ECOLOGICAL INVESTIGATIONS ON THE CEREAL LEAF BEETLE, OULEMA MELANOPUS (L.), AND THE PRINCIPAL LARVAL PARASITE, TETRASTICHUS JULIS (WALKER)

Dissertation for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
STUART HARGRAFT GAGE
1974

This is to certify that the

thesis entitled

ECOLOGICAL INVESTIGATIONS ON THE CEREAL LEAF BEETLE, *OULEMA MELANOPUS* (L.), AND THE PRINCIPAL LARVAL PARASITE *TETRASTICHUS JULIS* (WALKER)

presented by

Stuart Hargraft Gage

has been accepted towards fulfillment
of the requirements for

PhD degree in Entomology

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Major professor

Date June 7, 1974

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ABSTRACT

ECOLOGICAL INVESTIGATIONS ON THE CEREAL LEAF BEETLE,
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Tetrastichus julis (Walker) is one of four parasites of the cereal leaf beetle, Oulema melanopus (L.) introduced and established at the Kellogg Biological Station, Hickory Corners, Michigan. This study examines some of the salient biological characteristics of T. julis, including rates of development, emergence, diapause, and its interaction with populations of O. melanopus and other parasites.

Quantitative estimates of parasite and host populations were made using a number of methods, including population counts of the host and parasites on winter wheat and spring oat foliage, and a sweep survey to obtain regional estimates of hosts and parasites at Gull Lake.

Parasitism of the total population of O. melanopus by T. julis increased from 0.7% in 1969 to 40% in 1973 in the section where T. julis was originally released. T. julis dispersed to other areas at Gull Lake and build-up lagged slightly behind the original release site.

Populations of O. melanopus decreased from 198 larvae per ft^2 per season in 1969 to 4 per ft^2 per season in 1973. Part of the decline in O. melanopus density is due to parasitism by T. julis and part to high mortality in 1971, when high soil temperatures and low rainfall during

and after pupation killed 49 and 58% of O. melanopus and T. julis in the pupal cell.

T. julis populations are vulnerable to some commonly practiced farming methods, such as plowing stubble after harvest and prior to adult T. julis emergence in the spring. Management procedures are suggested to optimize sampling and survival of T. julis on a regional basis.

It was not possible to show that T. julis populations were responsible for the general decrease in O. melanopus density since 1969. However, by 1973, T. julis was contributing to more than 80% of O. melanopus mortality in the soil. T. julis is an important parasite of O. melanopus, and a regional management scheme for regulation of O. melanopus populations must include the possibility of natural control by T. julis.

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Entomology

1974

To Patricia and Jennifer

ACKNOWLEDGEMENTS

I would like to thank James E. Bath, Chairman, Department of Entomology, Herman E. Koenig, Chairman, Department of Electrical Engineering and Systems Science, and the U.S.D.A. for providing encouragement and financial assistance during this study.

To Fred W. Stehr, R. Lal Tummala, Don J. Hall and Jim E. Bath I would like to extend my appreciation for serving on my guidance committee and reviewing this manuscript.

Several individuals helped with field work and data processing and I thank them all. I would especially like to thank Mike Connor who did excellent field work for several seasons, Mary Citadino, who served as my number one helper during the final stages of putting the manuscript together and Lucy Wells for typing the final draft.

Above all, I sincerely appreciate the guidance given me throughout this study and many of my other endeavours by Dean L. Haynes who was my major professor. I am very proud to have been one of Dean's students.

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INTRODUCTION

The cereal leaf beetle, *Oulema melanopus* (L.), (Coleoptera: Chrysomelidae), is an introduced insect pest of small grains. Haynes (1973) has described aspects which are considered important to the management of cereal leaf beetle populations in North America.

One of the important management options available is that of introduced parasites, especially since the insect was introduced to North America in the absence of its parasite complex. The cereal leaf beetle is not significantly important in reducing small grain yield in Europe except locally (Miczulski 1971), and it was postulated that regulation may be occurring due to the beetle's parasite complex.

Studies were initiated in 1965 to examine the cereal leaf beetle parasite complex in Europe, resulting in shipment of the major parasites to the U.S. Four parasites were released and established at Michigan State University's Gull Lake Biological Station, Hickory Corners, Michigan. The order of establishment of each of the parasites was as follows: *Anaphes flavipes* (Foerster) Hymenoptera, Mymaridae (Maltby *et al*. 1971); *Tetrastichus julis* (Walker) Hymenoptera, Eulophidae (Stehr 1970); *Diaparsis carinifer* (Thomson) Hymenoptera, Ichneumonidae (Stehr and Haynes 1971); and, *Lemophagous curtus* (Townes) Hymenoptera, Ichneumonidae (Stehr *et al*. 1974).

This study is mainly concerned with the biology, build-up, and impact of *T. julis* on cereal leaf beetle populations at Gull Lake.

This parasite species was selected for detailed investigation because its population built up very rapidly during 1970. The rate of build-up indicated T. julis could have a significant impact on cereal leaf beetle populations. It was felt that it might be possible to manage T. julis through manipulations, such as crop rotation and planting dates, and with these manipulations, develop a system of optimal management of cropping practices that would enhance the effectiveness of T. julis as a mortality factor operating on cereal leaf beetle populations.

Important considerations in the development of a realistic scheme for the management of a pest insect population are the characteristics of the pest population with respect to its distribution, year to year changes in density, and type and amount of damage caused. Fortunately, these aspects have been investigated, or are being investigated at the present time, on a regional basis (Haynes, in preparation) so that new management techniques, when operational, can be tested against historical information and provide a measure for the degree of success. Regional surveys are essential to the understanding of the gross behavior of populations in the areas where they are distributed. However, surveys cannot yield the in-depth understanding of the interactions between populations (i.e., host-plant and host-parasite), and synchrony of the populations with the environment which are necessary to develop adequate models for management schemes. This study provides some of the basic elements needed prior to development of integrated programs providing regional control.

In 1971 the CLB population dynamics project became one of a class of environmental problems within the context of a grant entitled

Ecosystem Design and Management, administered by the College of Engineering through the Electrical Engineering and System Science Department (NSF, GI-20). Developments evolving from this grant, and through the co-operative efforts between members of the CLB population dynamics group and systems scientists, a pest management grant was prepared. Within this grant, five components of pest management were envisioned and are documented to serve as guidelines for the development of a pest management prototype with the initial focus on the cereal leaf beetle. The five components are: (1) environmental monitoring which provides the component of climate and weather in relation to biological activity of the insect populations and their interacting components; (2) biological monitoring which is a regional survey of the biological populations to detect changes in population density and crop configurations; (3) biological research which involves studies of populations in detail and provides parameters which can be used in (4) pest ecosystem modeling for simulation and mathematical experimentation; and, finally, (5) system operation and maintenance which brings all the components together and provides information in a usable context for operation and management decisions at regional and/or local levels.

Within the context of this pest management framework, this study is principally a contribution to the biological research component but with strong ties to systems modeling. Because of the local nature of the study (Gull Lake), the regional aspects of population changes through time over a broad area are considered by extrapolation using environmental monitoring. Information obtained during this study has been utilized to provide parameter estimates and biological insight regarding the role of natural enemies of the cereal leaf beetle within the context of the cereal leaf beetle management system (Haynes 1973, Gage *et al*. 1973, Barr *et al*. in preparation, Tummala *et al*. in preparation).

A major effort during this investigation has been to make this pest management effort as useful as possible. This framework has provided specific objectives for this research, such as to determine (1) the effect of crop management on larval parasites, (2) the synchronization of the parasites with the host and how this synchrony may be manipulated through crop management, (3) the interaction between introduced parasites of the cereal leaf beetle, (4) parasite emergence rates to provide on-line estimates of sampling times for regional parasite distribution and dispersal, and (5) measurement of biological components which lead to a quantitative understanding of the interaction between the cereal leaf beetle and *T. julis*.

LITERATURE REVIEW

The cereal leaf beetle, hereafter CLB, has become a serious pest of small grains, especially spring grains, in some areas of North America. Population densities sufficient to cause economic loss were first noticed in spring oats in southwestern Michigan in the early 1960's (Castro *et al*. 1965), and since then the CLB has spread throughout the lower penninsula of Michigan, Illinois, Indiana, Ohio, Pennsylvania, New York, West Virginia, Kentucky, and eastern Ontario (Haynes 1973).

In Europe, the probable source of the Michigan inoculation, the CLB is widely and continuously distributed from the North African coast to central Scandanavia and from the Atlantic coast (including the United Kingdom) east to central Asia (Castro *et al*. 1965). Economic damage caused by the CLB occurs sporadically in the Balkan states and southwest U.S.S.R. (Hilterhaus 1965; Venturi 1942) but there is little firm evidence why this insect is not a major pest of small grains in Europe.

Initial studies on the CLB in the U.S. began with the work of Castro *et al*. (1965) who investigated the biology of the insect. Research has continued on many aspects of the ecology and biology of the CLB and a bibliography of these works has been published (Wellso *et al*. 1970). Additional information on specific components of biology and field ecology is included in works by Helgesen and Haynes (1972) on within-generation mortality, by Ruesink and Haynes (1973) on a sweepnet model for CLB adults, by Ruesink (1971) on adult biology and a systems model of the CLB, and by Gage (1972) on the interaction between the CLB and its host plants.

Because of the impact of CLB populations on small grains in Michigan and in other parts of North America, a major attempt by the U.S.D.A. was made in Europe to find parasites of the CLB. The initial surveys were conducted in 1963 and mass collections began in Europe in 1965. Introductions of parasites of the CLB into the U.S. began in 1964 and are still continuing. Dysart _et al_. (1973) present data on these collections (summarized in Table 1) to indicate the general status in Europe of the three significant larval parasites with respect to constancy, occurrence at high and low host density, dominant parasite species, and mean percent parasitism based on examination of pupal cells after larval rearing. In addition, Andersen and Paschke (1968) give a biological sketch of the egg parasite, _A. flavipes_, and Dysart _et al_. (1973) describe the biology of each of the larval parasites. Some of the salient biological features of each parasite are summarized in Table 2.

Dysart _et al_. (1973) discuss interaction between species of the larval parasites in Europe and note that when more than one egg of _D. carinifer_ occurs within a host (superparasitism) only one larva survives. They presume this to be the case with the other solitary ichneumonid, _L. curtus_. Competition exists between _D. carinifer_ and _T. julis_. Dysart _et al_. (1973) note that _D. carinifer_ supercedes _T. julis_ if both are in the larval stage within the host. However, the larvae of _T. julis_ may be able to compete with _D. carinifer_ if an egg

TABLE 1: Status in Europe of three larval parasites of O. melanopus based on 44 collection sites (Adapted from Dysart et al. (1973)).

	Diaparsis carinifer	Tetrastichus julis	Lemophagus curtus
Constancy*	100	91	73 (91)[2]
Occurrence at high host densities	100	83	100
Occurrence at low host densities	70 (50)[3]	50	10
Dominant	59	34	9
Average parasitism (range)	12.3 (.4-50)	10.4 (0-56)	5.6 (0-29)

*All values in percent. Constancy refers to the presence of parasites in European collection sites.

[1]Taxonomic status is unclear.

[2]L. curtus was not detected in the Iberian Peninsula.

[3]Diaparsis sp. was only parasite detected in 50 percent of low host densities.

TABLE 2: A summary of some biological aspects of parasites imported from Europe as noted by Anderson and Paschke (1968) on the egg parasite and Dysart *et al*. (1973) on the larval parasites.

Characteristic	Parasite species			
	A. flavipes (Hymenoptera: Mymaridae)	*T. julis* (Hymenoptera: Eulophidae)	*D. carinifer* (Hymenoptera: Ichneumonidae)	*L. curtus* (Hymenoptera: Ichneumonidae)
Voltinism	multivoltine[1]	multivoltine[2]	univoltine	multivoltine[3]
Solitary or gregarious	gregarious	gregarious	solitary	solitary
Host stage preference	early egg	all larvae	small larvae	all larvae
Peak oviposition period	well after peak	first and last larvae	prior to peak larvae	first and last larvae
Recognition of parasitized hosts	no	no	no	no
Overwintering stage	adult[4]	free larvae within CLB cell	cocoon in CLB cell	adult in cocoon[4]

[1]Several generations per year.

[2]At least two generations in southern France.

[3]Two generations--possibly more.

[4]Imperfectly known.

of the ichneumonid is deposited when T. julis larvae are large. It was also noted (Dysart et al. 1973) that encapsulation by the host is widespread in Europe and that D. carinifer is most commonly encapsulated, particularly if the host contains supernumary eggs. T. julis was not as severely affected by this host reaction although encapsulation occurred in 4% of the total oviposition (Dysart et al. 1973).

Dysart et al. (1973) discuss the parasite shipments, release, and recovery. The number of parasites of each species released (by state) from 1964-1972 is summarized from Anonymous (1972). The significance of the ability of MSU personnel to enable maximum build-up of T. julis at Gull Lake under field conditions (Stehr 1970; Stehr and Haynes 1971; this study) is indicated.

Four parasite species have been introduced in an attempt to control the CLB in North America. The egg parasite, Anaphes flavipes (Foerster) (Hymenoptera:Mymaridae) was first studied in Europe (Andersen and Paschke 1968, 1969) and was first released in 1966, followed by larger releases in 1967 and 1968. It became established in 1968 (Maltby et al. 1971). The gregarious larval parasite, Tetrastichus julis (Walker) had been released by Purdue personnel since 1964, and by Niles Station and Michigan State University personnel since 1967. However, establishment was not recorded until 1969 (Stehr 1970). Establishment of the first solitary larval parasite, Diaparsis carinifer (Thomson), was recorded in 1970 (Stehr and Haynes 1971) and establishment of the second solitary larval parasite, Lemophagus curtus (Townes), was recorded in 1972 (Stehr et al. 1974), thus completing the establishment of all parasites imported from Europe.

Prior to the discovery of the CLB in Michigan, and even subsequent to the studies initiated in Europe by the U.S.D.A., very little detailed information was known about this pest and its parasite complex in Europe or other areas where the beetle was distributed. It has been recognized as a pest of small grains in Europe since 1737 (Lyubenov 1956), and Hodson (1929) studied the bionomics of the CLB in England.

The larval parasites which were dissected or reared from CLB larvae are given in Dysart et al. (1973). Two primary parasites that were reared from CLB larvae but were not introduced to the U.S. for biological control of the CLB were Meigenia mutabilis (Fallen) (Tachinidae) and Pnigolio pectinicornis (L.) (Eulophidae). M. mutabilis was introduced against the asparagus beetle, Crioceris asparagi (L.), in 1939 but the parasite never became established (Clausen 1956). Bjegovic (1967) found that parasitism of CLB larvae by M. mutabilis reached 3% in 1966 in Yugoslavia. P. pectinicornis was reared from CLB larvae collected in France. Boucek and Askew (1968) indicate that this eulophid is a widely polyphagous solitary ectoparasite attacking lepidopterous and coleopterous leafminers, and Dysart et al. (1973) note that it has been recorded in the literature as both a primary and secondary parasite.

It must be noted that the CLB co-exists in European grain fields with a related species, Oulema gallaeciana (Heyden). Dysart et al. (1973) report that the bionomics of O. gallaeciana is very similar to the CLB except that pupation occurs on the plant leaves and stems, and the eggs and larvae cannot be distinguished from CLB eggs and larvae in the field. Carl (1968) summarizes the distribution and abundance of O. gallaeciana and compares it to O. melanopus. However, O. gallaeciana does not occur in the U.S.; and, although the identification problem is not present, the importance of the co-existence in Europe of the two species may have an important bearing on host-parasite interactions.

An attempt has been made to examine the biology of T. julis and its interaction with the CLB. It was evident that without developing some management scheme to protect T. julis from insecticide application, and other agricultural perturbations, biological control of the CLB might be inhibited. Lloyd (1960) is one of a number of workers who noted that whenever introductions of natural enemies have given complete control (for commercial purposes), or partial control, these successes have been attained on perennial crops. Lloyd (1960) attributed the lack of success on annual crops to the dynamics of these crops due to the constant disruptions by cropping and other sequences of present-day agricultural systems.

