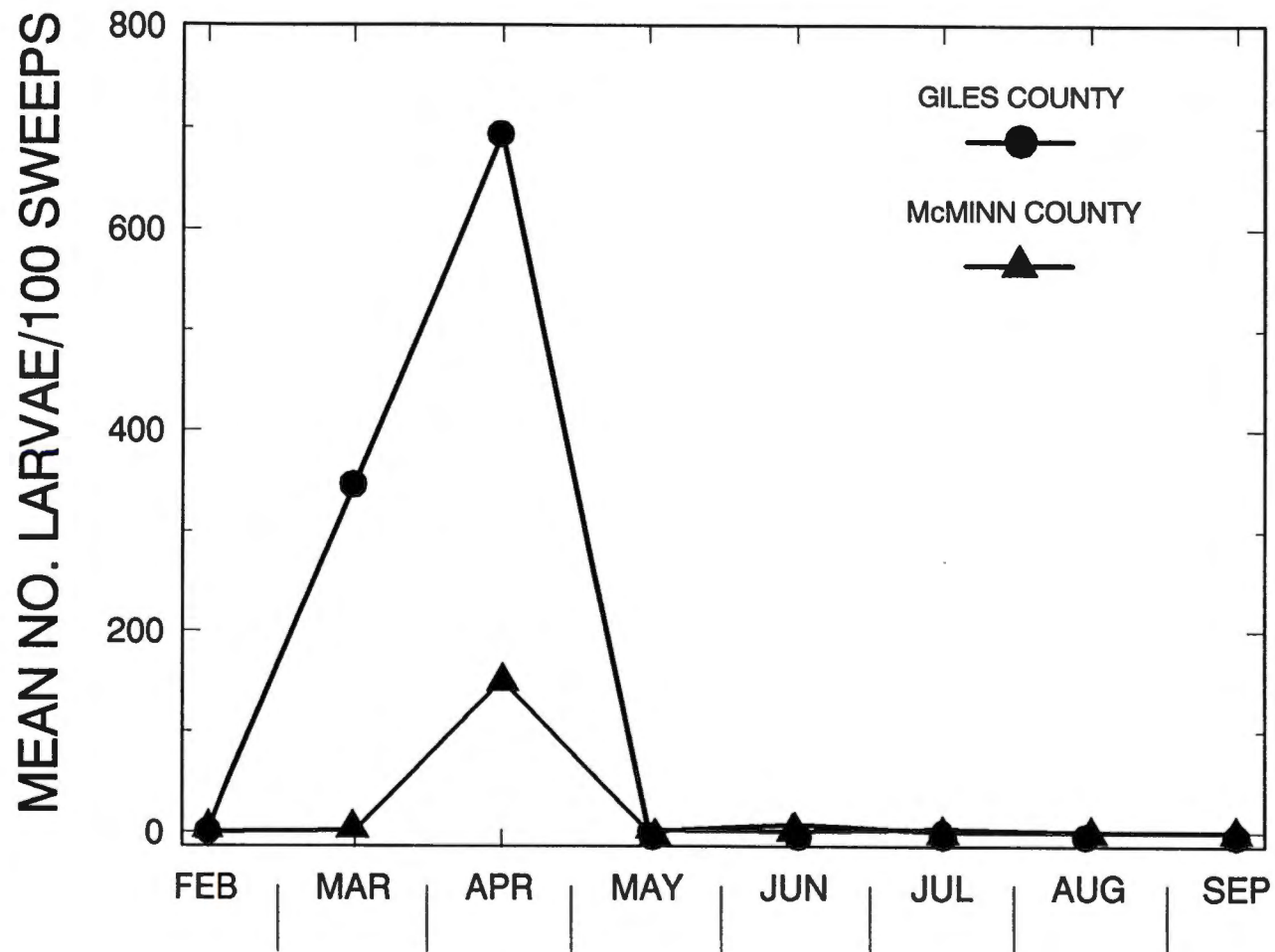


Figure 3. The mean number of alfalfa weevil larvae/100 sweeps collected from alfalfa in Giles and McMinn Counties from February to September, 1994-1995.

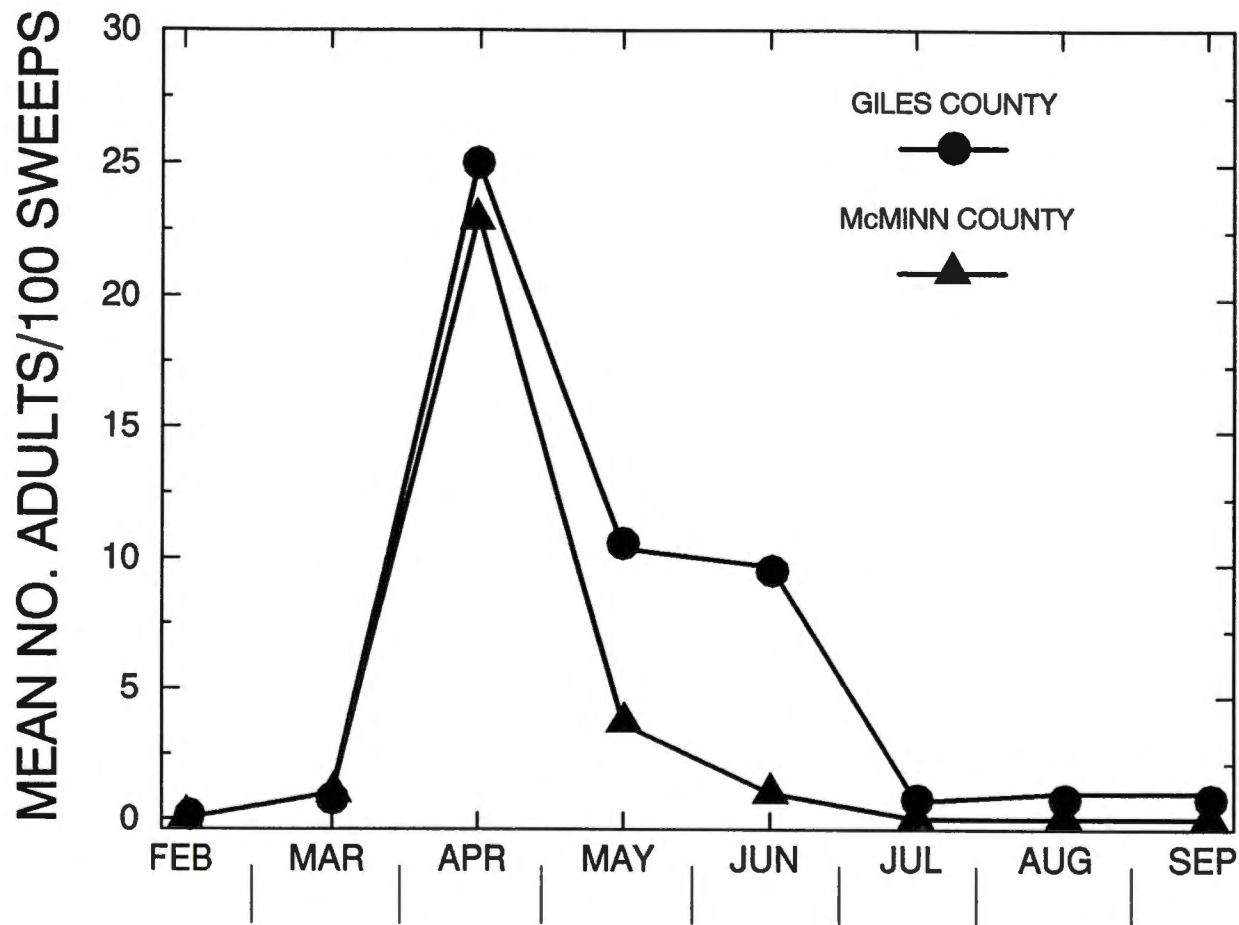


Figure 4. The mean number of alfalfa weevil adults/100 sweeps collected from alfalfa in Giles and McMinn Counties from February to September, 1994-1995.

Incidence of Parasitoids and *Erynia*

By combining and evaluating data from field-collected larvae in Giles and McMinn Counties, a general overview of seasonality of biological control agents of the alfalfa weevil was developed (Figure 5). *Bathyplectes anurus*, a parasitoid of alfalfa weevil larva, was present from early March to early June, and *B. curculionis*, another parasitoid of alfalfa weevil larva, was present from early March to early May. *Microctonus aethiopoides*, an alfalfa weevil adult parasitoid, was present in alfalfa fields from early April to late July. *Erynia* sp., a fungal pathogen that infects alfalfa weevil larvae, was detected from early March to late April. During this time, larval densities were at their peak.

Bathyplectes anurus and *B. curculionis* were reared from alfalfa weevil larvae collected from both counties. Parasitism of alfalfa weevil larvae was first detected in April in McMinn County (Figure 6) and in March in Giles County (Figure 7). *Bathyplectes anurus* was the predominant larval parasitoid detected in Giles and McMinn Counties. In McMinn County, parasitism of alfalfa weevil larvae by *B. anurus* was greatest in April, when about 17% of all larvae were parasitized (Figure 6). In Giles County, parasitism by *B. anurus* was greatest in March, when about 20% of all larvae were parasitized (Figure 7). Significantly greater numbers of *B. curculionis* were found in Giles County (1.16 adults/100 sweeps) than in McMinn County (0.09 adults/100 sweeps). Parasitism of alfalfa weevil larvae by *B. curculionis* peaked at about 1 and 7% in McMinn and Giles Counties, respectively (Figures 6 and 7).