In recent years considerable emphasis has been placed on the concepts of integrated control of pests (Stern et al. 1959) in relation to management practices. Rabb (1970) notes that integrated control refers to modification of insecticidal control to protect and enhance the activities of beneficial insects. He defines pest management as "the reduction of pest problems by actions selected after the life systems of the pests are understood and the ecologic as well as economic consequences of these actions have been predicted, as accurately as possible, to be in the best interest of mankind." Southwood and Way (1970) note that the basis of management is the planned manipulation of the various processes that influence economic injury level, so as to minimize the economic effect of the pest. Emphasis has been placed on a better understanding of the dynamics of pest populations and the processes which influence pest dynamics (Clark 1970). Varley (1970), on the other hand, stresses that there is considerable information on pest numbers and changes in pest populations, but that information on the dynamics of beneficial insect populations and life table studies of these beneficial insects is generally lacking.

There is not a total lack of information on the dynamics of beneficial insects or pertinent life table information, however. Many good examples of this type of information can be found in Clausen (1956), DeBach (1964), Huffaker (1971), and Corbet (1971) who have edited evaluations of biological control studies conducted in the U.S. and Canada. Huffaker and Kennett (1969) examined the effect of natural enemies, and Hassell and Rogers (1971) examined insect parasite responses in the development of population models. Royama (1971) published an extensive paper comparing different models of predation and parasitism.

Each pest species and its predator complex must, to some degree, be treated separately because different species behave differently to environmental stimuli, hosts, etc. In the literature, many successful examples of biological control of pest insects have been cited (Turnbull and Chant 1961; Pimentel 1963; DeBach 1972). Considerable controversy has been raised as to the order of introduction of natural enemies, and whether or not all natural enemies should be introduced at once or on a priority basis. There seems to be no clear-cut answer; but, DeBach (1972) suggests, among other aspects, that multiple introduction of diverse natural enemies is the only practical manner of obtaining the best natural enemy for a given habitat, or the best combination of natural enemies for a habitat, or the best combination for the entire host range. In most cases, this philosophy has been followed by the importing agency and multi-species introductions are a fact of life for the field researcher. This was the case with imported parasites of the CLB (Dysart et al. 1973), even though there were attempts made to restrict release of some of the parasites to certain parts of Michigan (Haynes, personal communication) so that each species and its interaction with the CLB could be studied separately. The potential for biological control has been stressed by Sailer (1972), and Stehr (1972) has mentioned biological control in the context of pest management.

In the last few years, much literature on insect control has stressed management, and population management of insects was a central theme for the International Congress of Entomology in Canberra (Geier et al. 1972). This, perhaps, stems from changing public views regarding the indiscriminate use of pesticides and the fact that pesticides were used during the 1950's and 1960's as a panacea. Since insect problems have not decreased even though pesticide types and use have been on the rise, other methods of control are being re-examined. Smith (1970) has examined some of the implications of the use and limitations of pesticides within the framework of management. Management of insect populations entails some management scheme which involves an array of viable options available to those who must attempt the actual manipulations. Most of the options (cultural practices, application of pesticides, release of parasites, etc.) are not fixed in time, but must be accomplished on a temporal basis and delicately synchronized with the life systems of the pest and the host crop. Within a particular season, the occurrence of biological phenomena are not synchronized with time, but with the state of the environment. Messenger (1970) shows the importance of climate in the success of certain biological control programs in California. In addition to the importance of climate in determining the distribution and success of some biological control programs, differences in weather from year to year can cause important variations in the timing of biological events. When it becomes necessary to know these variations in biological events in advance to apply some within-season strategy on a regional basis, the options are limited unless on-line environmental monitoring is available. Haynes et al. (1973) have conceptualized a scheme to collect this information. Similar efforts are now evolving (Purdue University and New Mexico State University) to record, collect, and process meteorological data continuously throughout the season, and to use this information to provide direction for real-time management decisions.

MATERIALS AND METHODS

Quantitative sampling methods. To measure populations of the CLB, its host crops, and significant parasites, several different methods of sampling were used. These methods depend on the stage of the species or crop, the accuracy of measurement necessary for the particular aspect being investigated, and the time domain in which the measurement must be taken. These methods can be divided into several categories and efforts were made to be as consistent as possible between studies conducted prior to this investigation and within this particular study as it evolved.

The methods used during this study and the life history stage to which the method is applied are listed in Table 3. Accurate estimates of CLB adult populations were not an objective of this study because these estimates have been the concern of other investigators involved in the project (Ruesink 1972; Ruesink and Haynes 1973; and, Casagrande personal communication). However, accurate estimates of the adult component have been determined (Ruesink and Haynes in preparation). Auxillary estimates of CLB adults were obtained during this study by quantitative sweepnet sampling to determine larval density estimates for analysis of parasitism, and by using emergence cages to determine estimates of *T. julis* emergence.

To measure densities of CLB eggs and larvae in the host crops, Helgesen (1969) and Helgesen and Haynes (1972) showed that the most

TABLE 3: Quantitative methods used to sample populations of the cereal leaf beetle and *T. julis*.

Method	Stage Sampled	
	CLB	*T. julis*
Emergence trap (1 yd^2)	adults	adults
Sweepnet (15" dia.)	adults larvae	adults eggs, larvae*
Population samples from plant foliage (2 linear ft.)	eggs, larvae	eggs, larvae*
Rotary flight trap (16" dia.)	adults	adults
Foliage vacuum (D. vac) 1 ft^2	--	adults
Soil sample (1/2 yd^2)	pupae	diapausing larvae pupae

*Dissection of CLB larvae.

efficient and accurate method of sampling was to collect 2 linear row feet of grain (ca 1 ft^2). This sample size was used consistently between 1967-1973, and in 1970 Gage (1972) modified the analysis to account for growth of the host crop and damage caused by CLB feeding. The number of samples taken within a crop varied depending on population density and, for the sake of logistics and processing, on the number of fields which were sampled. To define the egg and larval populations through time, sampling frequency varied depending on the factors mentioned above as well as on temperature. As a rule, sampling took place once per week, but twice weekly samples were attempted during peak larval density. The eggs collected from these samples were reared to estimate parasitism by *A. flavipes*, while the larvae in each sample were dissected to determine the proportion parasitized by larval parasites.

Four methods were used to estimate adult densities of the larval parasites. To measure emergence rates of parasites from the soil, a trap was designed to capture the adults as they moved to and up the lumite screen sides and into glyceryl in the container at the top. The rubberized canvas at the trap bottom was placed in a shallow trench dug around a yd^2 frame and buried to prevent escape through the soil at the bottom of the trap. Depending on the experimental intent, emergence was measured hourly, daily, weekly, periodically, or at the end of the emergence period. Two methods were used to estimate field densities of adult parasites: the "D-Vac" which is a gasoline powered vacuum cleaner, and the sweepnet. The D-Vac samples 1 ft^2 and sampling consisted of a number of ft^2 estimates within a crop. After completing sampling of the desired crop, the holding bag was removed and replaced by another. These samples were then taken to the laboratory, the insects anesthetized using CO_2, and the parasites were identified and counted.

The sweepnet was used as a multi-purpose sampling method, both quantitatively and as an index to measure densities of CLB adults, larvae, and adult parasites over a large area in a relatively short time interval. Sampling was conducted using a standard 15-inch sweep-net (Ruesink and Haynes 1973) into which a plastic liner was placed. The basic sample size was 100 sweeps per field. An effort was made to sample fields within as short a time interval as possible. After each field was sampled, FAA was used to preserve the specimens and each bag was labeled, tied, and taken to the laboratory for separation. To separate the insects, the contents of each bag was placed in a large, inverted carboy containing 95% ETOH. The bottom of the carboy had been removed and a rubber stopper containing a glass rod and short length of Tygon tubing was inserted in the neck. The tubing contained a removable cork. Separation occurred by gravity and within a short time the insects were in the tubing. A circular piece of 1/2-inch hardware cloth placed in the carboy trapped plant debris. To collect the insects for identification or preservation the cork was removed from the tubing and the insects were siphoned into a vial or washed onto a screen and placed in a vial containing FAA. The FAA was used as a preservative for eggs and larvae of parasites within CLB larvae. To maintain rapid gravitation, the 95% ETOH was replaced after about 20 fields were processed and the used ETOH was distilled and recycled when convenient. For identification and counting, the insects from each sample were placed on a white enamel tray. By this method, adults and larvae of the CLB and adult parasites were sorted, counted and replaced in the vials for an identification check, a recount, and dissection of the CLB larvae for immature parasite stages. Up to 100 larvae were dissected from each sample. The dissection process involved measuring the head capsule of the larva and counting the number of eggs and larvae of the parasites of the CLB.

Rotary flight traps (Helgesen and Haynes 1969) were used to capture adult *T. julis*. These motorized traps were placed in different crops at different heights to determine the flight activity of the adult parasites. Each trap consisted of two nets suspended at variable heights from a 12 ft. cross-beam. Specific characteristics of the trap are given by Helgesen and Haynes (1969).

To estimate CLB and parasite mortality in the soil after pupation, and also to determine the density of parasites in diapause at the end of the season, quantitative soil samples 36 X 18 X 3 in. were taken in the host crops. Depending on CLB densities and resources available, variable numbers of soil samples were collected and processed during the study. The procedure involved collecting a set of samples from a field and washing each sample through a screen small enough to trap pupal cells and cell parts (1/8-inch^2 hardware cloth). The material remaining in the sampling container after washing (rocks, plant debris, insects, etc.) was spread onto a series of screens and washed again (Figure 1). After examination of this material and extraction of the pupal cells and cell parts, the cells and fragments were examined and classified as to cell content.

The relationship between insects and weather is dynamic. To relate CLB population phenomena to environmental factors, it was

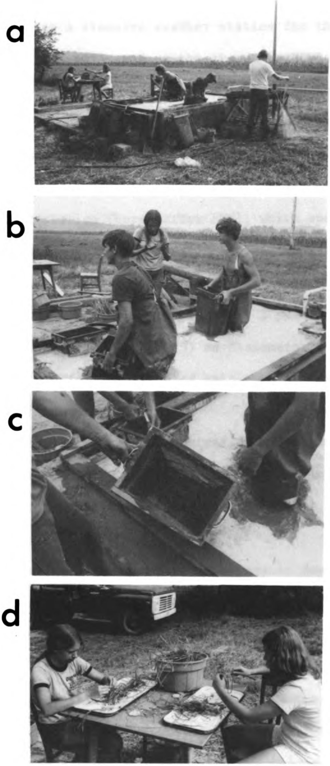


Fig. 1. Procedures for extraction of cereal leaf beetle pupal cells from soil samples.

important to monitor environmental parameters. The Gull Lake Biological Station operates a standard weather station for the Department of Commerce. Information collected at the standard station (hereinafter SWS) consists of (1) daily minimum and maximum temperatures, and (2) daily precipitation. In addition to the Gull Lake Station, a CLB field weather station was established because in some circumstances more accurate weather information was needed at the sampling site. At the CLB field weather station (hereinafter FWS), which operated during the field season (April-August), information collected was compatible with the SWS, but also included (1) a hygrothermograph to allow continuous temperature and humidity monitoring, (2) a pyrheliometer to monitor solar radiation (gm-cal/cm^2), (3) an anamometer to record wind speed and direction, and (4) an automated rain gage to monitor accumulation of rain at 15 minute intervals.

The SWS was used for general historical data because of the continuous nature of the records. However, when specific information regarding weather was needed for a particular experiment, the data from the FWS was used.

Limited microweather data was also necessary in developing certain relationships. For example, to monitor emergence of _T. julis_ from soil which was treated differently, it was important to monitor soil temperatures at the soil-pupal cell interface which is 2 inches below the soil surface. This was accomplished using thermocouples and a multipoint potentiometer. Due to the necessity of monitoring soil temperatures during the winter, a heated shed was used and a timing mechanism was designed to monitor the temperatures six times per day (noon, 4pm, 8pm, midnight, 4am, 8am).

<u>Sampling time and logistics</u>. To establish quantitative interactions between insect populations, host plants, natural enemies, and the physical environment, it is first necessary to accurately measure these populations. Some basic understanding of temporal relationships is necessary even before adequate sampling schemes can be designed to accurately assess population densities. If these temporal synchronies are not well understood, samples are usually taken more or less frequently than necessary when one is attempting to quantitatively describe the population density through time. To quantitatively define regional temporal synchrony, population synchrony must be defined with respect to environmental parameters such as temperature, due to the poikilothermic nature of insects and plants.

Gage (1972) used degree-days to define the interaction between the CLB and its host plants, described the method, and found this useful. The wheat and oats respond to temperatures at one threshold (42° F) and the CLB egg and larval stages at another (48° F). Sample size (n) required to determine density estimates of the different life stages of the CLB and its parasites varied depending on the density of the stage being measured. As a general rule, attempts were made to use a large enough sample size so that the standard error was between 10 to 20% of the mean. Although this is a useful criteria, it is not always feasible to maintain this degree of precision, especially when measuring population density through time. In general, sample size was determined after taking an initial sample using an arbitrary sample size, then determining the degree of precision and adjusting n.

Information on the occurrence of spring and summer adults, total eggs, total larvae, and spring and summer emergence of <u>T. julis</u> adults is shown in Figure 2. Maximum occurrence is indicated at maximum vertical distance, and all occurrences are based on the temperature threshold of 48° F. As well as indicating when the various populations or population components occur in nature, Figure 2 can be used as a good approximation for sampling these populations, although the habitat where these populations occur must be taken into account. CLB adults emerge from the edges of woods and trashy areas along fence rows, etc. (Castro *et al*. 1965; Ruesink 1972); eggs and larvae occur in winter wheat and spring oats (Helgesen and Haynes 1973; Gage 1972); the spring generation of *T. julis* emerges from grain stubble (Stehr 1970; this study); and, the summer adults of *T. julis* and the CLB from the maturing grain crop. The degree-day intervals given for CLB eggs and larvae in Figure 2 pertain to spring planted oats; for winter wheat the occurrence is about 100 degree-days earlier.

An attempt has been made to monitor the CLB and parasite populations from the time eggs are first laid in the grains (late April) until the summer CLB adults complete emergence (mid-July). Since the same emergence cages were used to estimate emerging populations of CLB and parasite adults, the traps had to be moved three times. CLB egg and larval populations were monitored at about 100 degree-day intervals during their occurrence in winter wheat and spring oats. Parasite emergence, parasite attack behavior, parasite field densities, and parasite flight activity were measured during this period and through the emergence of the second parasite generation. During the same period, sweepnet surveys of the Gull Lake area were conducted. Soil sampling to determine parasite density and CLB and parasite mortality was conducted from mid-June through mid-July and later.

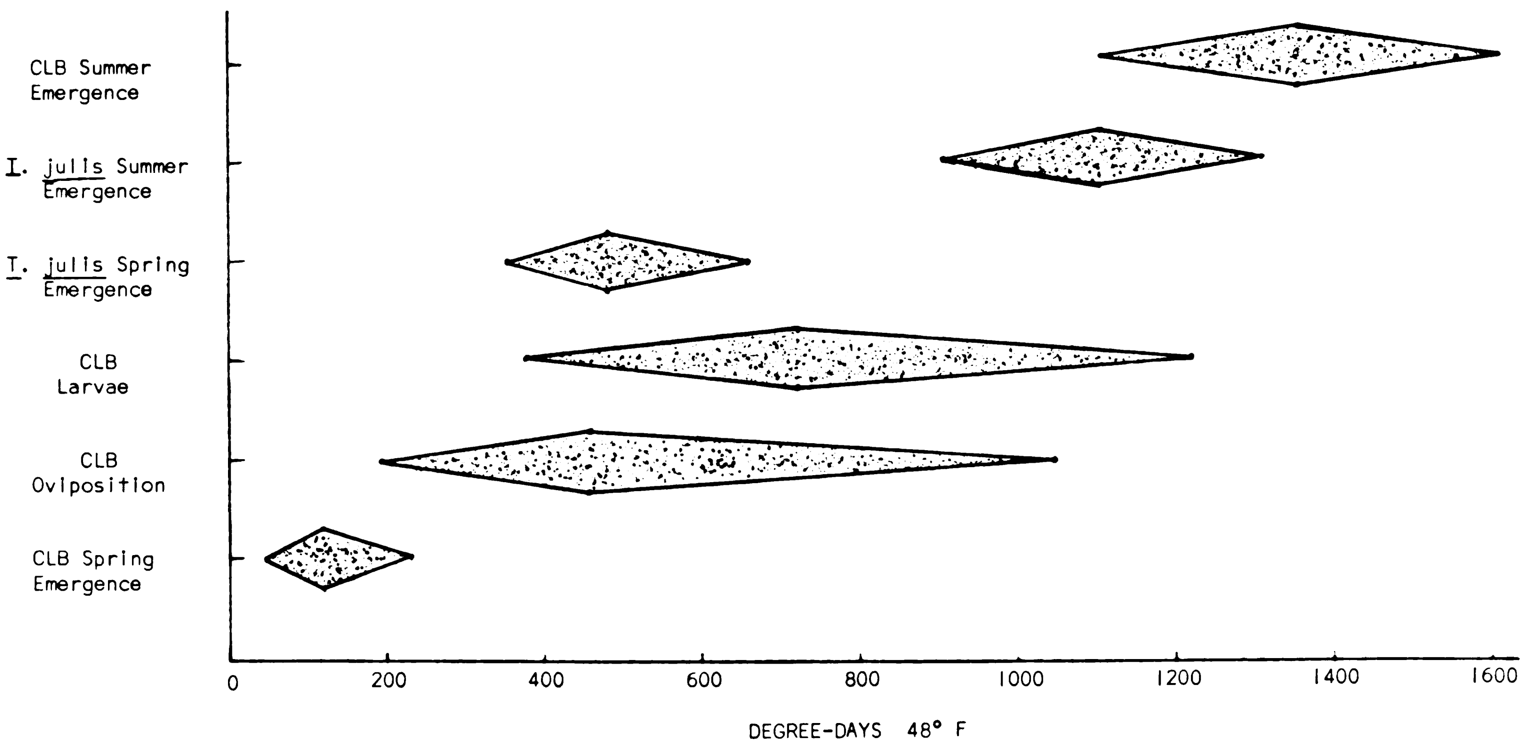


Fig. 2. Average occurrence of life stages of the cereal leaf beetle and *T. julis* at Gull Lake in spring oats ($^{o}D_{48}$).

Specific activities involving measurements of population densities, behavioral parameters, emergence patterns, etc., occurred at different times during the study. Some of the activities involved sampling CLB densities in different areas, studying the development and behavior of *T. julis*, measuring emergence rates of *T. julis* under manipulated conditions, etc. Many biological characteristics of the parasite were determined at different times because at the outset of this study the biology of *T. julis* was imperfectly known. Table 4 attempts to give an illustration of the sampling activities conducted to determine the biology and significance of *T. julis* on CLB populations at Gull Lake.

Gull Lake management plan. Co-operation between the Kellogg Biological Station and CLB research personnel was facilitated through a grant from APHS (now APHIS) for land rental. The three areas of the Experimental Farm included within the context of this grant are shown in Figure 3. The intent behind this request was to have control over the crop configurations, planting dates, and the application of pesticides in these areas.

Within these locations, plantings of winter wheat and spring oats have been manipulated with the objective of providing maximum potential for the increase of CLB parasites. The philosophy behind specific manipulations and variable crop planting dates was: (1) oat stubble should be protected because plowing may cause mortality of overwintering parasites, (2) winter wheat should be planted next to oat stubble because the CLB population is usually found first in the winter grains and parasites emerging from oat stubble would have a short distance to travel to find hosts, (3) spring oats should be planted next to winter

TABLE 4: Field sampling activities in sections 5, 8, and 9 at Gull Lake.

Activity	1970	1971	1972	1973
CLB population (ft^2 samples of eggs and larvae, weekly)	8, 9	5, 8, 9[1]	9[2]	9[2]
CLB sweep survey (larvae, 100 sweeps per field)			5, 8, 9[3]	5, 8, 9[3]
T. julis density est. (emergence traps)		5, 8, 9[4]	5, 8, 9[4]	5, 8, 9[4]
T. julis daily emergence rates (emergence traps)		9[5,6]	9[5,6]	9[5]
T. julis flight activity (flight traps)			9[7]	9[7,8]
T. julis adult densities (D-vac)			9[9]	9[9,10]
T. julis diapause incidence			9[11]	8, 9[11]
T. julis attack behavior		9[12]	9[12]	8, 9[12,13]
T. julis overwintering estimate (soil sample)	8, 9[14]	5, 8, 9[14]	5, 8, 9[14]	5, 8, 9+[14]

Emphasis

1. between section CLB population densities
2. examination of effect of crop age on CLB density
3. regional CLB population estimate
4. parasite distribution between areas
5. rate of parasite emergence
6. control of parasite emergence
7. flight activity during summer generation
8. flight activity during spring generation
9. field density estimates during search for hosts
10. field density estimates in oat stubble
11. definition of diapause through time
12. field observations on attack behavior
13. movies of attack behavior
14. estimate of overwintering parasite density and mortality

Fig. 3. Aerial photograph of the Gull Lake Biological Station and surrounding area indicating sections 5, 8, and 9 where detailed cereal leaf beetle research was conducted.

wheat for the reason in (2), and (4) late plantings of winter wheat and spring oats may provide late and/or additional CLB larvae to assist the increase in overwintering parasite densities.

Through these manipulations it was intended to establish parasite densities of sufficient magnitude to facilitate re-colonization under field conditions rather than under laboratory conditions because of problems involved in laboratory production of the larval parasites. Variations of this scheme were carried out through 1974. The actual plantings and manipulations in the three areas are given in Figure 4.

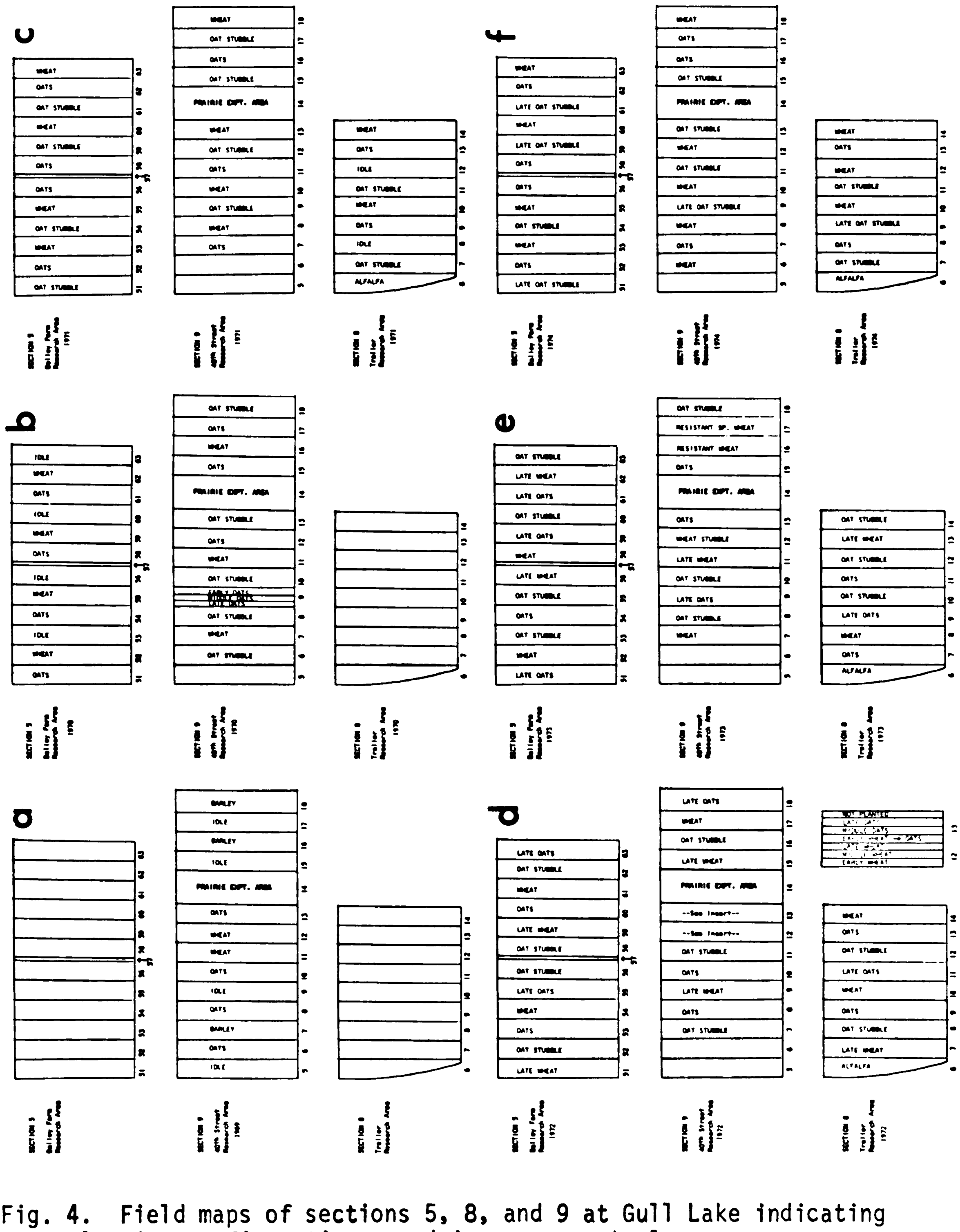


Fig. 4. Field maps of sections 5, 8, and 9 at Gull Lake indicating crop planting configurations used in management plans.

RESULTS

Development of *T. julis* under laboratory conditions. In spring, as the temperatures increase, the parasite larvae within the CLB pupal cell respond to a temperature threshold and initiate development. To determine the temperature threshold for development, Gage and Gage (unpublished data) exposed *T. julis* larvae, which had been stored at 40° F for 14 weeks, to several constant and oscillating temperatures.

The incubators used consisted of water baths in insulated small plastic buckets. Temperatures were controlled using one or two aquarium heaters depending on whether or not oscillating temperatures were required. For temperature oscillations, one heater was set to the lowest desired temperature and the other regulated with a stepping timer to increase at a desired rate to the maximum temperature and then to decrease at a similar rate until being shut off. The water baths were agitated with air and the temperature of each water bath was monitored using thermocouples and a 24-point potentiometer.

The developmental period from overwintering (post-diapause) larva to adult stage at the different temperatures is given in Table 5. The number of days to complete the above development is transformed to % per day ($1/x \cdot 100$ where x is the developmental period in days at each temperature). Figure 5 shows this relationship. The regression equation estimates the developmental threshold temperature for the parasite to be 47.1° F.

TABLE 5: Development of _T. julis_ at constant and oscillating temperatures.

Temperature		Days to emergence $\bar{X}$±SE	% per day	n
Constant Temperatures				
C	F			
32.2	90*			
29.4	85	12.16±.56	8.2	12
26.7	80	11.03±.11	9.1	40
23.9	75	14.48±.29	6.9	27
21.1	70	16.72±.31	6.0	29
18.3	65	22.71±.41	4.4	35
15.6	60	31.75±.49	3.15	8
12.8	55	43.75±.25	2.29	4
10.0	50**			
Oscillating Temperatures				
80--90 (85)		12.0±.58	8.3	6
70--80 (75)		13.14±.38	7.0	14
60--70 (65)		26.50±.43	3.8	6

*100% mortality.

**No development after 55 days.

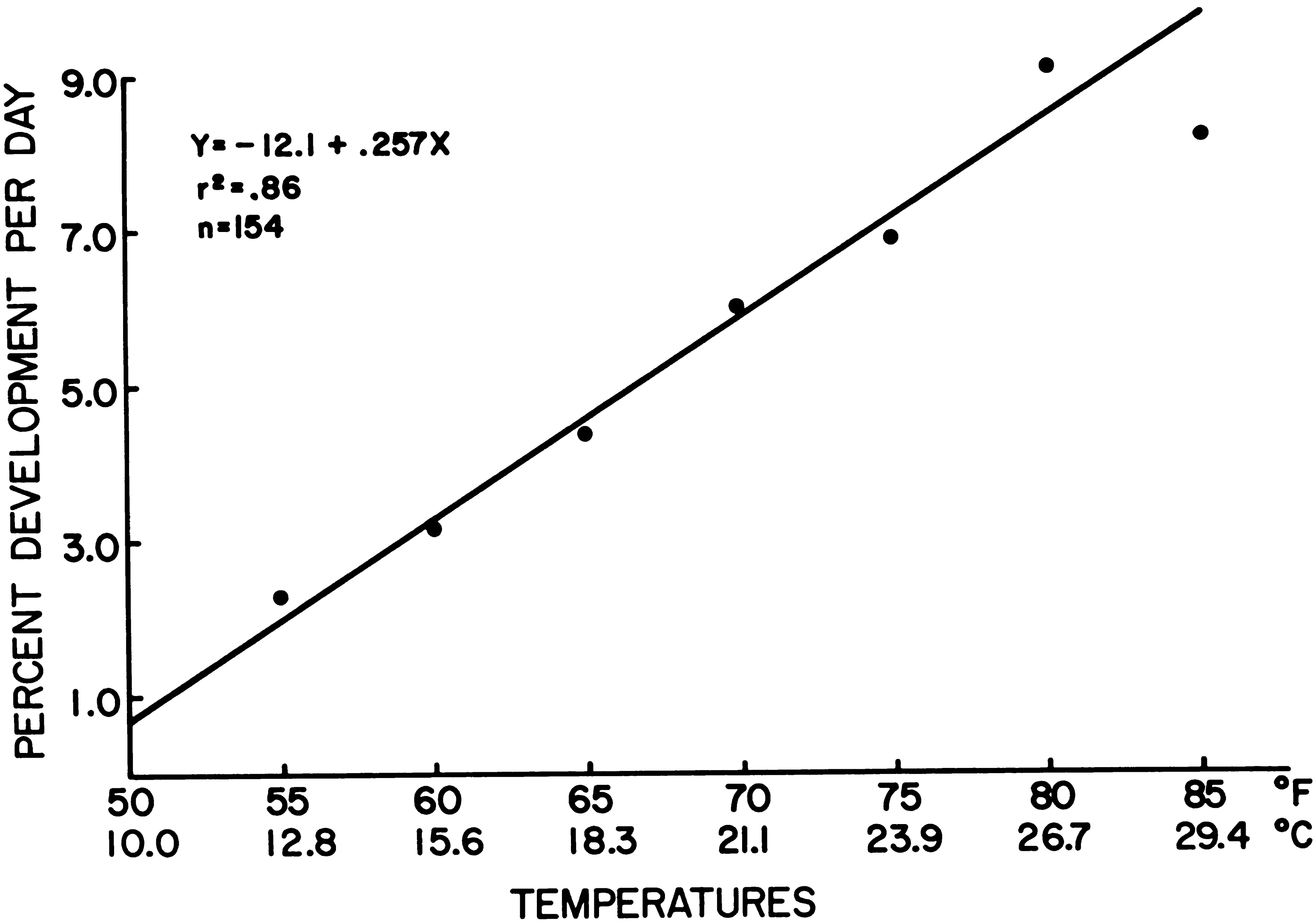


Fig. 5. Percent development per day of _T. julis_ post-diapause larvae at different temperatures.

Because of the increase in developmental time above 85° F, the calculated line would have intersected the x-axis at a slightly higher temperature; but, since 48° F is used as the developmental threshold for eggs and larvae of the CLB (Helgesen and Haynes 1972; Gage 1972), the 48° F threshold will be used as the parasite overwintering developmental threshold for ease of computation and generalization.

In addition to measuring the total time for emergence to occur from the time pupal cells were removed from cold temperatures until adult emergence, within-stage development of _T. julis_ was examined at constant temperature (70° F). Parasite larvae were removed from CLB pupal cells and the developmental stages of _T. julis_ were arbitrarily visually classified into seven consistently identifiable categories: (1) larva, (2) larva with meconium, (3) larval differentiation into head, thorax, and abdomen, (4) pupa with white eyes, (5) pupa with red eyes, (6) pupa with black body, and (7) emerged adult. Figure 6 shows these various developmental stages of _T. julis_.

This information was used as a method to bioassay development in the field and enabled accurate timing for setting out emergence cages to monitor adult _T. julis_ emergence and density. This bioassay was accomplished by collecting CLB pupal cells from the soil, examining _T. julis_ within the cells, and holding the parasites at 70° F. A comparison of development in the field with Table 6 enabled allocation of resources for preparation and setting out parasite emergence cages. For example, if the average coded development from field-collected parasites was 3.5, then most of the population had developed to the white-eyed pupal stage and adjustments were made accordingly.