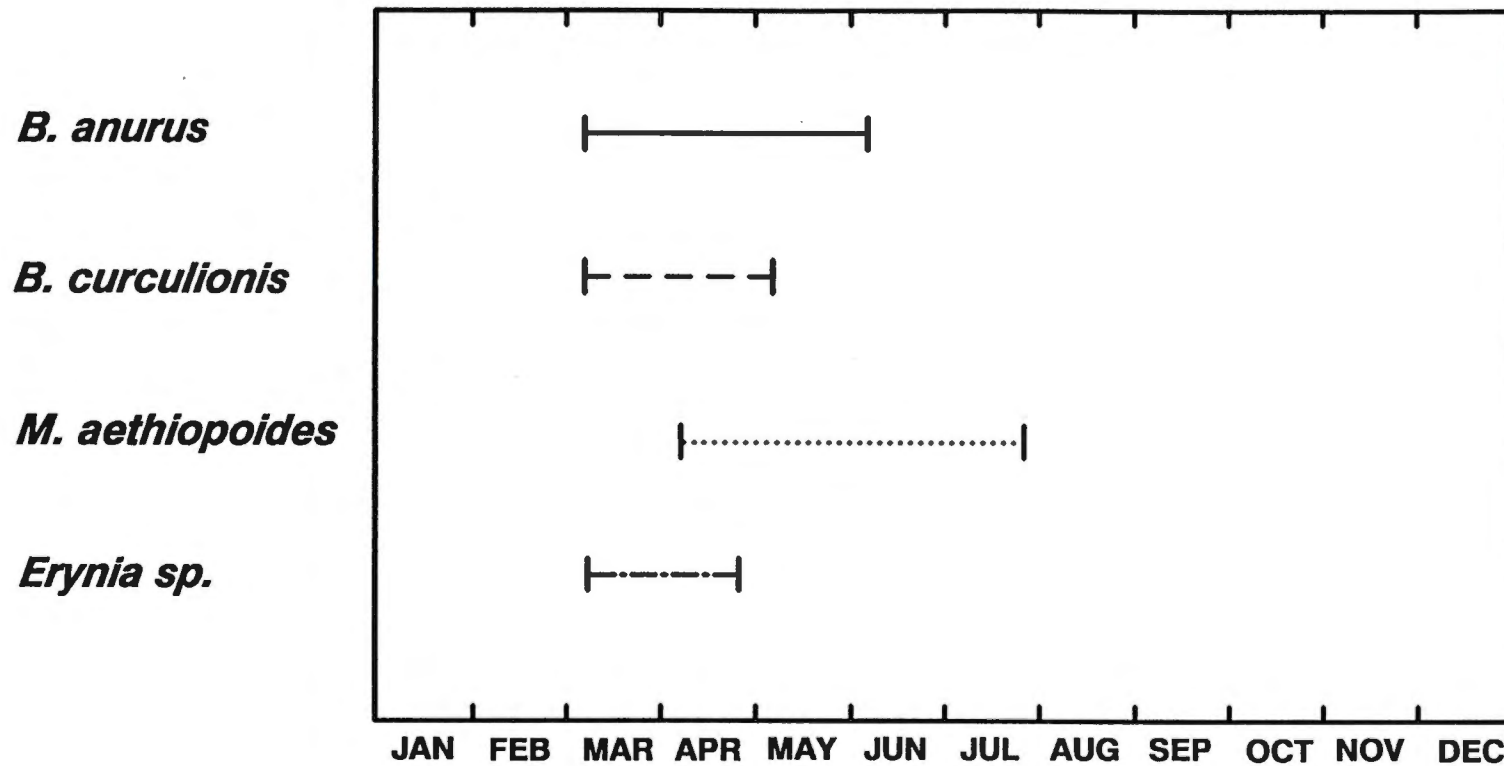


Figure 5. Seasonality of parasitoids and fungal pathogens of alfalfa weevil as determined by field-collected larvae in Giles and McMinn Counties, 1994-1995.

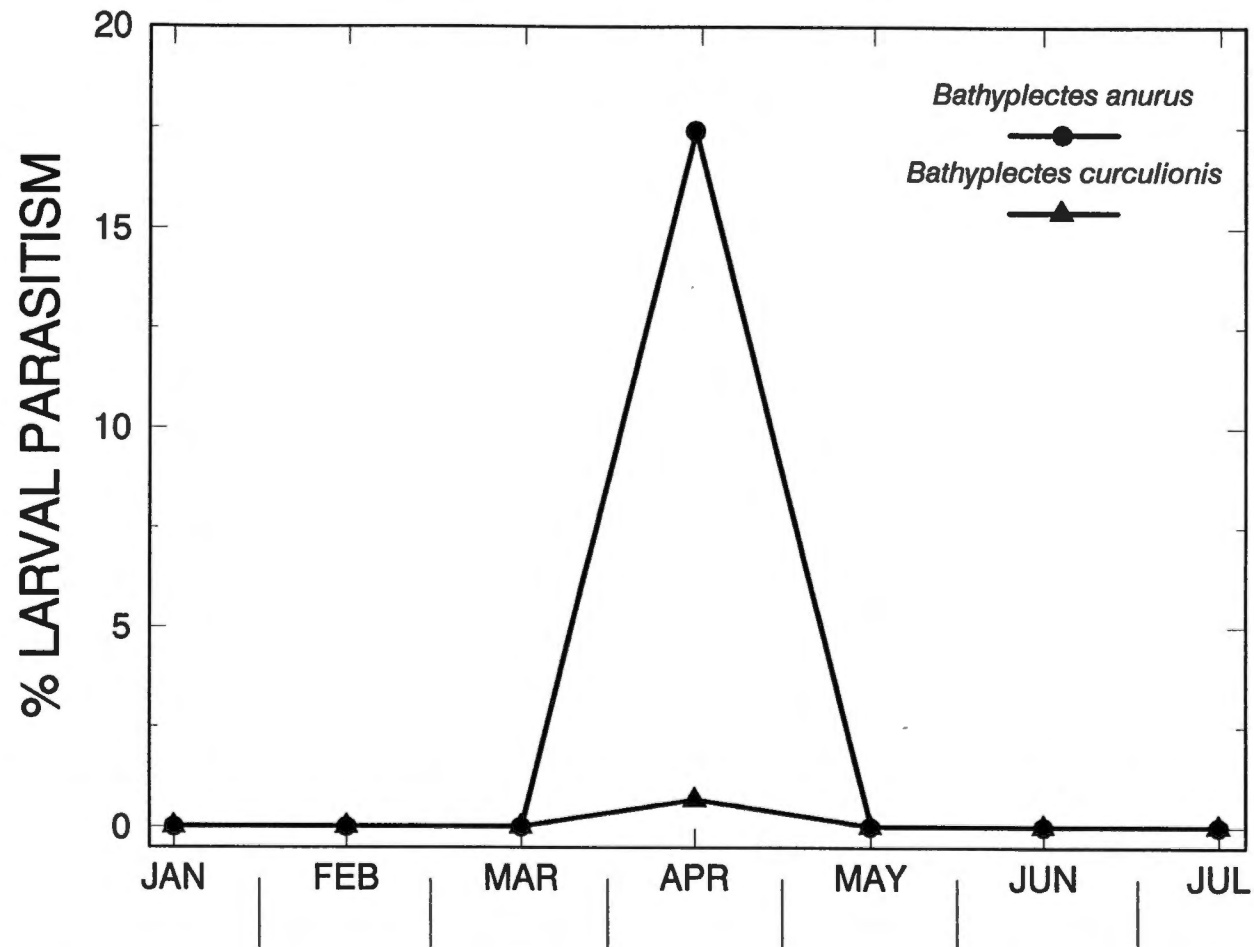


Figure 6. Percent parasitism of alfalfa weevil larvae by *Bathyplectes* spp. in McMinn County from January to July, 1994-1995.

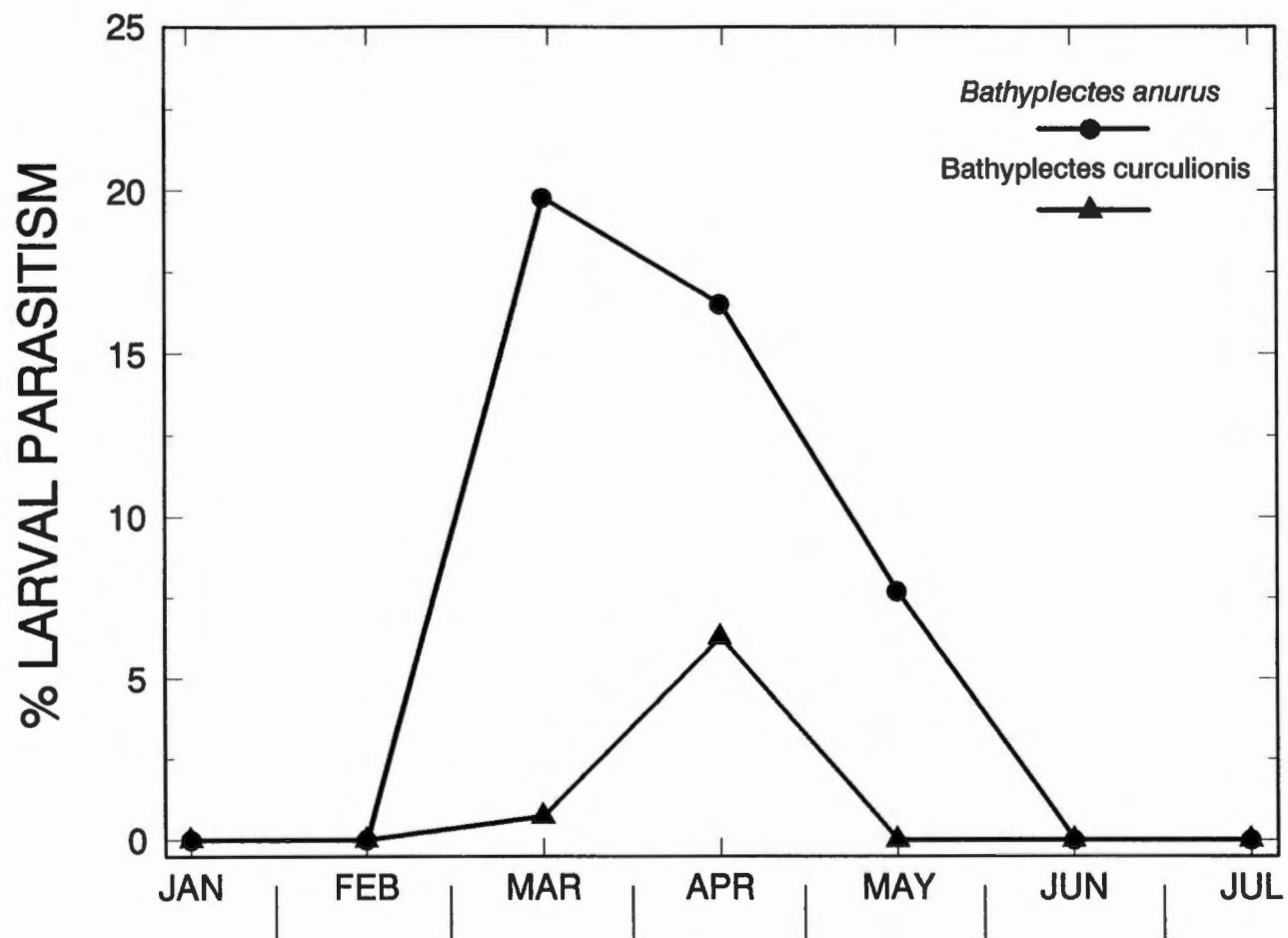


Figure 7. Percent parasitism of alfalfa weevil larvae by *Bathyplectes* spp. in Giles County from January to July, 1994-1995.