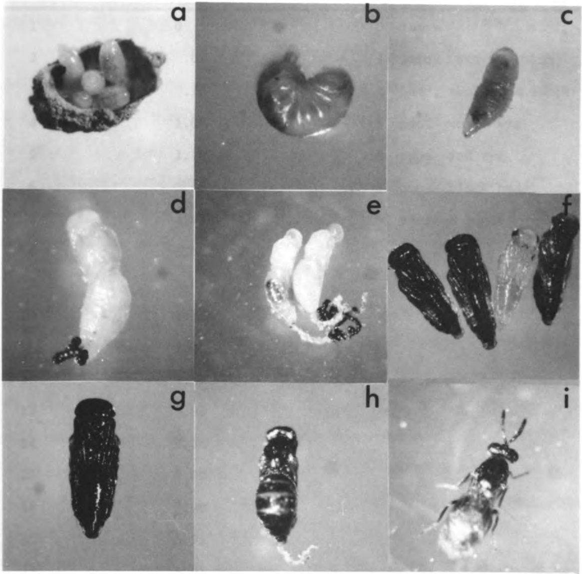


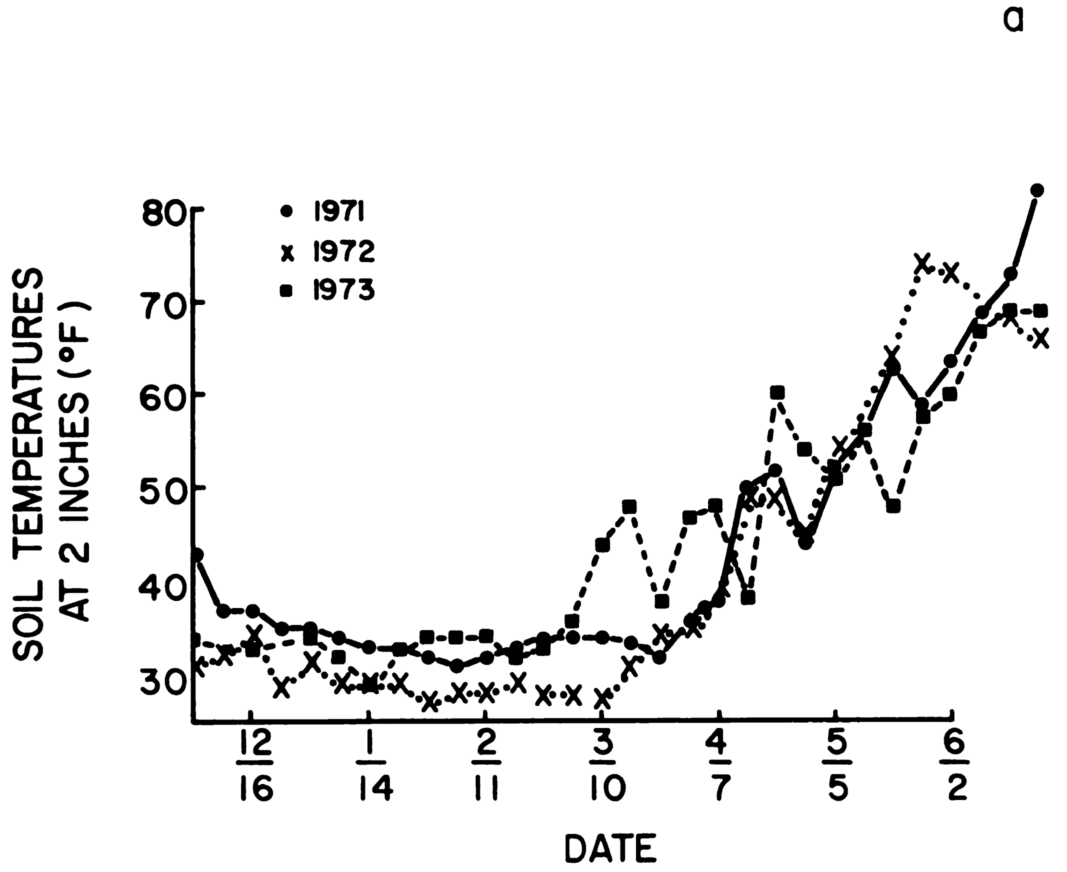
Fig. 6. Developmental stages of T. julis from diapausing larvae in cereal leaf beetle pupal cell (a) to an emerged adult (i).

TABLE 6: Development of *T. julis* at 70° F from time of removal from storage (42° F) until adult emergence.

Day	Coded developmental stages of *T. julis* (n = 21)	Code
1	0	0 larva
2	.05	1 larva with meconium
3	.19	2 head, thorax, abdomen
4	1.05	3 pupa--white eye
5	1.76	4 pupa--red eye
6	2.60	5 pupa--black body
7	3.43	6 emerged adult
8	3.67	
9	3.94	
10	3.97	
11	4.25	
12	4.57	
13	4.92	
14	5.38	
15	5.50	
16	5.90	
17	5.91	
18	5.91	
19	6.00	

Daily emergence of T. julis and summer CLB adults. Emergence of T. julis was monitored daily in specific sites during the emergence period at Gull Lake. This was done to study the synchrony of this parasite with its host; and, to enable prediction of T. julis on a regional basis by quantifying emergence as a function of temperature, rather than limiting the observations to time alone. The most useful method for accomplishing this is to calculate degree-days (°D) above the developmental threshold of the parasite (48° F) and plot T. julis emergence over $°D_{48}$.

Since T. julis overwinters in the soil at a depth of about 2 inches, development depends on soil temperatures at this depth. Soil temperature records are almost non-existant in Michigan (only 2 sites). For this reason, emergence of T. julis was quantified using $°D_{48}$ accumulated in the air. However, soil temperatures were measured at 2 inches so that conversions could be made if and when soil temperature information was available. Average weekly soil temperatures measured at Gull Lake are shown in Figure 7a. Figure 7b shows the relationship between weekly accumulations of °D under standard conditions (x) and at 2 inches in the soil (y) collected from the same sites. Table 7 gives the equations for conversion of $°D_{48}$ from standard air temperature records to $°D_{48}$ accumulated in the soil at 2 inches under undisturbed oat stubble and under oat stubble covered with straw. These relationships are linear but considerable variation exists because of variability in the amount of cover over each temperature sensor in the field. It is necessary to be aware that lag times exist between warming soil and warming air temperatures. Standardization of temperature recording sites would have reduced variability, but because of natural variability



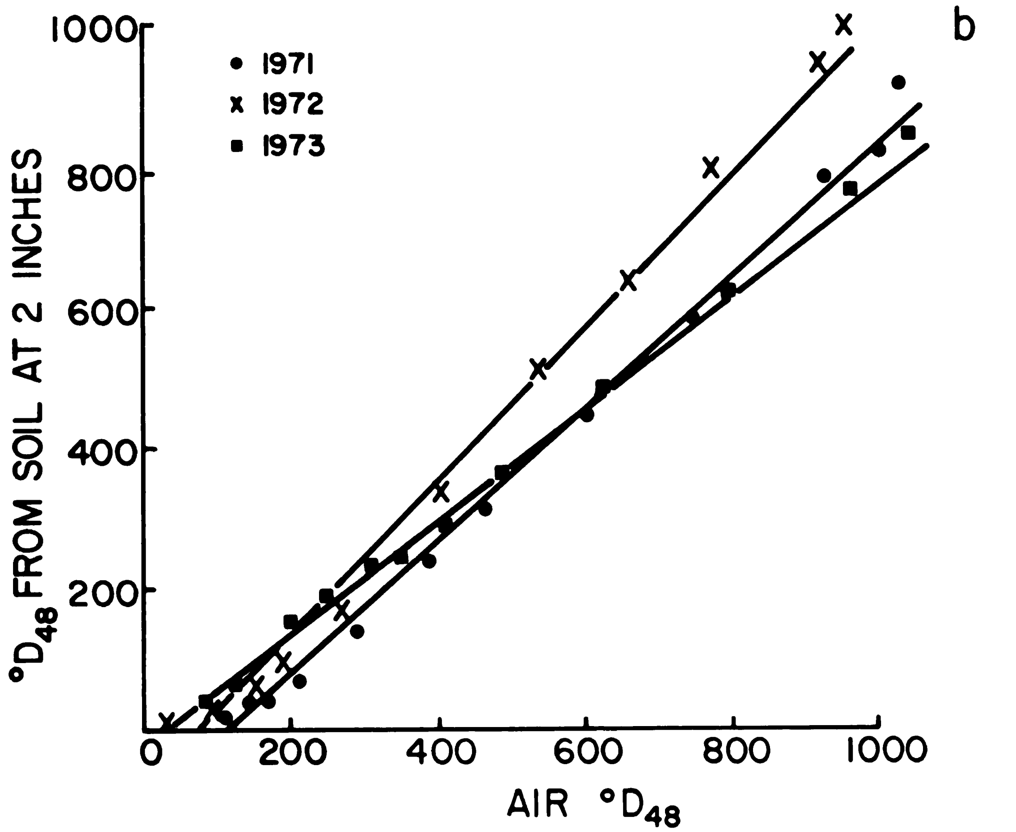


Fig. 7. Average weekly soil temperatures at two inches in oat stubble at Gull Lake (a), and the relationship between air $^{o}D_{48}$ and soil $^{o}D_{48}$ (b).

TABLE 7: Regression equations relating the number of degree-days accumulated above a threshold of 48° F (°D_{48}) in air (°D_a) to °D_{48} accumulated 2 inches deep in the soil (°D_s) at Gull Lake.

Year	Treatment	Regression equation	r^2
1971	oat stubble	°D_s = -109.9 + .95°D_a	.994
1971	straw covered oat stubble	°D_s = -180.7 + .74°D_a	.998
1972	oat stubble	°D_s = - 80.7 + 1.10°D_a	.994
1972	straw covered oat stubble	°D_s = - 65.2 + .94°D_a	.994
1973	oat stubble	°D_s = - 27.5 + .82°D_a	.999
1973	straw covered oat stubble	°D_s = - 58.9 + .63°D_a	.982

in cover this would not have proved meaningful. It was concluded that this variability could at least be averaged within a field by proper distribution of emergence cages. This difficulty and inadequate regional information on soil temperatures led to the use of air temperature information for analysis of emergence.

T. julis has two generations per year; the first emerges from the past season's oat stubble, and the second emerges from the current crop after attacking CLB larvae feeding in the crop. After the emergence of the overwintering generation had been monitored, the traps were moved into the growing crop. The timing of this move was critical: if the traps were moved too early, then larvae in the crop would be protected from attack; and if moved too late, emergence of the second generation would be missed. To time the movement of the traps between generations, pupal cells were collected and parasites bioassayed to determine the state of development After emergence of the second generation of T. julis, summer CLB adults emerged and were trapped as they emerged from the current crop.

In addition to measuring emergence in the spring from oat stubble, different methods were used to manipulate soil temperatures. For example, clear plastic was spread over oat stubble in 1971 to determine whether or not parasite emergence could be advanced by increasing soil temperature, thus providing a greenhouse effect. Straw was used to insulate the soil in 1971 through 1973, and it was hypothesized that emergence would be retarded. The need for understanding the effects of different soil treatments on parasite emergence time stemmed from the possibility that the introduced parasites might not be well synchronized with CLB larval populations. If this were the case, some manipulation might then be necessary to provide better synchrony, and hence, more efficient parasitism.

Figure 8 shows comparative information for the spring and summer generations of T. julis. The emergence curves were defined by calculating cumulative percent emergence. The solid lines through the emergence data (x) were calculated using probit analysis (Finney 1971). Although probit analysis has been primarily used for testing insecticides, a method similar to the one used here was used by Morris and Fulton (1970) to model the effects of heat units and heat requirements on the survival of Hyphantria cunea (Drury). The procedure for calculating the cumulative emergence curve is as follows: probit analysis is performed on cumulative percent emergence and the resulting equation $Ep = \alpha + \beta\ {}^{\circ}D_{48}$ is a linear transformation of the cumulative emergence curve, where Ep is the predicted emergence in probits, ${}^{\circ}D_{48}$ is accumulated degree-days above a threshold of 48° F, and α and β are constants. After deriving the probit equation, the curvilinear cumulative percent emergence curve can be obtained by looking up the appropriate probit values which correspond to different percentages and rearranging the linear probit equation. For example, 5 is the probit value for 50%; therefore, $\frac{5 - \alpha}{\beta} = {}^{\circ}D_{48}$ represents the number of ${}^{\circ}D_{48}$ at which 50% of the population has emerged. This equation can be solved for different percentages and will define the curves in Figures 8 and 9. In many cases the curves can be approximated by sight-fitting a line through the emergence data and reading the °D values directly from a graph. The probit equations calculated from emergence data in Figure 8 are given in Table 8.

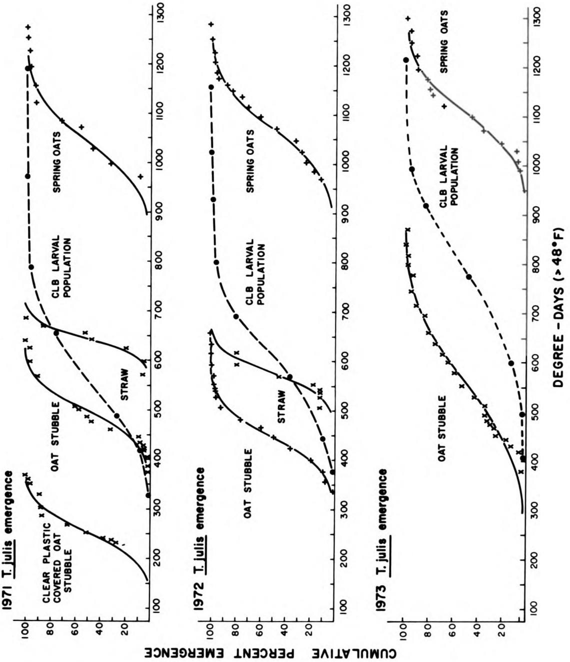


Fig. 8. Cumulative percent emergence of T. julis adults trapped daily from different treatments. The solid lines were fitted using probits. The dotted lines were sight fitted through cumulative percent occurrence of cereal leaf beetle larvae.

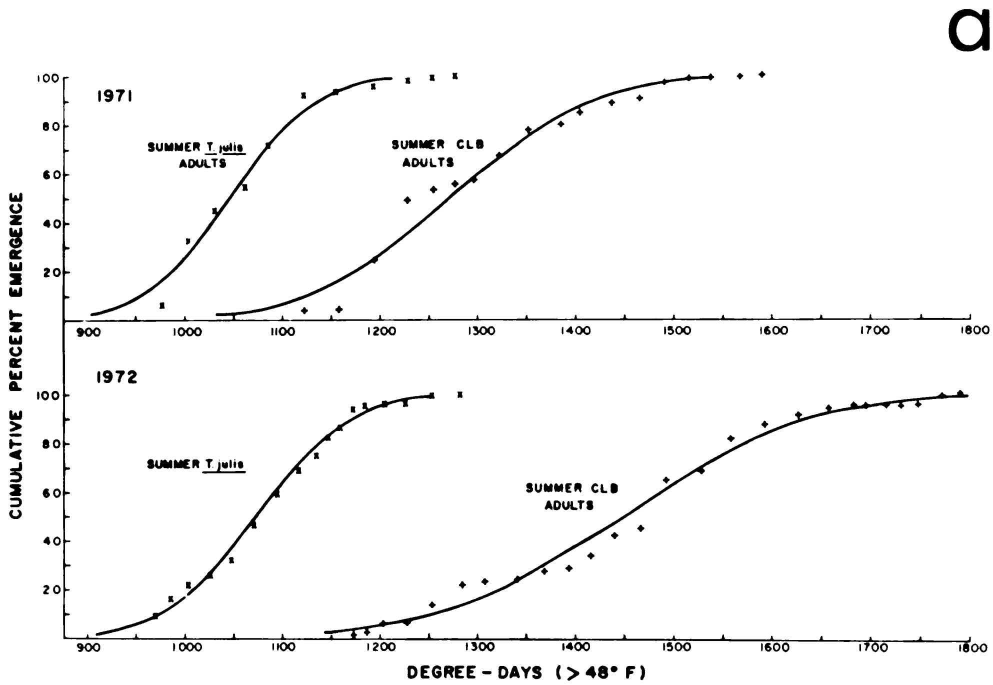


Fig. 9a. Cumulative percent emergence of second generation _T. julis_ adults and summer cereal leaf beetle adults in 1971 and 1972.

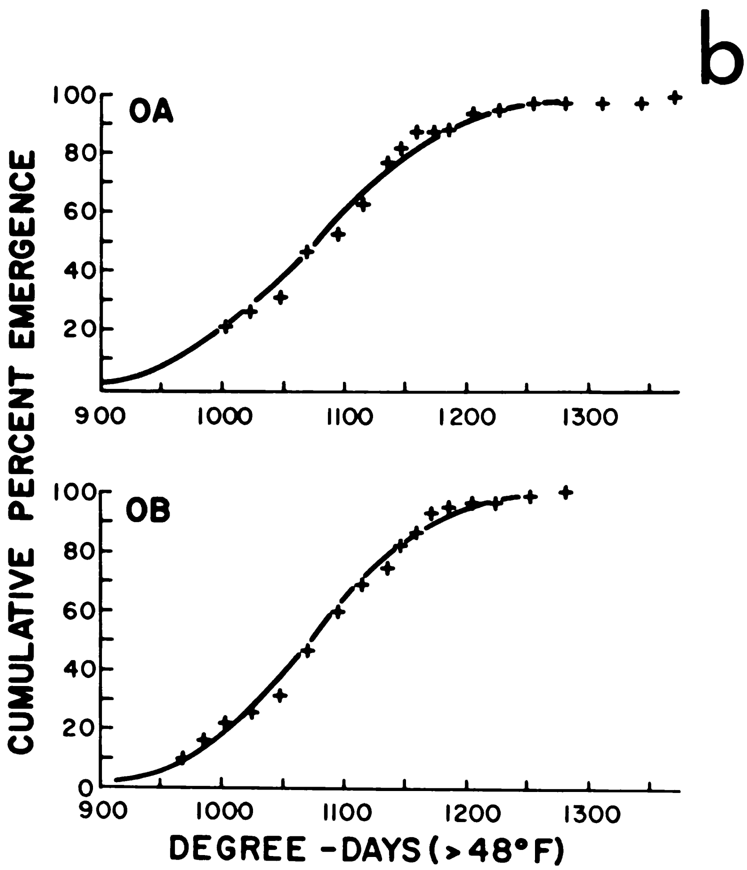


Fig. 9b. Emergence of _T. julis_ adults from early (OA) and late (OB) planted oats in 1972.

TABLE 8: Probit equations, X^2 values, and degrees of freedom for adult *T. julis* emergence curves shown in Figure 8. Ep is probit emergence and $°D_{48}$ is accumulated heat above 48° F (air temperature).

Year	Treatment	Probit equation	X^2	df
1971	Clear plastic	$Ep = -.47 + .021°D_{48}$	3.0	9
	Oat stubble	$Ep = -4.82 + .019°D_{48}$	8.2	16
	Straw	$Ep = -16.80 + .034°D_{48}$	16.5	5
	Spring oats	$Ep = -9.53 + .014°D_{48}$	12.8	9
1972	Straw	$Ep = -10.30 + .027°D_{48}$	1.8	7
	Oat stubble	$Ep = -3.10 + .018°D_{48}$	4.9	16
	Spring oats	$Ep = -8.86 + .013°D_{48}$	1.3	15
1973	Oat stubble	$Ep = .71 + .008°D_{48}$	3.6	28
	Spring oats	$Ep = -9.35 + .013°D_{48}$	2.2	14

In Figure 8, oat stubble represents the untreated condition compared to clear plastic-covered oat stubble and straw-covered oat stubble. The deviation from 50% emergence in oat stubble caused by covering the soil with clear plastic was $254°D_{48}$, or an 18 day difference in 1971. Straw, on the other hand, delayed emergence by $148°D_{48}$, or about 7 days. Straw had a similar effect in 1972 but the delay was less because of a lighter straw cover. The dotted line (Figure 8) represents cumulative percent occurrence of CLB larvae in oats. Parasite emergence from normal oat stubble is well synchronized with the occurrence of CLB larvae. Note, however, that the second generation of *T. julis* does not begin to emerge until over 90% of the CLB larvae have pupated (Figure 8). The second generation of *T. julis* is shown in contrast to emergence of summer adults of the CLB in Figure 9a. Note that *T. julis* is still emerging when emergence of CLB adults starts. This indicates that many *T. julis* adults are present after larvae have all but disappeared. Figure 9a also indicates that attack by *T. julis* occurs over a relatively short time interval due to *T. julis*'s short life span, compared to the extended period of oviposition and longevity of the adult CLB.

Emergence of *T. julis* was also measured in oats planted two weeks apart in 1972 to test if differences in the time of emergence could be detected. The parasite emergence curves in Figure 9b show that crop age had little effect on parasite emergence time, although, as will be shown later, the density of emerging parasites was different because of host selection by CLB adults.

An average adult *T. julis* emergence curve was developed from data collected daily during the first and second generations in 1971-1973.

The $°D_{48}$ at which each of five levels of cumulative percent emergence occurred in each year for both generations is given in Table 9. The average values for the three years are graphed in Figure 10. The average values from Table 9 can then be used as an estimate of parasite emergence on a regional basis by using $°D_{48}$ accumulated at different weather stations in the region. This aspect will be developed further in a later section.

Emergence trap efficiency. Tests were made to determine the capture efficiency of the emergence trap. Three traps were used and the foliage (oats) within each trap was cut to a different height. Male and female *T. julis* which were reared in the laboratory were placed in the cages at 10pm and the cages were checked until no more adults were captured.

Prior to release, the parasites were sexed and placed in petri dishes. Twenty-five of each sex were placed in each dish. The dishes were placed in the cages at night. In the morning the dishes were removed and the parasites which died in each dish were counted and subtracted from the total released. Table 10 shows the number of *T. julis* captured at different foliage heights.

The trap efficiency for females was 84% for the three foliage heights and was independent of foliage height. For males, the efficiency was less (39%) and dependent on foliage height. Male *T. julis* adults are more delicate than females and, in the laboratory, females live longer than males: about two weeks for females compared to three days for males. The same appears to be true under field conditions.

TABLE 9: Degree-day values for different percent emergence of adult *T. julis* during the first and second generations (1971-1973).

Percent emergence	1971	1972	1973	$\bar{X}$±SD
First Generation (Oat Stubble)				
5	415	355	350	373±36
25	470	410	475	452±36
50	500	450	565	505±58
75	535	485	650	557±85
95	585	590	735	636±85
Second Generation (Spring Oats)				
5	925	950	955	943±16
25	1000	1030	1050	1027±25
50	1045	1075	1100	1073±28
75	1090	1125	1155	1123±33
95	1165	1200	1230	1198±33

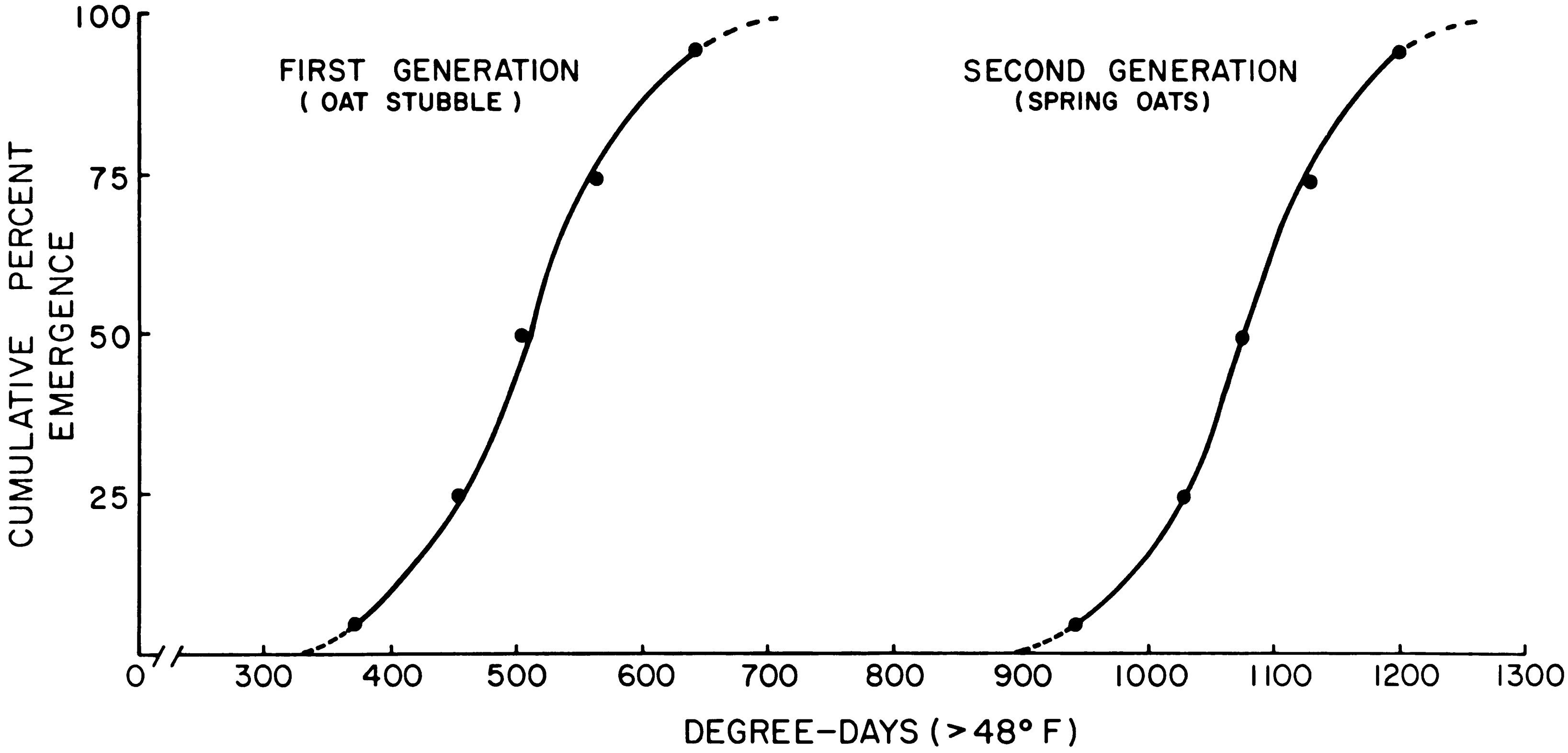


Fig. 10. Average cumulative percent emergence of _T. julis_ adults during the first and second generations.

TABLE 10: The number of female and male *T. julis* trapped in emergence traps containing foliage cut at different heights.

Time trap checked	Foliage Height (in.)					
	0"		6"		18"	
	Female	Male	Female	Male	Female	Male
8:30 am	8	0	1	0	3	1
9:35	6	2	14	4	13	0
11:15	2	1	2	1	1	0
12:30 pm	0	1	2	1	0	0
2:00	0	0	0	0	0	0
3:30	0	0	0	0	0	0
5:15	0	0	0	0	0	0
7:30	0	0	1	0	0	0
9:00 am	0	0	0	0	0	0
11:00	0	0	1	0	0	0
No. released	25	15	25	20	25	15
No. dead in dish	5	8	3	8	5	5
% recovery	80	57	86	50	85	10

Flight behavior of T. julis. The activity of adult T. julis after emergence from overwintering sites was monitored using rotary flight traps placed in different crops at different heights. Although actual dispersal of adults was not measured directly, the information obtained could give some indication about the rate at which adults moved into the crop to search for hosts, as well as the height of flight attained either within the overwintering sites above the oat stubble from which the parasites emerged, or above the crop containing hosts to be parasitized.

Early observations of T. julis activity in the laboratory indicated that adults did not fly readily but tended to spring or hop from plant to plant in search of hosts. This behavior could not be extrapolated to field situations with respect to dispersal potential so traps were placed at different heights and monitored daily whenever possible.

Figure 11 and Table 11 show the relationship between the trap net height and the percent of the total T. julis adults caught in different crops during the first and second generations in 1973. Although the parasite is not a strong flier, and flight above 4 ft. does not represent a major component of activity, it is apparent that wind can play a significant role in dispersal since 4 ft. is well above the height of the crop.

The flight trap at the 2 ft. height in oat stubble also describes parasite emergence, and partially aids in denoting emergence trap reliability. Figure 12 shows the comparison between emergence of parasites per sq. yd. and flight trap catch (Σ/hours the trap was run).

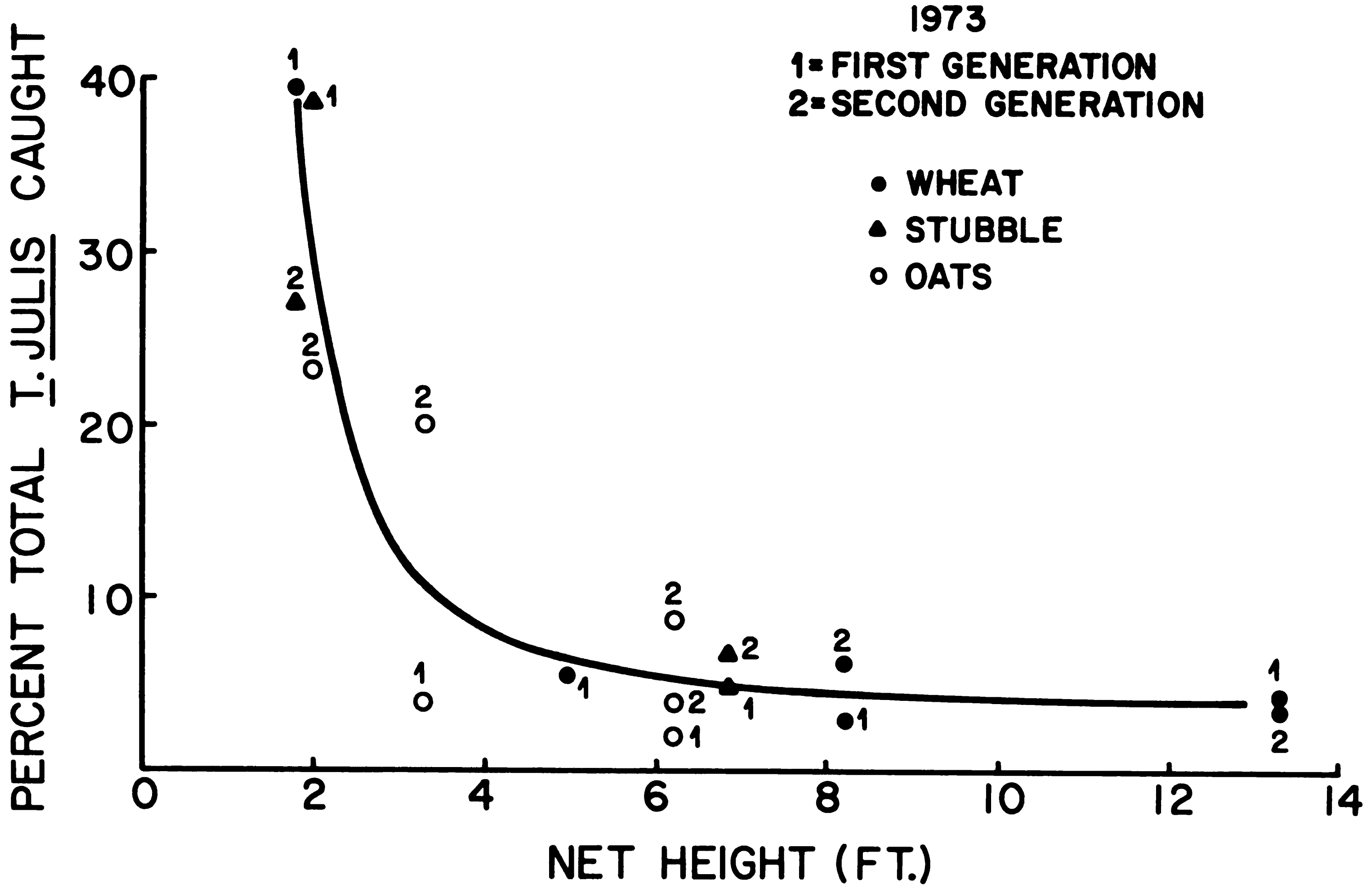


Fig. 11. The relationship between rotary flight trap net height and percent of total number of adult *T. julis* caught.

TABLE 11: Total number of *T. julis* caught in rotary flight traps in different crops at different trap heights during the spring and summer generations, 1973.