In sweep-net collections, significantly greater numbers of *Bathyplectes* spp. were collected monthly in Giles County than in McMinn County (Figure 8). Densities of *Bathyplectes* spp. peaked in Giles County in March and in McMinn County in April (Figure 8). Adult *Bathyplectes* spp. were generally recovered in sweep-net samples from March through May in both counties, and during June and July in Giles County.

In the laboratory, significantly greater numbers of *Bathyplectes* spp. were reared from alfalfa weevil larvae in 1995 [258 *Bathyplectes* spp. (n=636)] than in 1994 [44 *Bathyplectes* spp. (n=527)]. Percent parasitism of alfalfa weevil larvae was much greater in 1995 (26% parasitism) than in 1994, when only about 8% of all larvae were parasitized.

Microctonus aethiopoides adults were recovered from alfalfa weevil adults collected from both counties. However, *M. aethiopoides* adults were recovered only from weevils in 1995. In McMinn County, eight *M. aethiopoides* (36% parasitism) were recovered from 22 alfalfa weevils captured in early April. In Giles County, three *M. aethiopoides* (6.52% parasitism) were recovered from 46 alfalfa weevils in mid-April. However, no *M. aethiopoides* were reared from 23 alfalfa weevils captured between late-May and mid-June. One *M. aethiopoides* (14.29% parasitism) was recovered from seven alfalfa weevils in mid-July. The low numbers of *M. aethiopoides* recovered could be attributed to their lack of establishment in Giles and McMinn Counties.

In 1995, greater numbers of *M. aethiopoides* were collected in sweep-net samples in Giles County (7) than in McMinn County (1). In 1994, only one *M. aethiopoides* was recovered in McMinn County, while none was recovered in Giles County. As mentioned

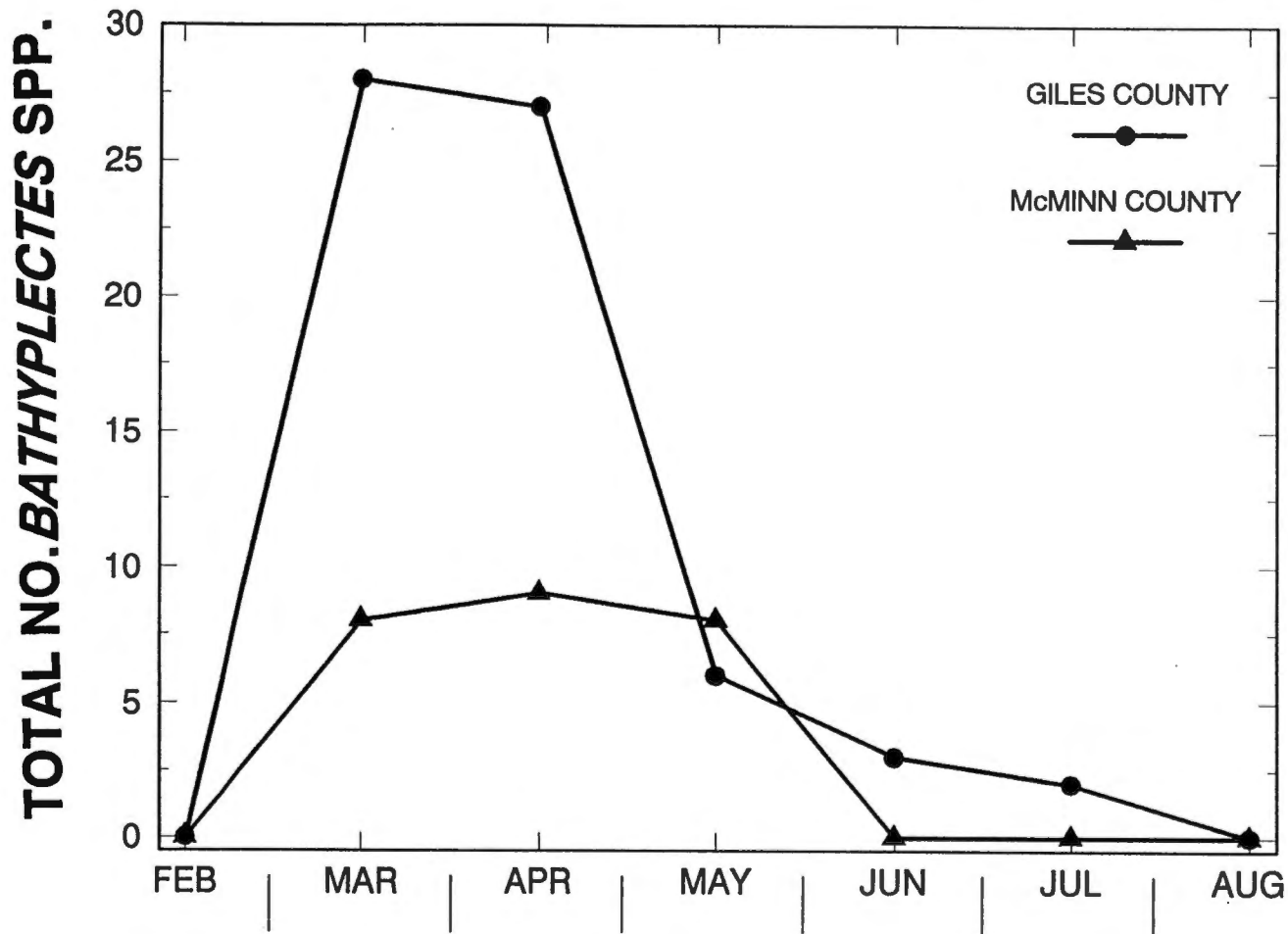


Figure 8. The total number of adult *Bathyplectes* spp./100 sweeps in alfalfa in Giles and McMinn Counties from February to August, 1994-1995.

earlier, no adults were found to be parasitized by *M. aethiopoides* in 1994. The total number of *M. aethiopoides* recovered from sweep-net samples or reared from field-collected adults in Tennessee in 1994 and 1995 was low. These low numbers may be attributed to environmental conditions and climate in both counties, resulting in the poor establishment of *M. aethiopoides*.

In Giles County, mortality of field-collected alfalfa weevil larvae due to *Erynia* in 1994 and 1995 was [17 infected larvae (n=77) and 42 infected larvae (n=557), respectively]. Alfalfa weevil larvae were infected in the spring after excessive rainfall and humid conditions.

Other Pests and Natural Enemies

In Giles County, in 1994, 13 collections were taken, and in 1995, 17 collections were taken (Table 2). The mean number of alfalfa weevil adults/collection date was greater in 1995 than in 1994. However, the mean number of alfalfa weevil larvae on each collection date was greater in 1994 than in 1995. Fewer threecornered alfalfa hoppers, *Spissistilus festinus* (Say), and potato leafhoppers, *Empoasca fabae* (Harris), were recovered on each collection date in 1994. More lady beetle adults were collected in 1995 than in 1994, while fewer lady beetle larvae were collected in 1995 than in 1994. Averaged across sampling dates, greater numbers of most beneficial insects, e.g., damsel bugs, lady beetle adults, big-eyed bugs, minute pirate bugs, rove beetles and tiger beetles, were collected in 1995 than in 1994. Fewer numbers of alfalfa weevil larvae collected in 1995 could be attributed to greater numbers of beneficial insects in alfalfa

Table 2. Diversity of beneficial insects and pests collected in sweep-net samples from alfalfa in Giles County, 1994 and 1995.

INSECTS	1994*		1995**	
	Total No. Collected	$\bar{x}$ No./Collection	Total No. Collected	$\bar{x}$ No./Collection
Alfalfa Weevil Adult	51	3.92	157	9.24
Alfalfa Weevil Larva	3,161	243.15	2,560	150.59
Threecornered Alfalfa Hopper	29	2.23	132	7.76
Potato Leafhopper	272	20.92	460	27.06
Damsel Bug	43	3.31	64	3.76
Lady Beetle Adult	65	5.00	168	9.88
Lady Beetle Larva	219	16.85	92	5.41
Spider	155	11.92	183	10.76
Big-eyed Bug	35	2.69	118	6.94
Rove Beetle	0	0.00	2	0.12
Tiger Beetle	0	0.00	1	0.06
Minute Pirate Bug	26	2.00	310	18.24

* Numbers based on 13 collection dates beginning on April 8 and ending on September 13.

** Numbers based on 17 collection dates beginning on February 24 and ending on August 27.

fields. Therefore, beneficial insects must be considered when developing a biological control program against the alfalfa weevil.

In McMinn County, in 1994, 18 collections were taken, and in 1995, 3 collections were taken (Table 3). In 1994, the mean number of alfalfa weevil adults/collection date was significantly greater in McMinn County [9.67 alfalfa weevil adults/100 sweeps] than in Giles County [3.92 alfalfa weevil adults/100 sweeps]. However, in 1994, the mean number of alfalfa weevil larvae/collection date was significantly greater in Giles County [243.15 alfalfa weevil larvae/100 sweeps] than McMinn County [46.50 alfalfa weevil larvae/100 sweeps] (Tables 2 and 3). Since sampling was discontinued in McMinn County in April 1995, an adequate comparison of 1994 and 1995 collection dates could not be made.

The alfalfa weevil was detected in Giles and McMinn Counties during both years of this study. Greater numbers of alfalfa weevil eggs, larvae and adults were found in Giles County than in McMinn County. *Erynia* sp., a fungal pathogen that infects alfalfa weevil larvae, was detected in early spring. In 1995, *Bathyplectes* spp. and many of the natural enemies of alfalfa weevil were recovered in greater numbers than in 1994. Parasitoids recovered in Giles and McMinn Counties were *B. anurus*, *B. curculionis* and *M. aethiopoides*. *Bathyplectes anurus* was the most abundant larval parasitoid, while *M. aethiopoides* was recovered in low numbers, suggesting poor establishment of this species of adult parasitoid in Tennessee. Parasitoids of adult weevils are important components of biological control of the alfalfa weevil. Alfalfa-producing states north of Tennessee (e.g., Iowa, Nebraska, and Missouri) do not treat most alfalfa fields with insecticides

Table 3. Diversity of beneficial insects and pests collected in sweep-net samples from alfalfa in McMinn County, 1994 and 1995.