Crop	Trap Ht.	Spring		Summer	
		Female	Male	Female	Male
Oat stubble	2' 0"	110	185	--	--
Oat stubble	5' 0"	37	6	--	--
Oat stubble	8' 2"	17	1	29	2
Oat stubble	13' 3"	18	0	17	2
Wheat	1' 8"	144	127	52	84
Wheat	6' 11"	36	4	20	10
Oats (late)	3' 3"	26	1	69	23
Oats (late)	6' 2"	12	2	21	4
Oats (early)	2' 0"	--	--	57	45
Oats (early)	6' 2"	--	--	31	7

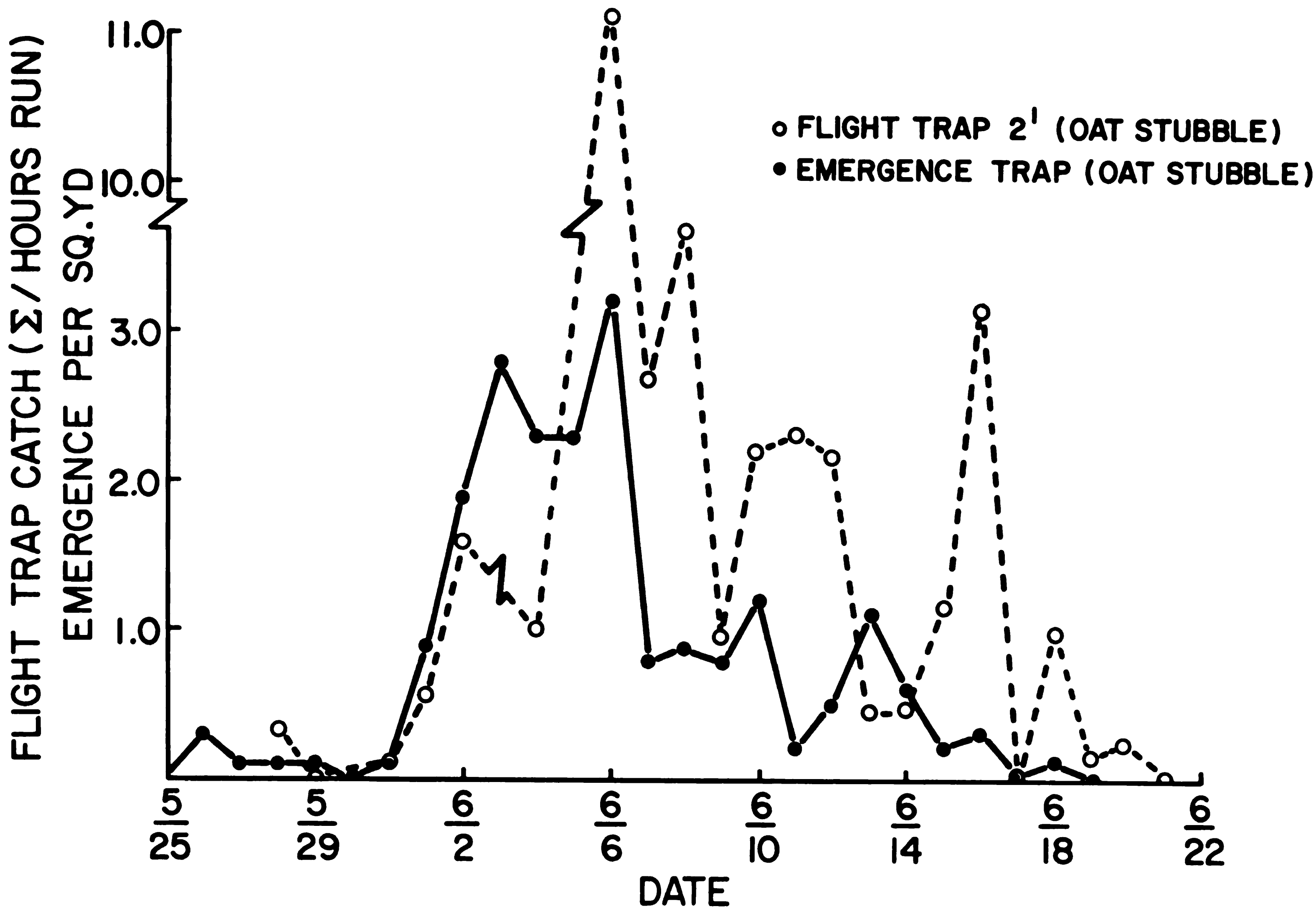


Fig. 12. Comparison of _T. julis_ adults caught in emergence traps in oat stubble and in a rotary flight trap two feet above oat stubble.

The flight activity of *T. julis* adults is a function of many factors. To estimate the temperature threshold at which flight could be sustained, a regression line was calculated on the number of *T. julis* caught daily over a 9 day period in a flight trap rotating 2 ft. above the oat crop, and mean temperature during the daily trapping period (Figure 13). The equation shows that the sustained flight threshold is about 60°F. Activity within the crop, as opposed to above it, did not seem to be affected by average temperatures as low as 63° F, but observations in the laboratory indicate that activity is severely restricted at 55° F.

Juillet (1964) studied the influence of weather on flight activity of 2 Families of Hymenoptera, Ichneumonidae and Braconidae, during three field seasons (April - September). He found that (1) maximum temperature was a significant indicator of flight activity; (2) an increase in humidity favored the flight activity of ichneumonids while it reduced that of braconids; and, (3) winds of low velocities stimulated flight activity and high velocities depressed it.

These factors also influence the flight activity of *T. julis*; but, rather than attempting to model specific activity as it relates to differences in weather, the activity was monitored at different trap heights to obtain some idea about the potential dispersal qualities of *T. julis*. The general influence of trap height on the percent of *T. julis* caught at different heights is shown in Figure 14. A perspective view of the effect of trap height on the number of *T. julis* caught per day is given in Figure 14a, which shows the total number caught in relationship to time and trap height (4 levels) above oat stubble during the first generation. This shows that as trap height

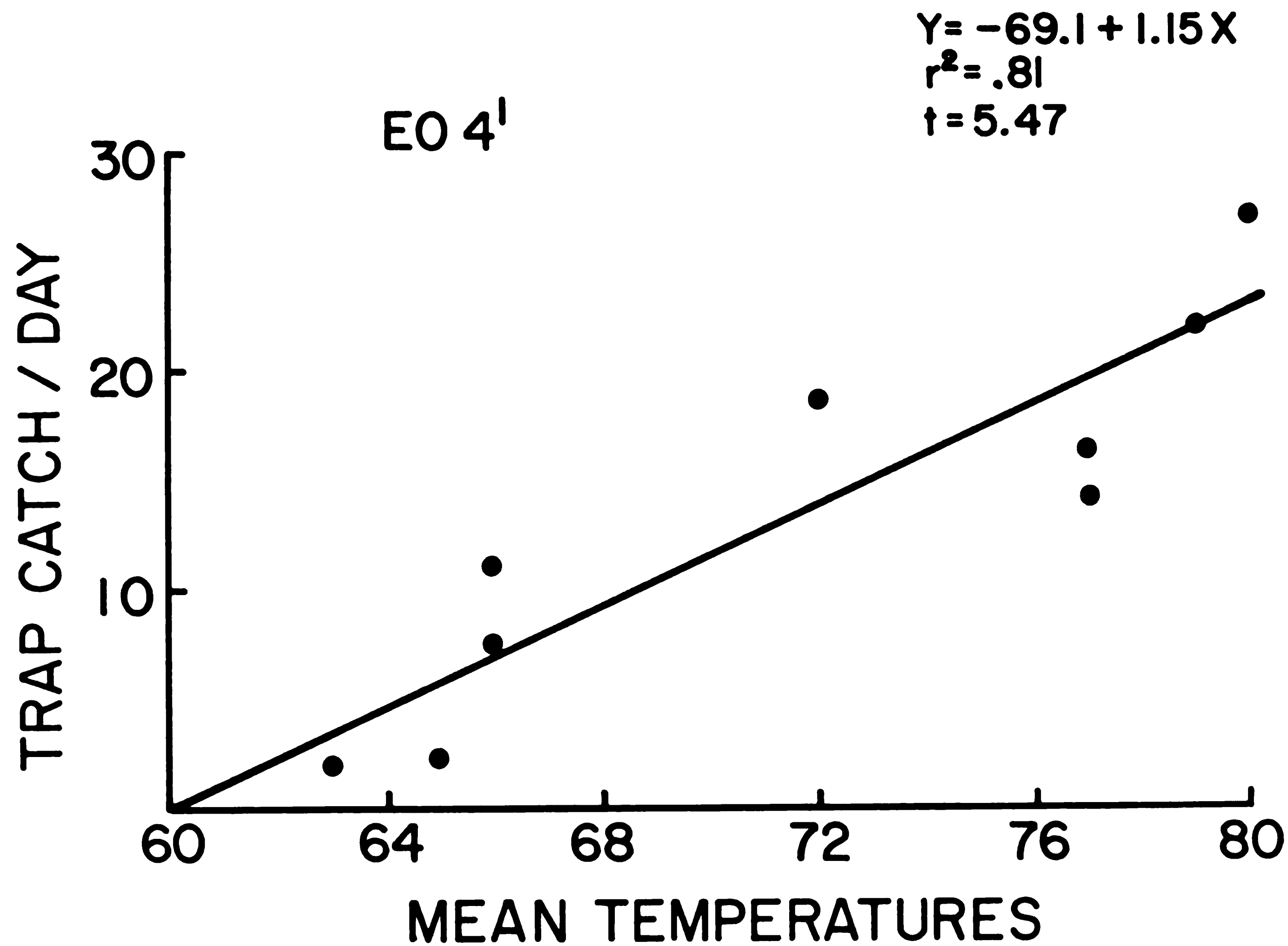


Fig. 13. The relationship between mean temperature during the trapping period and number of *T. julis* adults caught in a rotary flight trap four feet above early planted spring oats.

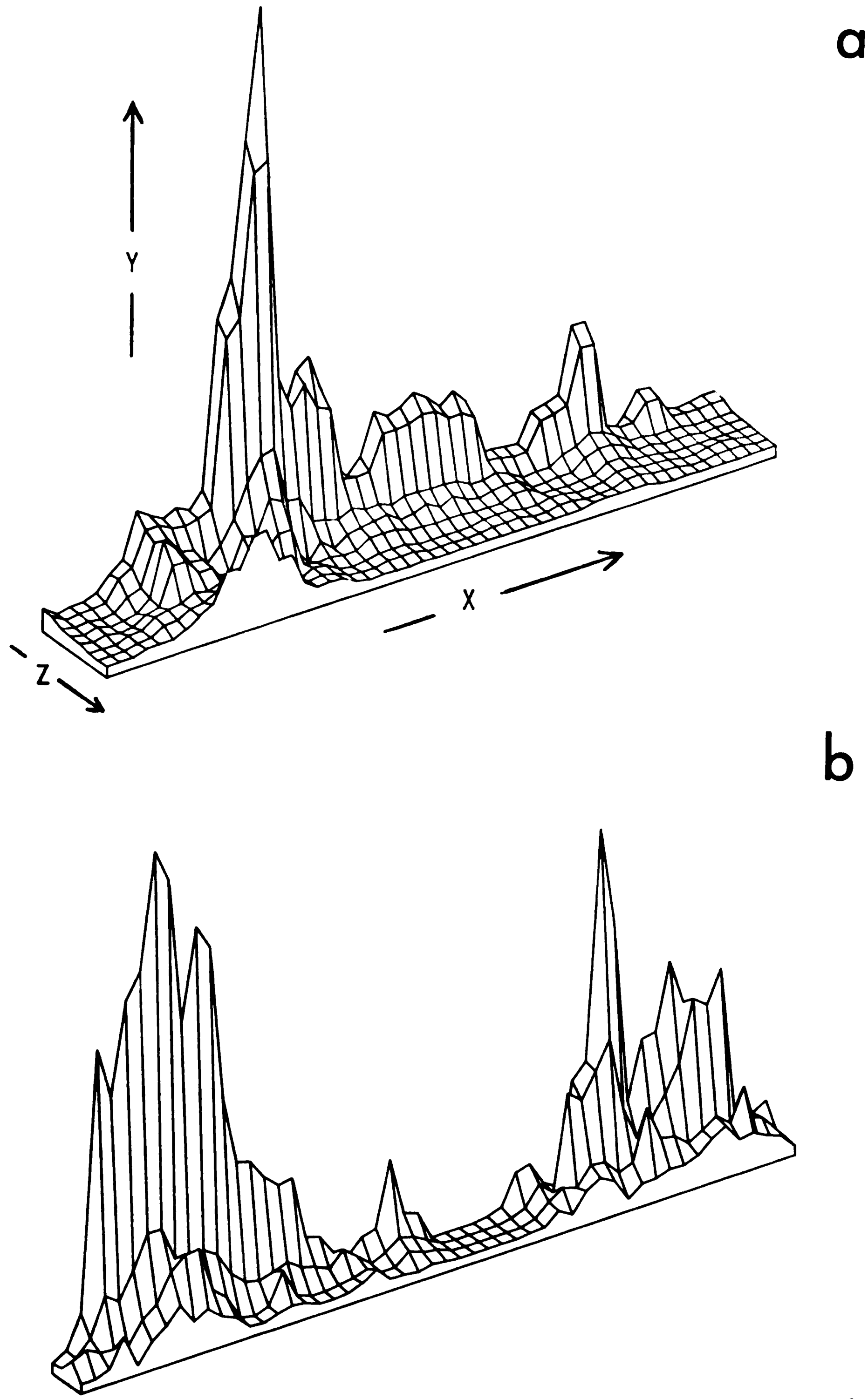


Fig. 14. A perspective view showing the influence of trap height (z) on the number of adult T. julis caught above oat stubble (y) during the first generation (x). Figure (b) shows a similar perspective of adults caught during the first and second generations above wheat and oats.

increases, catch decreases. A portion of the population of T. julis is trapped above the oat stubble and this component of the population is actively dispersing to nearby wheat or oat fields, or is being dispersed passively by wind to other areas. Figure 14b shows a similar relationship, but these data were obtained from within and above a wheat and oat field. In this case, the numbers caught represent the number of individuals moving through or above the crop and represent a component of dispersal or active searching, especially during the first generation when the population has moved from oat stubble, where it emerged, to the crop where hosts are located. The first and second generations of T. julis are well delimited in Figure 14b.

Attack behavior of T. julis. Observations in the field including time lapse photography led to the structuring of T. julis attack behavior from the time the adult female had detected its host and had selected the larva for potential oviposition until the attack was complete and the parasite left the host vicinity. I have divided attack behavior into five components: (1) approach, (2) mounting, (3) position selection on larva, (4) oviposition, and (5) dismounting and cleaning.

After a larva has been detected, the adult female may walk up and down the leaf on which the larva is feeding. Eventually the parasite approaches to within ca. 1/4 inch of the larva and remains motionless for about 5 minutes ($\bar{X} = 4.93 \pm 1.60$). During this time each antenna is moving alternately at about once per second. The body position may be changed during the approach period depending on whether or not the larva is moving as it feeds. After the approach period, the parasite attempts to mount the larva. Some larvae do not react to the mounting parasite while others lift their abdomen up and down while clinging to the leaf. During mounting, the parasite lifts her wings vertically over her thorax to avoid becoming stuck to the viscous fecal coat on the back of the larva. The avoidance reaction by the larva may discourage mounting and the parasite may dismount and return to the approach behavior condition on the same larva or may discontinue the attack and leave the area. If the mount is successful, the female positions herself to an area on the larva which minimizes disturbance by the abdominal movements of the larva. This position varies considerably. It may be on the back of the abdomen where movement is great, on the thorax just behind the head capsule, or on other locations such that the movements of the larva do not interfere with the act of oviposition. Oviposition takes place with wings held high over the thorax. The antennal movement during oviposition is slower and more deliberate than during the approach. Time needed to oviposit an average of 5.67 ± 1.84 eggs/larva is 18.8 ± 4.22 minutes. When oviposition is disturbed by larval movements, the act is discontinued and the female rarely continues any attack phase on the same larva. When oviposition is complete the parasite dismounts from the larva and moves several inches away from the larva. For several minutes the female cleans her antennae, wings, legs, and abdomen. A schematic diagram of these activities is summarized in Figure 15. Broken lines in the diagram represent disturbance of the activity, and the direction of flow represents the repetition of the behavioral components or abandonment of attack.

There are several factors which have been observed that cause attack abandonment or repetition of earlier behavioral components.

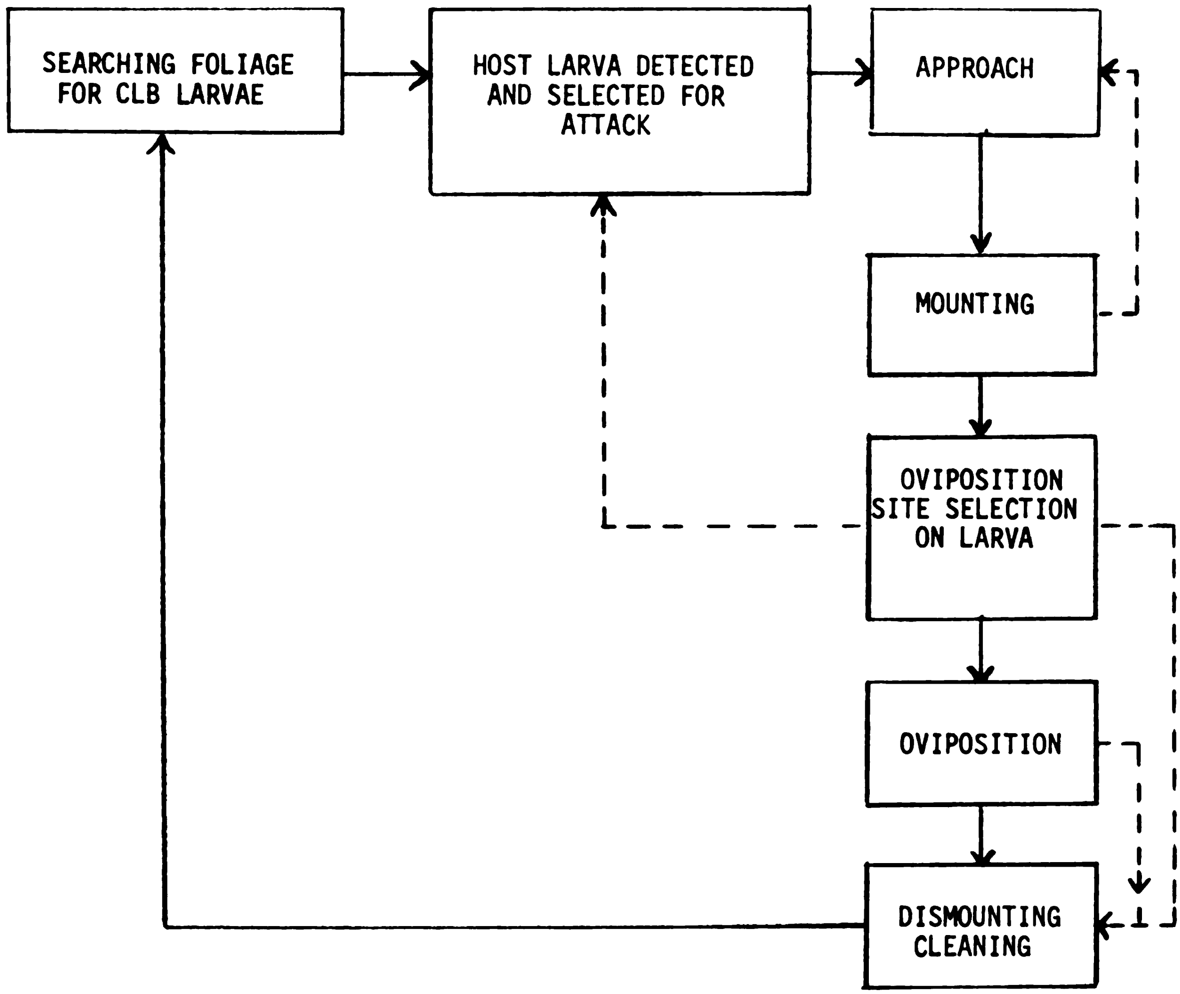


Fig. 15. A schematic representation of the principal components of attack by _T. julis_ females.

One of these, mentioned earlier, is the defence reaction (rapid abdomenal movement) by the larva. Unsuccessful attacks have also been observed when: leaf movement caused by wind touches the parasite while on the host, host drops to the soil or another T. julis female mounts the same larva.

Laboratory assessment of T. julis fecundity. The determination of fecundity, the rate of egg production, and the length of adult life of T. julis were studied using several methods. The behavior of this animal is not easily investigated in the laboratory because of constraints placed on its movement by the universe in which it is studied. In one set of studies, lantern globes placed over pots of barley on which CLB larvae were placed were used as the universe and adult T. julis were introduced and exposed to five hosts. Adult parasites were changed regularly but survival was low due to moisture buildup within the globes. In addition, the parasites generally spent most of the time on the gauze covering the top of the globe. To determine the proportion parasitized, the CLB larvae were allowed to complete development and pupate. This introduced an additional mortality source.

After testing several types of universes, the one giving the most satisfactory results was a 6 in. cylindrical cage made from Lumite screen with a diameter of 1 in. The top and bottom were plugged with removable pieces of sponge. A young barley plant was placed through a slit in through the bottom sponge. Three third instar CLB larvae were placed on the leaves, and mated adult T. julis were introduced. The cages were kept at 70° F and were placed in a rack over a shallow water pan into which the roots of the plant seedlings penetrated. At 2-day intervals the adult parasites were introduced to new larvae on fresh seedlings. CLB larvae were dissected and the number of eggs in each larva was counted. The following data are based on 17 females. Figure 16a shows the average numbers of eggs laid per day by females which remained alive at the time females were transferred to a fresh cage. All females were still alive by the tenth day. Egg production peaked on the eighth day reaching a maximum of 9.5 eggs/2 days/female and decreased until day 26 when only one female was alive, and she laid 2 eggs. The cumulative number of eggs laid per female is shown in Figure 16b where 50% of the eggs had been oviposited by the eighth day. Eggs laid per female decreased after day 8 and female survival decreased linearly after day 10 (Figure 16c).

The average longevity, eggs laid per day, and fecundity and range of each determined from the 17 females tested is summarized below:

Longevity (days)	18.18±1.30	(10-26)
Eggs/day/female	2.95± .29	(1.55-5.90)
Total eggs/ female	59.53±4.09	(28-84)

These data may not be definitive because of the small number tested and the possibility that a better universe exists. Fecundity estimates from earlier experiments indicated a maximum of 40 eggs per female; less than one-half of the maximum measured in these tests.

Incidence of diapause in *T. julis*. CLB larvae were collected from fields throughout the season and placed on flats containing host plants. After pupation, pupae were removed from pupation medium and individually placed in small petri dishes. Emerging adult parasites or beetles were counted and removed daily. After emergence was complete,

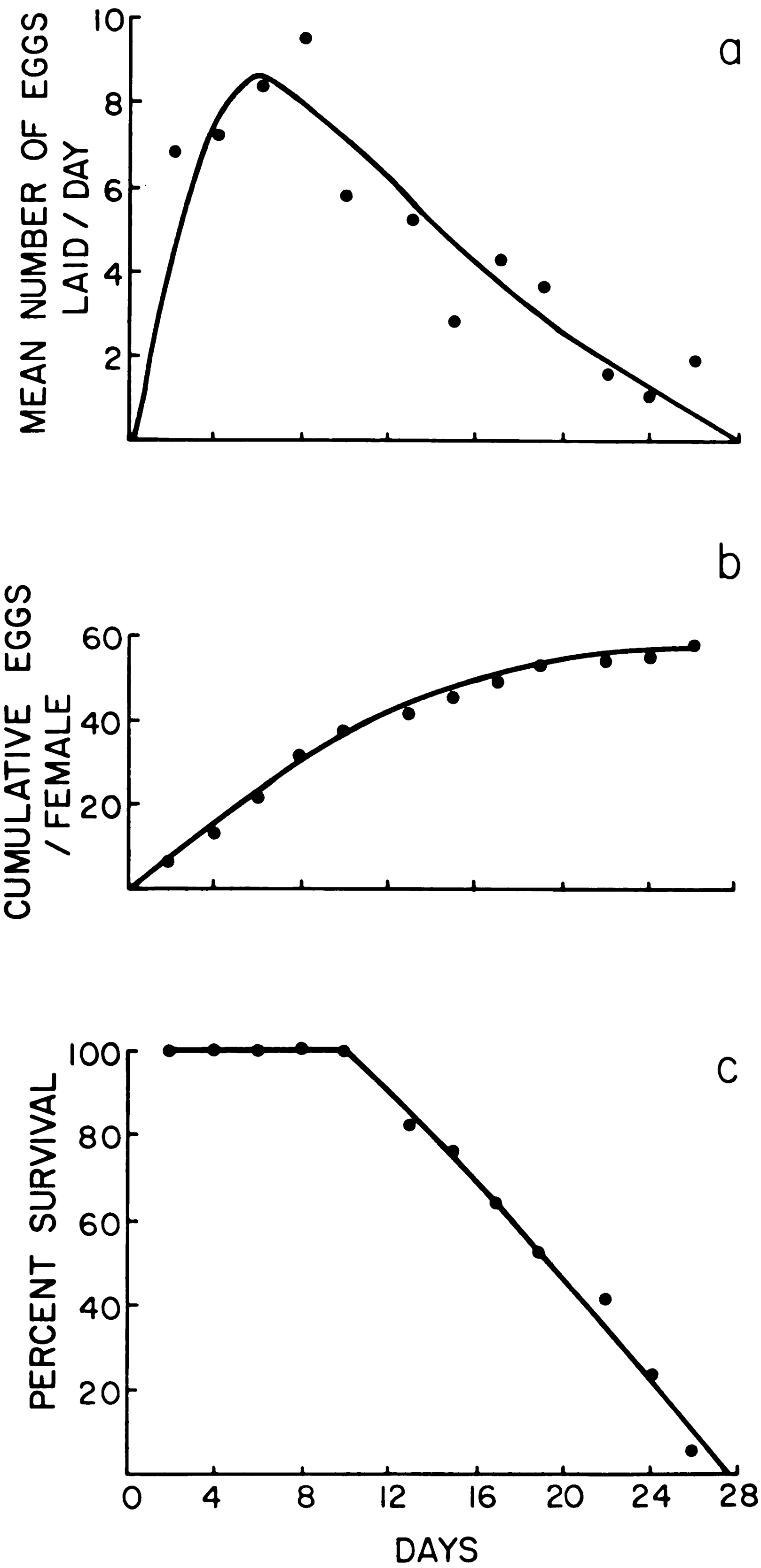


Fig. 16. The relationship between days and eggs laid per _T. julis_ female (a), cumulative eggs per female (b), and female survival (c).

the pupal cells were dissected to determine the cell content and the number of diapausing T. julis larvae was recorded.

Figure 17 shows the percentage of T. julis diapausing. Points prior to 650°D in Figure 17 result from larvae collected from winter wheat fields, and points after 650°D result from larvae collected from spring oats. This was because larvae are found first in winter wheat and later in spring oats.

It is also during this period when adults of the first generation of T. julis have completed attacking CLB larvae. Few T. julis adults are present during 650-800°D and the number of larvae being parasitized during this interval is low; therefore, an estimate of diapause is difficult during this time. There is an obvious switch from a relatively low proportion diapausing prior to 650°D to a high proportion entering diapause after 750-800°D.

There are several factors that may be responsible for the induction of diapause including the influence of photoperiod, the age of the ovipositing female, the number of eggs oviposited in a larva, etc. Probably, it is a combination of several factors. In several instances both diapausing and non-diapausing larvae have been found within the same CLB larva. It is not clear whether the female has control over diapause or as the number of larvae within a CLB larva becomes larger than some threshold, diapause is not induced.

Table 12 compares the number of non-diapausing and diapausing T. julis in CLB pupal cells collected at different dates during the field season. The number of individuals per cell averages consistently higher in non-diapausing T. julis. Table 13 compared the distribution of individuals within pupal cells where the laboratory reared individuals

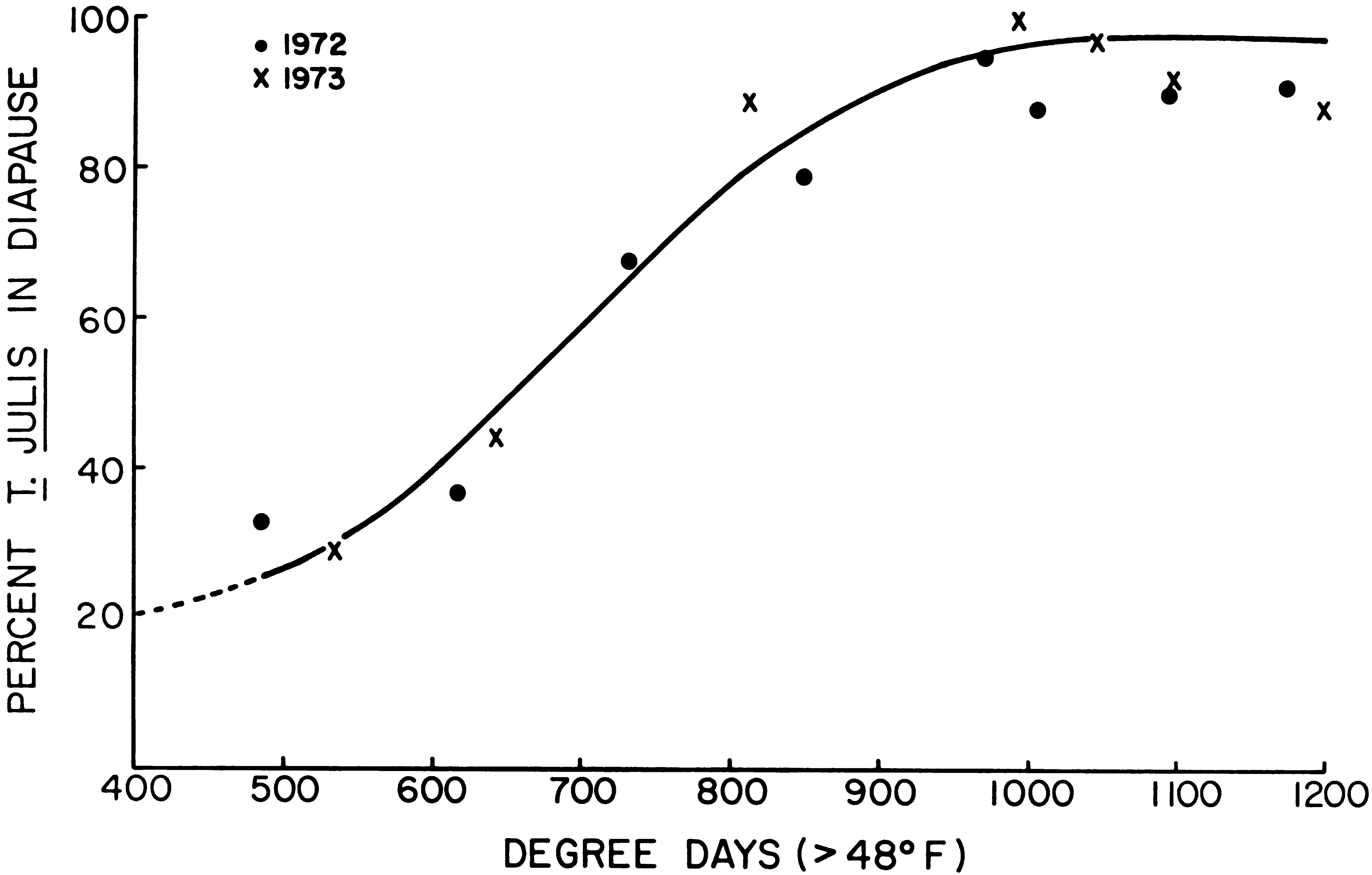


Fig. 17. Percent of _T. julis_ in diapause throughout the season.

TABLE 12: Comparison of the number of non-diapausing and diapausing *T. julis* in CLB pupal cells collected at different dates.