INSECTS	1994*		1995**	
	Total No. Collected	$\bar{x}$ No./Collection	Total No. Collected	$\bar{x}$ No./Collection
Alfalfa Weevil Adult	174	9.67	14	4.67
Alfalfa Weevil Larva	837	46.50	146	48.67
Threecornered Alfalfa Hopper	203	11.28	18	6.00
Potato Leafhopper	102	5.67	4	1.33
Japanese Beetle	3	0.17	0	0.00
Damsel Bug	17	0.94	0	0.00
Lady Beetle Adult	168	9.33	1	0.33
Lady Beetle Larva	106	5.89	0	0.00
Spider	89	4.94	51	17.00
Big-eyed Bug	34	1.89	0	0.00
Minute Pirate Bug	1	0.06	1	0.33
Praying Mantis	6	0.33	0	0.00
Spined Soldier Bug	1	0.06	0	0.00

* Numbers based on 18 collection dates beginning on April 4 and ending on September 26.

** Numbers based on 3 collection dates beginning on March 12 and ending on April 3.

because alfalfa weevil parasitoids are effective. Fewer insecticide treatments are necessary because of the abundance of *M. aethiopoides* and its impact on alfalfa weevil adults. Without parasitoids that attack alfalfa weevil adults, biological control will not be successful, as larval parasitoids cannot control the alfalfa weevil by themselves. Further research needs to evaluate other potential adult parasitoids in controlling the alfalfa weevil in Tennessee.

CHAPTER III

STATE-WIDE DISTRIBUTION OF PARASITOIDS OF THE ALFALFA WEEVIL IN TENNESSEE

i. Introduction

The alfalfa weevil, *Hypera postica* (Gyllenhal), was accidentally introduced into the United States from Europe at the beginning of the twentieth century (Anonymous 1991, Bryan et al. 1993). This insect pest threatened alfalfa production, especially in the southeastern United States (Grant and Lambdin 1990). Because host-specific natural enemies of the alfalfa weevil were absent in the United States, researchers directed emphasis towards implementing biological control to reduce populations of the alfalfa weevil (Chamberlin 1924, Anonymous 1991). In 1911, several species of parasitoids were imported from Europe and released into alfalfa fields in Utah (Duodu and Davis 1974).

Since 1962, in Tennessee, several exotic parasitoid species have been released against the alfalfa weevil (Bennett 1968, Brunson and Coles 1968, Dysart and Day 1976, Grant and Lambdin 1990, Bryan et al. 1993). Two of the most commonly released parasitoids, *Bathyplectes curculionis* (Thomson) and *Bathyplectes anurus* (Thomson), attack alfalfa weevil larvae (Dysart and Day 1976, Giles et al. 1994, Hogg 1994).

Microctonus aethiopoides (Loan) is a parasitoid species that has been released to attack

alfalfa weevil adults (Flessel and Niemczyk 1977, Grant and Lambdin 1990). This adult parasitoid is considered to be one of the most important biological control agents of the alfalfa weevil and has the greatest potential to reduce alfalfa weevil populations because it parasitizes adult weevils, therefore reducing egg production (Flessel and Niemczyk 1977, Van Driesche and Gyrisco 1979, Munir and Sailer 1984, Kingsley et al. 1993).

A state-wide assessment is necessary to determine the establishment and distribution of parasitoids of the alfalfa weevil in Tennessee. Although numerous releases of parasitoids have been made in Tennessee, little information is known about the success of these releases. Research is necessary to determine the role of these introduced parasitoids as regulators of populations of the alfalfa weevil. The objective of this study was to determine parasitoid species composition and level of parasitism of the alfalfa weevil in Tennessee.

ii. Materials and Methods

To determine state-wide establishment and distribution of introduced parasitoids, nine counties throughout Tennessee were selected for evaluation, three each in eastern, middle, and western Tennessee (Figure 9). All fields sampled in this study were selected in cooperation with the county agent, and each field represented a typical alfalfa field in production. Information on each field is provided in Appendix I. In each county, three alfalfa fields were sampled twice, ca. 4-8 weeks apart, during early season (March to May), and all sampling was completed before the first cutting of alfalfa.

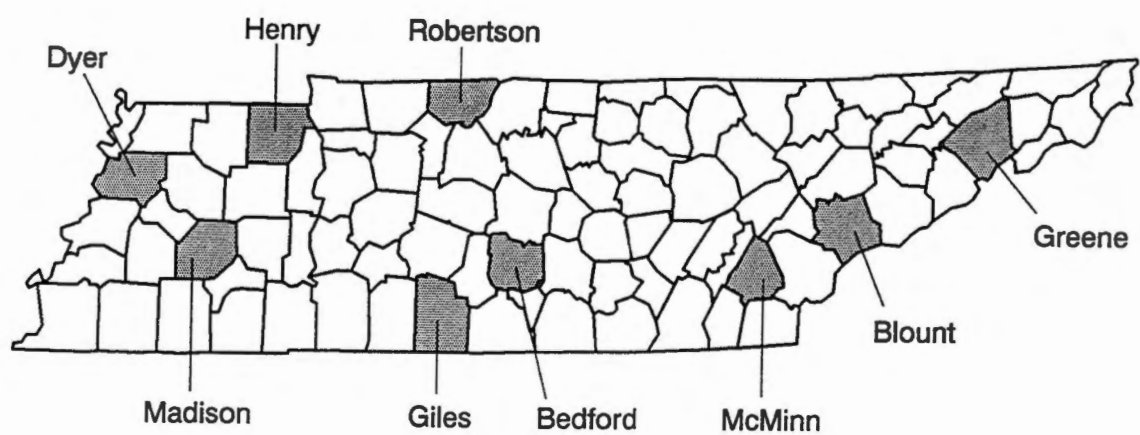


Figure 9. Location of alfalfa weevil sampling sites in Tennessee, 1994-1995.

a. 1994

On each sampling date, temperature (°C) was recorded at each field location. Alfalfa height (cm) was measured at random on one plant at each of five locations with the alfalfa plant measured from ground level to the tip of the bud, and average height was recorded. On each sampling date, 100 sweep-net (15-cm diameter) samples were taken in each field. Samples were collected in four sets of 25 sweeps each. The contents of each set of sweeps were placed into a labeled paper bag (35 x 17 cm), placed in a cooler, and taken to the laboratory, and processed.

In the laboratory, each labeled bag was emptied into a plastic pan (32 x 26 cm), and the contents were evaluated. Alfalfa weevil adults were counted, removed, and placed in 48 petri dishes (100 x 15 mm). The numbers of adult weevils placed in petri dishes were dependent upon the number collected; however, to avoid overcrowding, no more than 20 alfalfa weevil adults were placed into each petri dish. Larvae of alfalfa weevil were separated by size (small, medium and large), placed (10 per size class) into 642 petri dishes (100 x 15 mm), and provided alfalfa foliage for food. Alfalfa weevils were maintained in an insectary at room temperature (ca. 29°C) at the University of Tennessee Plant Science Farm and monitored every other day. Adults and larvae were held until death, adult emergence, or emergence of parasitoids. The numbers of parasitized larvae and adults, and percent parasitism, were determined. The larval parasitoids, *B. curculionis* and *B. anurus*, were identified by the color and shape of the cocoon. The adult parasitoid, *M. aethiopoides*, was identified by its cocoon and emergence from adult alfalfa weevils. The numbers of larvae infected by a fungal

entomopathogen (*Erynia* sp.) also were recorded. All data were compared among counties and geographical regions of the state.

b. 1995

The same procedures were conducted in 1995 with an additional modification. On each sampling date, an additional 100 sweep-net (15-cm diameter) samples in four sets of 25 sweeps each were taken in each field. The contents of each set of sweeps were collected and taken to the laboratory as discussed previously.

The additional 100 sweep-net samples (four sets) were placed in a freezer (-17°C) and held until they could be sorted and processed. Each set was then emptied into a plastic pan (32 x 26 cm), and small portions of the samples were observed under a microscope to determine beneficial insects and pests of alfalfa. During processing, adult parasitoids, such as *B. curculionis*, *B. anurus* and *M. aethiopoides*, were separated from the sample, labeled and pinned. As stated previously, all data were compared among counties and geographical regions of the state.

Data for all tests were analyzed using General Linear Models. Means were separated using Duncan's Multiple Range Test ($P \leq 0.05$) (SAS 1989).

iii. Results and Discussion

Alfalfa weevil larvae were detected in all nine counties. The greatest mean number of larvae/25 sweeps was detected in Robertson County and the lowest number

was collected in Bedford County (Figure 10, Table 4). In general, greater numbers of larvae were found in middle Tennessee (Figure 10), and this difference could be attributed to more alfalfa in production in middle Tennessee. The lowest number of larvae was found in west Tennessee, where less alfalfa is grown. The total numbers of larvae collected were significantly different among counties (Table 4). Significantly greater numbers of larvae were found in Robertson County than in all other counties except Giles County. Environmental conditions may have been more optimum for alfalfa weevil survival in Robertson County. Differences in larval densities occurred among counties in each region of the state (e.g., east, middle and west).

The total number of larvae was significantly different between the first and second sampling dates, as significantly greater numbers of larvae were collected in sample one [80.55 larvae/100 sweeps (n=204)] than in sample two [3.22 larvae/100 sweeps (n=203)]. However, when sample one was collected, alfalfa weevil larvae were predominant, whereas alfalfa weevil adults were predominant when sample two was collected.

Alfalfa weevil adults were recovered in the nine surveyed counties. The greatest density (ca. 3/25 sweeps) of alfalfa weevil adults occurred in Blount County (Figure 11, Table 5). The mean numbers of adults collected were significantly different among counties (Table 5). The greatest mean number of adults/25 sweeps was detected in Blount County, and the fewest adults were found in Henry County. Possible poor timing of insecticides and a delayed first cutting may have contributed to a greater success rate of pupation of alfalfa weevil in Blount County. The numbers of alfalfa weevil adults

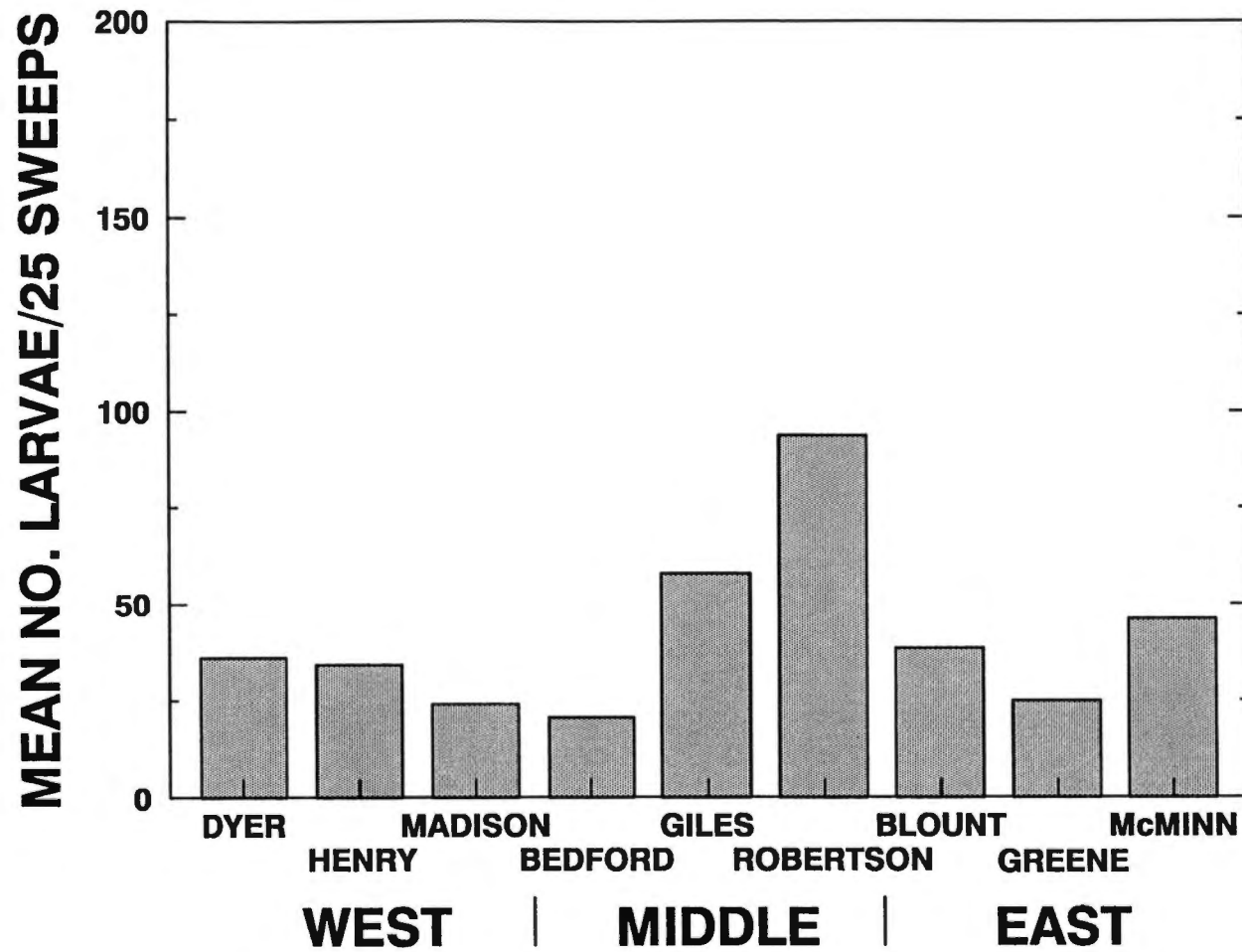


Figure 10. The mean number of alfalfa weevil larvae/25 sweeps collected in counties in each region of Tennessee, 1994-1995.

Table 4. Mean number of alfalfa weevil larvae collected in state-wide study during 1994 and 1995.

County	Mean/25 sweeps
Robertson	91.31a*
Giles	60.54ab
McMinn	45.42bc
Blount	39.36bc
Dyer	36.71bc
Henry	31.79bc
Greene	23.71c
Madison	22.28c
Bedford	20.19c

* Means with the same letter are not significantly different ($P > 0.05$).

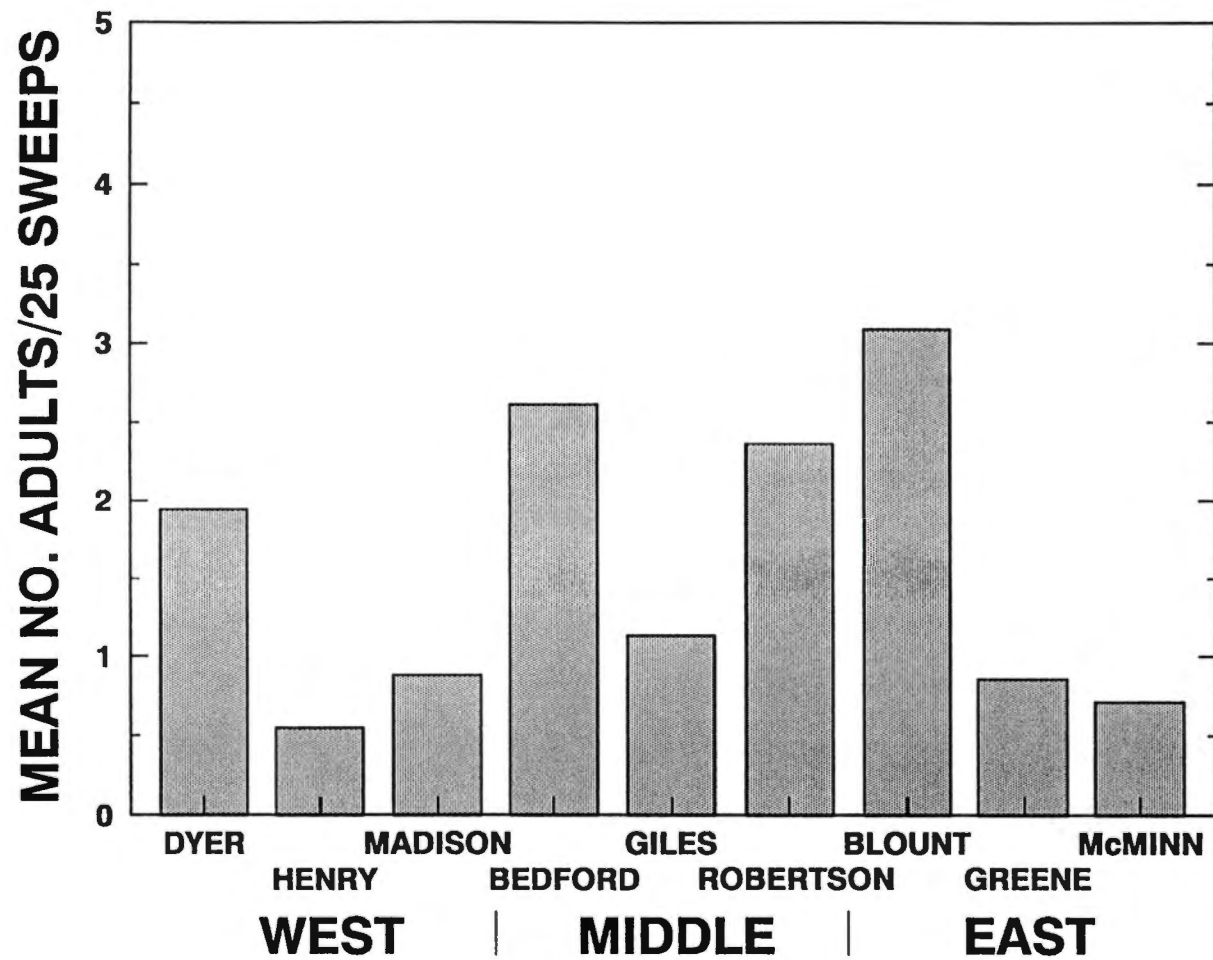


Figure 11. The mean number of alfalfa weevil adults/25 sweeps collected in counties in each region of Tennessee, 1994-1995.

Table 5. Mean number of alfalfa weevil adults collected in state-wide study during 1994 and 1995.

County	Mean/25 sweeps
Blount	3.03a*
Bedford	2.58ab
Robertson	2.42abc
Dyer	1.98abcd
Giles	1.08bcd
Greene	0.96bcd
Madison	0.85cd
McMinn	0.77cd
Henry	0.52d

* Means with the same letter are not significantly different ($P > 0.05$).

collected from sweeps were significantly different between years. Significantly greater numbers of adult weevils were found in 1995 [2.58 weevils/100 sweeps (n=216)] than in 1994 [0.29 weevils/100 sweeps (n=191)]. In 1995, environmental factors may have been more favorable for alfalfa weevil development, as mild winter conditions may have enhanced developmental rate of alfalfa weevils.

The total numbers of *Bathyplectes* spp. reared from alfalfa weevil larvae were significantly different between years. Significantly greater numbers of *Bathyplectes* spp. were reared from alfalfa weevil larvae in 1995 [493 *Bathyplectes* spp. (n=3,776)] than in 1994 [200 *Bathyplectes* spp. (n=2,439)]. Significantly greater numbers of *Bathyplectes* spp. were found in the first sample [2.81 *Bathyplectes* spp./100 sweeps (n=204)] than in the second sample [0.69 *Bathyplectes* spp./100 sweeps (n=203)]. This greater number of *Bathyplectes* spp. in the first sample can be partially attributed to the greater numbers of alfalfa weevil larvae present during the first sample. *Bathyplectes* spp. emerge in early spring at the time when alfalfa weevil larvae are most abundant.

Percent parasitism of alfalfa weevil larvae by *Bathyplectes* spp. was significantly different due to year and county. Parasitism of alfalfa weevil larvae by *Bathyplectes* spp. was significantly greater in 1995 [11.29% parasitism (n=3,776)] than in 1994 [7.23% parasitism (n=2,439)]. This greater percentage of parasitism in 1995 may be attributed to more favorable environmental conditions than in 1994, and insecticide applications may have been timed more accurately, allowing more *Bathyplectes* spp. to parasitize alfalfa weevil larvae. In 1994 and 1995, parasitism was highest [26.23% (n=568)] in Greene County and lowest in Madison County [4.67% (n=515)] (Table 6). Percent

Table 6. Percent parasitism of alfalfa weevil larvae by *Bathyplectes* spp. during 1994 and 1995.

County	Percent Parasitism
Greene	26.23 (n=568)*
Blount	18.75 (n=544)
Giles	14.60 (n=918)
Henry	10.36 (n=780)
McMinn	9.75 (n=718)
Robertson	7.12 (n=969)
Bedford	5.93 (n=354)
Dyer	5.18 (n=849)
Madison	4.67 (n=515)

* Numbers in parentheses represent total number of alfalfa weevil larvae.

parasitism in the other counties ranged from about 5.18% (Dyer County) to 18.75% (Blount County). The higher level of parasitism in Greene County may be attributed to more alfalfa weevils and greater alfalfa hectarage.

The numbers of *B. anurus* collected state-wide were significantly different due to year, county and sample number. Significantly greater numbers of *B. anurus* were reared from alfalfa weevil larvae in 1995 [298 *B. anurus* (n=3,776)] than in 1994 [122 *B. anurus* (n=2,439)]. Parasitism by *B. anurus* was greater in Blount, Giles and Greene Counties than in Bedford, McMinn, Robertson, Dyer, Henry and Madison Counties (Table 7). As a result of greater numbers of *B. anurus* in the eastern region of the state, climatic conditions may be more favorable for adaptability. Significantly greater numbers of *B. anurus* were collected on the first sampling date (2.14 *B. anurus*/100 sweeps) than on the second sampling date (0.01 *B. anurus*/100 sweeps). The significantly greater numbers of *B. anurus* collected on the first sampling date may be attributed to greater numbers of alfalfa weevil larvae present in the field on the first sampling date.

The numbers of *B. curculionis* collected state-wide were significantly different due to year and county. In 1995, the number of *B. curculionis* reared from larvae [195 *B. curculionis* (n=3,776)] was significantly greater than those reared in 1994 [78 *B. curculionis* (n=2,439)]. Parasitism by *B. curculionis* varied among counties (Table 8). Percent parasitism by *B. curculionis* was greatest in Henry County and lowest in Blount County. In general, percent parasitism by *B. curculionis* was highest in west Tennessee and lowest in middle Tennessee.

Table 7. Percent parasitism of alfalfa weevil larvae by *B. anurus* during 1994 and 1995.

County	Percent Parasitism
Greene	20.42 (n=568)*
Blount	18.01 (n=544)
Giles	13.62 (n=918)
Bedford	5.08 (n=354)
McMinn	3.20 (n=718)
Dyer	1.53 (n=849)
Robertson	1.44 (n=969)
Madison	1.17 (n=515)
Henry	1.00 (n=780)

* Numbers in parentheses represent total number of alfalfa weevil larvae.

Table 8. Percent parasitism of alfalfa weevil larvae by *B. curculionis* during 1994 and 1995.

County	Percent Parasitism
Henry	9.36 (n=780)*
McMinn	6.55 (n=718)
Greene	5.81 (n=568)
Robertson	5.68 (n=969)
Dyer	3.65 (n=849)
Madison	3.50 (n=515)
Giles	0.98 (n=918)
Bedford	0.85 (n=354)
Blount	0.74 (n=544)

* Numbers in parentheses represent total number of alfalfa weevil larvae.

Microctonus aethioides was recovered in low numbers state-wide. In 1995, 460 alfalfa weevil adults were collected and maintained in the laboratory to determine parasitism, and only two *M. aethioides* emerged from alfalfa weevil adults (0.43% parasitism). In Robertson County, one *M. aethioides* emerged from 69 adult weevils collected on the second sampling date (1.5% parasitism). In Dyer County, one *M. aethioides* emerged from 23 adult weevils collected on the second sampling date (4.3% parasitism). The greatest number of *M. aethioides* collected in sweep-net samples was found on sample date one, corresponding to emergence of alfalfa weevil adults. Seven *M. aethioides* were recovered in Henry, Madison, Bedford, Giles, Blount and McMinn Counties. One *M. aethioides* was recovered in Henry County on the second sampling date. The low numbers of *M. aethioides* may be attributed to its inability to adapt to the environmental and climatic conditions in Tennessee.

Erynia sp., a fungal pathogen that infects and kills alfalfa weevil larvae, was detected in all nine sampled counties from March to late April. Alfalfa weevil larvae were infected by this pathogen in the spring after excessive rainfall and high humidity conditions.

Alfalfa weevils were detected in each county, and alfalfa weevil parasitoids were active in each alfalfa field. However, the low number of parasitoids detected in each alfalfa field cannot effectively control the alfalfa weevil. Therefore, further research needs to address additional releases of larval parasitoids and other potential adult parasitoids. Research with other potential adult parasitoids is important because of the low numbers of *M. aethioides* in Tennessee. *Microctonus aethioides* is more

numerous and more effective in alfalfa-producing states north of Tennessee. In New York, parasitism of alfalfa weevil adults by *M. aethiopoides* ranged from 20-88% and oviposition by parasitized alfalfa weevil populations was reduced an average of 47% (Van Driesche and Gyrisco 1979). Alfalfa producers need to be educated on proper timing of insecticides, and to determine if insecticide treatment is needed, because insecticides have a direct influence on the survival of alfalfa weevil parasitoids. Until these issues are addressed, a biological control program against the alfalfa weevil will not be successful in Tennessee.

CHAPTER IV

EVALUATION OF ALFALFA WEEVIL MANAGEMENT PRACTICES IN TENNESSEE

i. Introduction

In Tennessee, the alfalfa weevil is present in all counties where alfalfa is grown (Burgess and Patrick 1992). As the most destructive pest of alfalfa in Tennessee, the alfalfa weevil limits alfalfa production. The alfalfa weevil also affects dairy operations that rely on alfalfa for its nutritional value, which can be lowered by feeding damage caused by larvae and adults (Wilson et al. 1979, Anonymous 1991).

Chemical insecticides are used extensively for control of the alfalfa weevil. Because of current environmental concerns and the ability of some pest insects to develop resistance to widely used insecticides, the alfalfa weevil cannot be controlled with a single-factor approach (Metcalf and Luckmann 1982).

Biological control is a method of control that utilizes another living organism to reduce populations of a pest. Biological control has numerous advantages, e.g., it is inexpensive and relatively safe to humans, plants and other non-target animals (Wilson and Huffaker 1976). Biological control cannot solve all pest problems, but it can offer an alternative solution to management of some pest situations. Successful biological control of alfalfa weevil should increase alfalfa production in the southeastern United

States, where alfalfa production has been limited since the introduction of the alfalfa weevil (Munir and Sailer 1984).

In Tennessee, little information is available on alfalfa production, the alfalfa weevil, and effectiveness of biological control programs for the alfalfa weevil in each county. To determine this information, an alfalfa weevil questionnaire or survey was distributed to extension agents in each county in Tennessee. The overall goal of this questionnaire was to evaluate alfalfa weevil management practices in Tennessee. The specific objectives of this study were to:

1. compare alfalfa production in counties in Tennessee,
2. determine what insecticides, and their rate, are applied for control
of the alfalfa weevil,
3. determine if extension agents are aware of releases of parasitoids against
the alfalfa weevil,
4. determine which pests are most damaging to alfalfa, and
5. determine what factors limit alfalfa production.

ii. Materials and Methods

An alfalfa weevil questionnaire (survey) was developed (Appendix II) and distributed via E:mail state-wide to adult agricultural extension agents in each of the 95 agricultural extension offices in June 1995. The questionnaire was developed in cooperation with Dr. Gene Burgess (Extension Entomology and Plant Pathology) and Dr.

Gary Bates (Extension Plant and Soil Science). In this survey, questions pertained to alfalfa production, alfalfa pests and their control, and the extension agent's knowledge of biological control of the alfalfa weevil. The requested return date was July 1, 1995. After the deadline date, a reminder was mailed to those extension agents who had not previously responded.

Information concerning alfalfa production obtained from this survey, e.g., hectares grown, cuttings per year, alfalfa insect pests, alfalfa weevil control methods, insecticide use and rate, and the extension agents knowledge of biological control agents of the alfalfa weevil, will be compiled and evaluated for each county, each district and each region in Tennessee. This survey will help to determine the importance of alfalfa and the alfalfa weevil in Tennessee. Therefore, alfalfa weevil control programs can be based on the needs of the county, district and region.

iii. Results and Discussion

As a result of the questionnaire, valuable information was obtained on alfalfa production in Tennessee. Of the 95 counties surveyed in Tennessee, extension agents in 87 counties responded to the questionnaire.

Total alfalfa production in Tennessee was similar in 1994 (23,858 hectares) and 1995 (23,934 hectares). Alfalfa hectarage varied throughout Tennessee (Figure 12). The western region of the state had fewer hectares of alfalfa. More row crops are grown in this region, and dairy operations are not as numerous. Eight of the responding 87

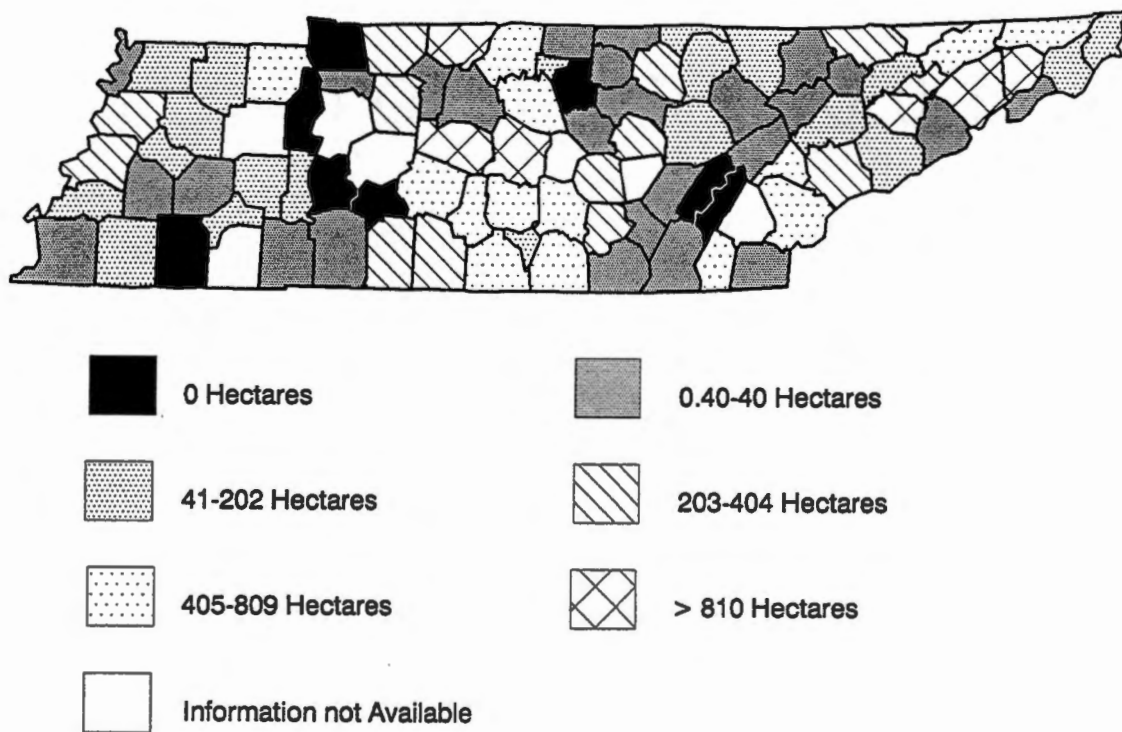


Figure 12. Hectares of alfalfa grown in counties in Tennessee, 1995.

counties did not grow alfalfa. Of those counties with alfalfa, 40 hectares or less were grown in 26 counties, while 47 counties grew between 41-809 hectares of alfalfa. Only six counties grew more than 810 hectares of alfalfa, and the amount of alfalfa grown in those six counties may be attributed to greater numbers of dairy operations in those counties.

The mean number of alfalfa cuttings per year varied in each county. Thirty counties averaged three cuttings per year, and 43 counties averaged four cuttings per year. Polk, Bradley, Maury, Grundy and Jackson Counties averaged five cuttings per year. Four of these five counties are located in the southern portion of Tennessee. These four counties may get five cuttings per year because of warmer climates, which would suggest a slightly longer alfalfa growing season.

The alfalfa weevil is the most important pest of alfalfa, resulting in high control costs and losses per year (Metcalf and Flint 1962, Dysart and Day 1976, Zavaleta and Ruesink 1980, Anonymous 1991). Since the introduction of the alfalfa weevil into Tennessee in 1959, it has become an important pest of alfalfa in most alfalfa-producing counties, where it is generally considered to be a major pest (Figure 13). State-wide, in 1995, a 15% reduction in alfalfa yield was attributed to the alfalfa weevil. In Tennessee, 78% of the agricultural extension agents listed the alfalfa weevil as a major pest of alfalfa, and 22% of the agricultural extension agents listed the alfalfa weevil as a minor pest. Agricultural extension agents ranked the obstacles that prevent alfalfa hectareage from increasing in Tennessee (Table 9). The number one limiting factor was

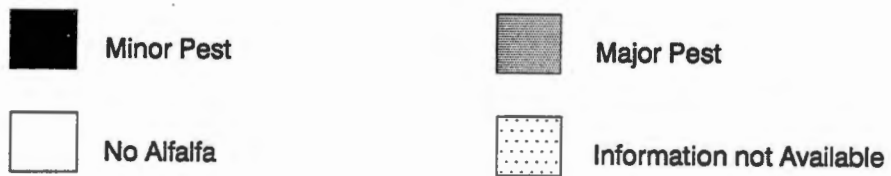
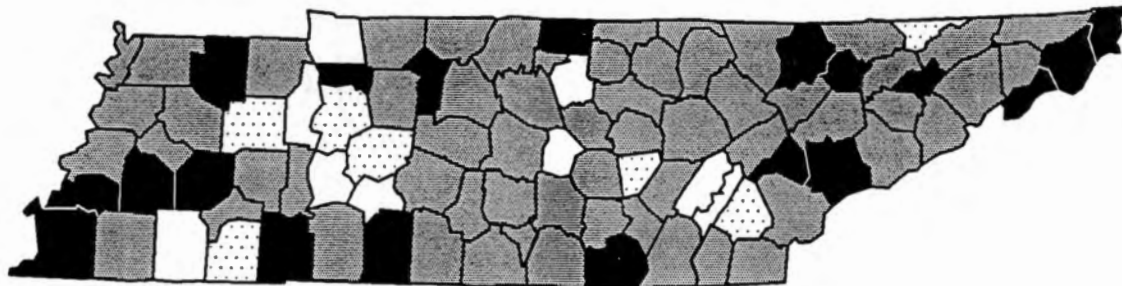


Figure 13. Location of counties in Tennessee where alfalfa weevil is considered to be a pest.

Table 9. Obstacles preventing alfalfa hectarage from increasing in Tennessee as determined by agricultural extension agents, 1995.

Obstacles	Weighted Value*
Expensive	22.3
Alfalfa weevil	25.6
Weeds	28.2
Hard to cut and cure	29.4
High fertility requirements	33.7
No land available	37.3
Diseases	42.4
Other insects	44.9
Do not need high quality	51.6
No demand	54.8

* Weighted values are based on a rating scheme of 1-10, where respondents ranked the importance of each obstacle [1=most important and 10=least important]. The lower the weighted value, the greater the importance of the obstacle.

the expenses involved in alfalfa production. Much of these expenses are attributed to the amount of insecticides that are applied to control the alfalfa weevil, as well as herbicides to control weeds that infest alfalfa fields. Agricultural extension agents listed the alfalfa weevil as the number two limiting factor of alfalfa production, and weeds were the ranked as the third most important limiting factor. The least limiting factor preventing alfalfa hectarage from increasing was the demand for alfalfa production.

Several methods of control (e.g., insecticides, resistant varieties, mowing, crop rotation and grazing) were used against the alfalfa weevil in 1994 and 1995. Information obtained from the questionnaire revealed that growers in 96% of alfalfa-producing counties applied insecticides [such as Furadan (carbofuran) at 0.57-2.34 l/ha, Methyl Parathion at 1.17 l/ha, Lorsban (chlorpyrifos) at 1.17-2.34 l/ha, Malathion at 1.75-2.34 l/ha, Ambush (permethrin) at 0.44-0.88 l/ha, Diazinon at 2.34-3.50 l/ha, Pounce (permethrin) at 0.29-0.58 l/ha, and Sevin (carbaryl) at 3.36 kg/ha]. Alfalfa hectarage treated with insecticides was similar between 1994 (16,540 hectares) and 1995 (16,509 hectares). Mowing was used to control alfalfa weevil in 41% of the counties in Tennessee. Resistant varieties were utilized in 16% of the counties, while grazing was used in 14% of the counties. Crop rotation was used in 9% of the counties, while spring seeding was used in only 1% of the counties.

Since the 1960s, parasitic wasps have been released for biological control of the alfalfa weevil. Results of the questionnaire indicated that 84% of the extension agents were familiar with parasitoids of alfalfa weevil. However, 41% of the extension agents were not sure if parasitoids had been released in their county when, in fact, parasitoids

had been released in several of those counties. This lack of knowledge suggests that better communication is needed between agricultural agencies and farmers. If extension agents and farmers are made aware of these parasitoids, current control methods such as spraying insecticides may be altered, therefore allowing sufficient time for parasitoids to establish in alfalfa fields in each county.

About 29% of all agents suggested that alfalfa hectareage may increase if alfalfa weevils were effectively managed in their counties. Forty-two percent of the agents suggested alfalfa hectareage might increase but were not sure, and 29% believed that alfalfa hectareage would not increase. This information provides a foundation for implementing an alfalfa weevil biological control program.

The total hectares of alfalfa in production, current alfalfa weevil control methods, and amount of alfalfa weevil damage occurring in Tennessee must be determined in each county to effectively implement a successful biological control program against the alfalfa weevil. This questionnaire suggests that an alfalfa weevil biological control program is needed to help manage alfalfa weevils in Tennessee. However, education underlies a successful alfalfa weevil biological control program. In Tennessee, several extension agents were not aware of the release of alfalfa weevil parasitoids in their counties. This lack of knowledge could be due to the extension agent turnover ratio in Tennessee. The new agents employed may not be aware of these parasitoids and would be unable to pass this knowledge on to the alfalfa producers in those counties who may not be aware of the importance of these parasitoids. Therefore, extension agents and alfalfa producers need to be informed about these parasitoids with educational meetings and field

demonstrations. In states where biological control programs against the alfalfa weevil are successful, educational meetings and field demonstrations have been conducted continuously over the last few years to demonstrate the importance of alfalfa weevil parasitoids. In Tennessee, to effectively manage the alfalfa weevil, this criteria must be implemented in alfalfa-producing counties.

CHAPTER V

CONCLUSIONS

Alfalfa, *Medicago sativa* L., is currently the leading hay crop in North America (Anonymous 1991). Because of alfalfa's high nutritional qualities and a field longevity of two to seven years, alfalfa is an important component of dairy operations (Christensen 1980, Grant and Lambdin 1990). However, as a long-lasting legume, alfalfa is subjected to numerous types of pests. The alfalfa weevil, *Hypera postica* (Gyllenhal), is the most important pest of alfalfa in the United States (Metcalf and Flint 1962, Dysart and Day 1976, Zavaleta and Ruesink 1980).

The alfalfa weevil was first detected in the United States in Utah in 1904 (Titus 1910). In Tennessee, the alfalfa weevil was first detected in 1959, and within five years the weevil had spread throughout the entire state (Bennett 1968). Alfalfa is successfully grown in Tennessee, but the alfalfa weevil has impacted alfalfa production (Reynolds et al. 1974). Since the introduction and establishment of the alfalfa weevil in Tennessee, alfalfa hectarage has been reduced from an all-time high of 76,113 hectares in 1958 to 20,243 hectares in 1994 (Anonymous 1995).

In 1994, a two-year research project was initiated to investigate biological control agents of the alfalfa weevil in Tennessee. One goal of this research project was to intensively investigate the life history of the alfalfa weevil. Other objectives of this research included state-wide monitoring of introduced parasitoids of the alfalfa weevil,

determining parasitism levels of the alfalfa weevil, monitoring disease incidence of alfalfa weevil larvae, and surveying county extension agents to evaluate alfalfa production in Tennessee.

During a two-year intensified study in Giles and McMinn Counties, alfalfa weevils overwintered in both the egg and adult stages. Overwintering eggs were detected in late October, and larvae were detected in early February. Densities of alfalfa weevil larvae peaked in both counties during April. Pupae were first found in April, and alfalfa weevil adults were present in the field throughout most of the year. Densities of alfalfa weevil adults also peaked in April, and no adult weevils were collected from alfalfa during August.

Bathyplectes anurus (Thomson) and *B. curculionis* (Thomson) were reared from alfalfa weevil larvae collected from Giles and McMinn Counties during 1994 and 1995. *Bathyplectes anurus* was the predominant larval parasitoid detected in Giles and McMinn Counties. In Giles County, parasitism was greatest in March, and in McMinn County, parasitism was greatest in April. *Microctonus aethiopoides* (Loan) adults were recovered from alfalfa weevil adults collected from both counties. However, *M. aethiopoides* was recovered in low numbers suggesting poor establishment of adult parasitoids in Tennessee.

Erynia sp., a fungal pathogen that infects alfalfa weevil larvae, was detected in early spring in Giles and McMinn Counties. Mortality of alfalfa weevil larvae due to *Erynia* sp. was significantly greater in Giles County in 1994 than in 1995.

Beneficial insects and pests of alfalfa were separated and counted in each sample to determine insect numbers and insect diversity. Greater numbers of beneficial insects were collected in 1995 than in 1994 [e.g., damsel bugs, lady beetle adults, big-eyed bugs, and minute pirate bugs].

In the state-wide study, alfalfa weevils were detected in each county, and alfalfa weevil parasitoids were present in each alfalfa field. Parasitism of alfalfa weevil larvae by *Bathyplectes* spp. was significantly greater in 1995 (11.29%) than in 1994 (7.23%). Percent parasitism was highest in Greene County (26.23%) and lowest in Madison County (4.67%). A higher level of parasitism in Greene County may be attributed to greater alfalfa weevil densities and greater alfalfa hectarage.

Bathyplectes anurus was the predominant larval parasitoid reared from alfalfa weevil larvae. Greater numbers of *B. anurus* were reared from alfalfa weevil larvae in 1995 than in 1994. State-wide, percentage parasitism by *B. anurus* was higher than percentage parasitism by *B. curculionis* (7.27% and 4.12%, respectively). Data suggest *B. anurus* has displaced *B. curculionis* in Tennessee. In the mid-1970s, displacement of *B. curculionis* by *B. anurus* was observed in Ohio (Dowell and Horn 1977), and in New Jersey and southeastern Pennsylvania (Day 1983). In 1990 and 1991, results confirmed *B. anurus* had displaced *B. curculionis* as the predominant larval parasitoid in Illinois (Oloumi-Sadeghi et al. 1993). *Bathyplectes anurus* was more abundant in the eastern region of Tennessee, and the greater numbers of *B. anurus* recovered could be attributed to more favorable climatic conditions.

The numbers of *B. curculionis* reared from alfalfa weevil larvae were greater in 1995 than in 1994. Parasitism by *B. curculionis* was greatest (9.36%) in Henry County and lowest (0.74%) in Blount County. By regions, percent parasitism by *B. curculionis* was highest in west Tennessee (5.50%) and lowest (2.50%) in middle Tennessee.

Microctonus aethiopoides was recovered in low numbers in 1994 and 1995. Two *M. aethiopoides* emerged from 460 adult alfalfa weevils reared in the laboratory. The low numbers recovered may suggest the inadaptability of *M. aethiopoides* to environmental and climatic conditions in Tennessee.

Erynia sp. was detected in all nine sampled counties from March to late April. State-wide, the number of larvae killed by *Erynia* was greater in 1994 [436 infected alfalfa weevil larvae (n=2,439)] than in 1995 [45 infected alfalfa weevil larvae (n=3,320)]. The mean percentage of alfalfa weevil larvae infected by *Erynia* state-wide during 1994 and 1995 was 10%. Alfalfa weevil larvae were infected in the spring after excessive rainfall and humid conditions.

Data from the alfalfa weevil questionnaire provided solid information concerning alfalfa production and the status of the alfalfa weevil in Tennessee. State-wide, 15% reduction in alfalfa yield was attributed to the alfalfa weevil, and 78% of the agricultural extension agents listed the alfalfa weevil as a major pest of alfalfa. Expenses were the number one limiting factor involved in alfalfa production. Much of these expenses are attributed to the insecticides applied to control the alfalfa weevil. The questionnaire revealed that growers in 96% of the alfalfa-producing counties applied insecticides to control the alfalfa weevil. Forty-one percent of the extension agents were not sure if

alfalfa weevil parasitoids had been released in their county. There is a need for educational meetings and field demonstrations for extension agents and alfalfa producers to demonstrate the importance of alfalfa weevil parasitoids.

Alfalfa weevils were detected in each alfalfa-producing county, and alfalfa weevil parasitoids were established in alfalfa fields throughout Tennessee. However, unlike alfalfa-producing states north of Tennessee, alfalfa weevil parasitoids are not reducing insecticide treatments on alfalfa. The low numbers of parasitoids detected in this study indicate that biological control of the alfalfa weevil is not successful in Tennessee. The absence of a successful adult weevil parasitoid allows alfalfa weevils to produce at much greater numbers, and larval parasitoids cannot sufficiently reduce alfalfa weevil densities below the economic threshold level. Therefore, future research needs to address additional releases of larval parasitoids and evaluation of other potential adult parasitoids. Alfalfa weevil adult parasitism is greater in northern states than in southern states, and the reduction in parasitism suggests that *M. aethiopoides* may not be well adapted to the southern climate. Until these issues are addressed, an alfalfa weevil biological control program will not be effective in Tennessee.

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APPENDIX

Appendix I. History of alfalfa fields in counties surveyed state-wide in 1994 and 1995.

County	Field	Alfalfa Variety	Age of Stand (years)	Previous Crop
McMinn	1	Alfagraze	4	Pasture
	2	Annstar	4	Corn
	3	Alfagraze	2	Pasture
Giles	1	Buffalo	2	Sudangrass
	2	Buffalo	4	Corn
	3	N/A*	N/A	N/A
Blount	1	Cimmaron	3	Corn
	2	Cimmaron	3	Corn
	3	Cimmaron	5	Wheat
Henry	1	Classic	3	Soybeans
	2	Cimmaron	3	Wheat
	3	Classic	3	Corn
Bedford	1	Cimmaron	1	Wheat
	2	Cimmaron	3	Wheat
	3	Annstar	1	Wheat/Soybean
Robertson	1	Buffalo	3	N/A
	2	Apollo	2	N/A
	3	Cimmaron	2	Timothy

County	Field	Alfalfa Variety	Age of Stand	Previous Crop
Dyer	1	Alfagraze	4	Pasture
	2	Buffalo	1	Soybeans
	3	Buffalo	9	Cotton
Greene	1	Cimmaron	6	Soybean
	2	Cimmaron	4	Soybean
	3	Annstar	1	Corn
Madison	1	Apollo	N/A	N/A
	2	Apollo	N/A	N/A
	3	N/A	N/A	N/A

* N/A = Information not available

Appendix II. Survey form distributed to county extension agents requesting information on alfalfa.

ALFALFA WEEVIL MANAGEMENT SURVEY QUESTIONNAIRE

Name: _____

County: _____

Address: _____

telephone - _____ **e-mail -** _____

1. Is alfalfa grown in your county?
_____ yes [if yes, go to #2] _____ no [if no, return questionnaire]
2. How many acres were grown in 1994? _____ acres
How many acres were grown in 1995? _____ acres
3. On the average, how many times is alfalfa cut during the year?
_____ cuttings/year
In a typical year, approximately when is the last cutting date? _____
The number of cuttings in an area can vary widely from field to field. In a typical year in your county, what is the range of cuttings among producers [i.e., what is the fewest number of cuttings and the most number of cuttings]?
_____ fewest cuttings/year _____ most cuttings/year
4. List the insects that cause problems for alfalfa growers in your county.

5. For the insects listed in #4, which ones are controlled with insecticides?

6. How would you classify alfalfa weevil as a pest in your county?
_____ not a pest _____ a minor pest _____ a major pest
7. If classified as a pest, when is alfalfa weevil a problem [time of year? and on which cutting(s)?]? _____

8. How would you assess damage caused by alfalfa weevil in your county?
_____ no damage _____ minor damage _____ major damage
9. How much yield reduction was caused by alfalfa weevil in your county in 1994?
_____ % yield reduction
10. What methods are used to control alfalfa weevil [be as specific as possible]? [e.g., grazing, mowing, crop rotation, burning, resistant varieties, insecticides, biological control, or other methods] _____

11. Of the methods listed for control of alfalfa weevil in #10, what percent of alfalfa grown in your county is managed by each method?

12. How many acres were treated with insecticide for alfalfa weevil in 1994? _____ acres. How many acres were treated with insecticide for alfalfa weevil in 1995? _____ acres
13. Which insecticide(s) and rates were used for alfalfa weevil control in 1995? What percent of alfalfa fields in your county were treated with each rate of insecticide?
- | | | | |
|-----------|-------|-----------|-------|
| Furadan | _____ | Lorsban | _____ |
| Methyl | _____ | Malathion | _____ |
| parathion | _____ | Others | _____ |

14. On the average, how many times was alfalfa treated for alfalfa weevil in 1995?
 _____ one treatment _____ two treatments _____ three treatments
15. Are you familiar with the release of parasitic wasps against alfalfa weevil in Tennessee?
 _____ yes _____ no
16. Have parasitic wasps been released against alfalfa weevil in your county?
 _____ yes _____ no _____ I don't know
17. If released, how effective have these parasitic wasps been in reducing alfalfa weevil damage?
 _____ not effective _____ somewhat effective
 _____ very effective
18. If released, have these parasitic wasps reduced use of pesticides against alfalfa weevil?
 _____ yes _____ no _____ I don't know
19. Would alfalfa acreage increase in your county if alfalfa weevils could more effectively be managed?
 _____ yes _____ no _____ maybe
20. Rank [from 1 to 10; 1 = most important] the following items as to their importance in preventing alfalfa acreage from increasing in your county:
- | | |
|----------------------|---|
| _____ weeds | _____ high fertility requirements |
| _____ diseases | _____ do not have the land needed for alfalfa |
| _____ alfalfa weevil | _____ hard to cut and cure |
| _____ other insects | _____ expensive |
| _____ no demand | _____ do not need this high quality |

VITA

Kenneth J. Copley was born in Columbia, Tennessee, on March 14, 1966. He graduated from Hickman County High School in 1984. He received his Associate of Science in Agriculture from Columbia State Community College in 1986, and his Bachelor of Science degree in Plant and Soil Science from the University of Tennessee at Martin in 1988.

Upon completion of his B.S. degree, he was employed with the University of Tennessee Agricultural Extension Service as an Assistant Extension Agent in Lewis County. As an agent, he conducted the adult agriculture program and the 4-H agriculture program in the county.

After working for five years, he entered the Department of Entomology and Plant Pathology at the University of Tennessee at Knoxville to begin work towards a Master of Science degree. Under the direction of Dr. Jerome F. Grant, he completed the requirements for a Master of Science degree in Entomology and Plant Pathology in December 1995.

Kenneth J. Copley is an active member of several organizations, including the Entomological Society of America, Tennessee Entomological Society and the Graduate Student Association at the University of Tennessee. He served as the student representative on the Institute of Agriculture Safety Committee at the University of Tennessee.

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