Collection date	°D_{48}	Crop	No. of *T. julis* per cell	
			Non-diapausing	Diapausing
5/27/72	486	W	8.50± .39 (58)*	4.60±.60 (10)
6/ 4/72	618	W	8.67± .43 (54)	4.43±.79 (7)
6/ 4/72	618	W	7.84± .20 (51)	5.50±.54 (10)
6/11/72	732	O	7.46± .37 (11)	5.00±.86 (6)
6/11/72	732	O	6.50± .62 (6)	4.67±.56 (6)
6/27/72	1003	O	6.75± .48 (4)	4.54±.36 (26)
6/27/72	1003	O	8.60± .74 (5)	3.89±.30 (36)
6/27/72	1003	O	6.40± .93 (5)	4.16±.24 (38)
7/ 1/72	1094	O	8.29±1.39 (7)	4.00±.42 (24)
7/ 6/72	1172	O	5.40± .81 (5)	3.63±.26 (27)
7/ 6/72	1172	O	8.00±2.58 (7)	3.97±.27 (30)
6/ 2/73	533	O	8.41± .65 (32)	5.80±.41 (13)
6/ 7/73	641	O	8.25± .66 (12)	4.91±.39 (11)
6/14/73	813	O	9.50±1.56 (4)	4.43±.36 (30)
6/21/73	991	O		4.19±.22 (48)
6/24/73	1044	O		4.94±.44 (32)
6/26/73	1095	O		6.08±.66 (24)
7/ 1/73	1194	O	8.33±1.20 (3)	6.46±.67 (22)

*Number of cells.

TABLE 13: Comparison of the percent frequency of *T. julis* individuals per CLB pupal cell from laboratory reared larvae (non-diapausing) with cells collected from the soil (diapausing).

No. per cell	1972		1973	
	Non-Diapausing	Diapausing	Non-Diapausing	Diapausing
1	0.0	4.0	0.0	1.4
2	1.1	6.3	0.0	5.8
3	2.2	16.5	0.0	8.7
4	2.6	15.9	10.3	17.4
5	9.9	23.3	10.3	30.4
6	17.6	20.5	12.1	17.4
7	20.1	10.8	19.0	11.6
8	15.8	1.1	10.3	2.9
9	9.9	0.6	15.5	1.4
10	9.2	0.6	6.9	0.0
11	3.7	0.0	1.7	1.4
12	2.2	0.6	5.2	1.4
13	2.6		3.4	
14	1.3		1.7	
15+	2.9		3.4	

are non-diapausing and the soil collected cells represent parasites in diapause. The highest percentage frequency occurs at 7 and 5 individuals per cell for non-diapausing and diapausing, respectively. This suggests the hypothesis that parasites may diapause when they are large and have sufficient reserves to enable survival throughout the winter.

Adults emerging from pupal cells vary in size depending on the number of individuals within the cell. To quantify this observation, the non-diapausing adults emerging from cells containing different numbers of parasites were measured. The measurements taken were total body length and head width. Figure 18 shows the regression of body length on a number of adults emerging per cell over a range of 4 to 23 adults emerging from single CLB pupal cells. Both male and female *T. julis* emerged from most of the cells and since a size difference was noted between sexes, Table 14 shows the mean body length (±SE) and head width of the parasites emerging from pupal cells. The regression equations for female and male parasites calculated separately are: female, $y = 2.28 - .042x$, $r = .74$, $n = 207$; and, male, $y = 1.82 - .028x$, $r = .62$, $n = 96$ where x is body length (mm) and y is the number of *T. julis* adults per cell.

Size of the individuals is related to the number within a CLB pupal cell, and these results could relate to the significance of the number per cell-diapause relationship stated earlier. This hypothesis was not tested but could proceed as follows: the overwintering parasite adults are larger and may lay more eggs per individual. The greater the number of eggs laid in a CLB larva, the less likely the progeny will enter diapause. The average size of the second generation of adults is smaller and they may lay fewer eggs, resulting in fewer

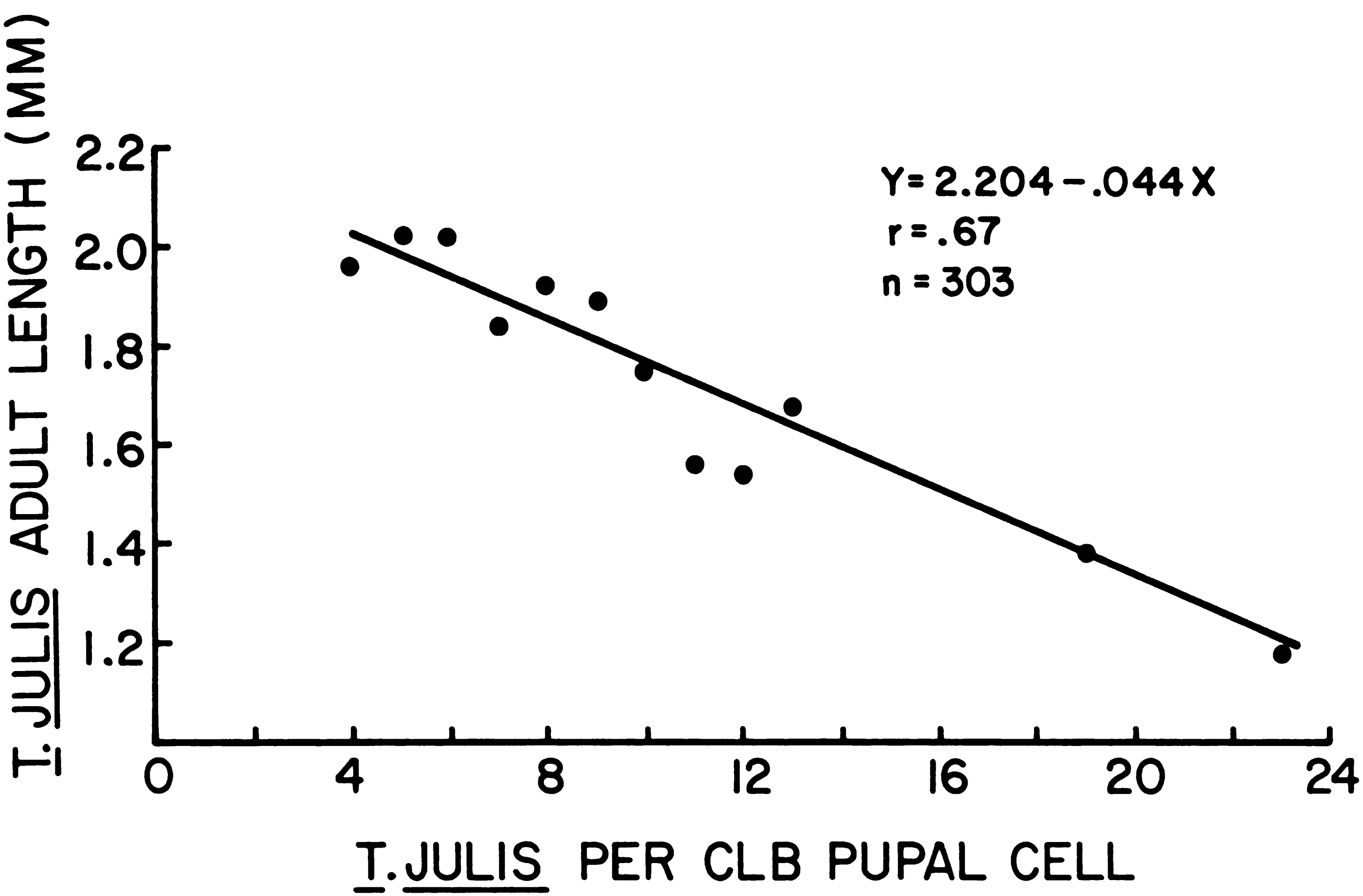


Fig. 18. The relationship between the number of *T. julis* per cereal leaf beetle pupal cell and adult *T. julis* body length.

TABLE 14: Mean length and width of female and male *T. julis* which emerged from cells containing different numbers of parasites ($\overline{X}$ ± SE(n)).

#/cell	Female			Male		
	L(mm)	W(mm)		L(mm)	W(mm)	
4	1.96±.02	.64±.01	(4)			
5	2.20±.06	.59±.01	(10)	1.63±.06	.51±.01	(5)
6	2.08±.06	.60±.01	(15)	1.71±.13	.54±.02	(3)
7	1.85±.04	.58±.01	(20)			
8	1.97±.03	.60±.01	(41)	1.62±.04	.52±.01	(7)
9	1.93±.03	.59±.01	(33)	1.77±.05	.54±.004	(12)
10	1.87±.02	.55±.01	(27)	1.54±.03	.48±.02	(13)
11	1.77±.03	.54±.01	(17)	1.34±.06	.43±.01	(16)
12	1.64±.04	.51±.01	(15)	1.37±.03	.45±.01	(9)
13	1.86±.03	.52±.01	(5)	1.57±.03	.48±.01	(8)
19	1.46±.02	.46±.01	(11)	1.27±.02	.44±.01	(8)
23	1.36±.03	.43±.01	(9)	1.22±.04	.39±.01	(14)

numbers of eggs per larva. Diapause would increase as CLB larvae would contain fewer parasites and each parasite may have more energy reserves to enable high overwinter survival.

No evidence of this mechanism was found in the literature. It is, perhaps, as likely that the female has control over diapause as suggested by Simmonds (1946) who found that as the female of a chalcid, *Spalangia drosophilae*, Ashm. (Spalangidae), grew older, there was a progressive tendency for more of her progeny to enter diapause, even though external conditions were kept constant. The importance of maternal origin and diapause was also noted by Saunders (1964) for the parasitic wasp, *Nasonia vitripennis*.

T. julis is a difficult species for studying this phenomenon in the laboratory because, usually, most of the first generation progeny enter diapause. This problem prevented mass rearing of *T. julis* for subsequent release and, until more research is completed which defines the factors controlling diapause, it is only feasible to define the proportion of diapausing parasites in the field.

Mortality of T. julis and CLB in the soil. In 1971, unusually high numbers of dead *T. julis* larvae and adults were found within pupal cells of the CLB. A large proportion of CLB prepupae, pupae, and adults were also dead within the cells. Table 15 summarizes the rainfall and heat ($°D_{48}$) accumulated during each month (April - July) for the years in which CLB population estimates were made (1967-1973). Note that rainfall was more than one standard deviation from the mean in April and June, 1971. Rainfall during May 1971 was also less than the mean, resulting in a dry period (April - June 1971) compared with

TABLE 15: Total rain (inches) and °D_{48} per month (April -July) for the years population density estimates were made for the CLB at Gull Lake.

Year	April		May		June		July	
	Rain	°D_{48}	Rain	°D_{48}	Rain	°D_{48}	Rain	°D_{48}
1967	4.73	151	2.34	250**	6.03	667	2.88*	669**
1968	2.95	178*	3.25	284	6.59*	608	5.37	727
1969	4.95	157	2.79	369	5.60	492**	4.47	759
170	3.45	164	4.09	442*	3.62	619	5.87**	768
1971	1.14**	135	2.33	328	1.63**	747*	5.64	700
1972	3.39	104**	3.79	421*	2.70	528**	4.94	721
1973	3.71	143	6.06*	275	3.63	667	3.76	770*
$\overline{X}$	3.48	148.0	3.52	338.4	4.26	618.3	4.70	730.6
SD	1.26	23.4	1.31	74.6	1.85	87.1	1.08	37.9
$\overline{X}$-SD	2.22	124.6	2.21	263.8	2.41	531.2	3.62	692.7
$\overline{X}$+SD	4.74	171.4	4.83	413.0	6.11	705.4	5.78	768.5

* > 1 SD.

** <1 SD.

the other six years. The accumulated $^{\circ}D_{48}$ during June was greater than one standard deviation above the mean, indicating that June 1971 was hotter than the other six years. Figure 19 shows the maximum average air temperature for 1967-1973 and the maximum air temperature in 1971. Total CLB larvae are indicated by the open circles. The period during June 1971 which was most detrimental to survival in the soil was between June 16 and June 30 when temperatures were above 85° F. Soil temperatures were measured at 2 inches in the oat crop from 4 p.m. on June 28 until 4 p.m. on June 30, during the period of highest maximum air temperature. Soil temperatures reached 119, 118, and 114° F on each of the three days.

Table 16 summarizes the percent mortality of CLB and *T. julis*. Accumulated $^{\circ}D_{85}$ is used as an index of heat causing mortality in the soil. However, without the combination of low rainfall and high heat, mortality would probably not have been as severe. Rainfall during April and May may also have to be taken into account because of potential stress placed on the host plant. The resulting poor food quality may also have been a factor contributing to low pupal survival.

The effects of manipulating the soil on *T. julis*. Some of the treatments used in this study are important from the perspective of farm management practices, whereas others are useful in determining, from a research standpoint, which treatments enhance or decrease survival of *T. julis*. For example, it is quite common to plow oat stubble to prepare the land for seeding to another crop like corn, winter wheat, or alfalfa because this is an accepted agricultural practice. Alternately, it is unlikely that a farmer would cover oat stubble with

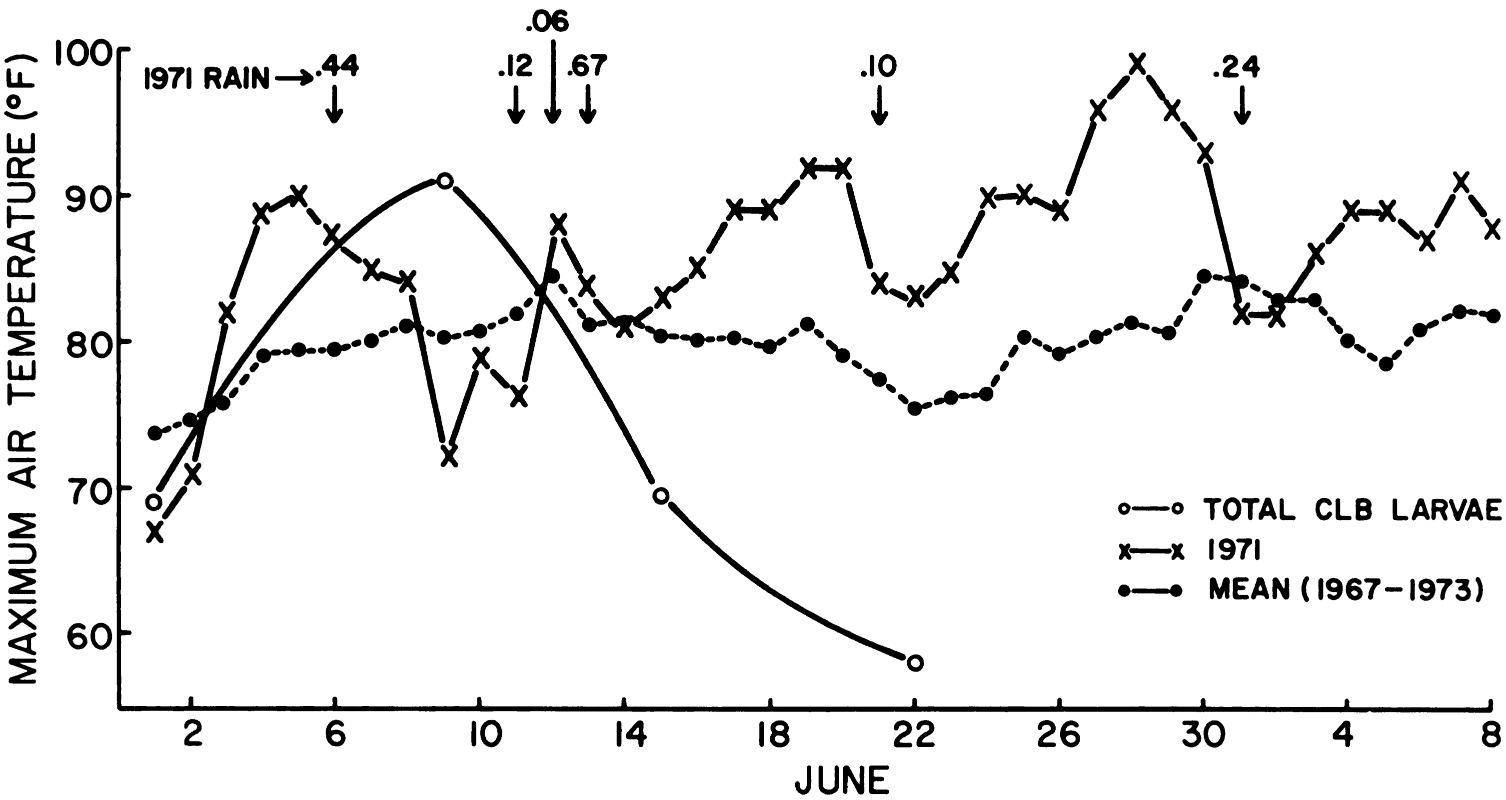


Fig. 19. Maximum daily air temperature during June and early July 1971 (x) compared to the average daily maximum, 1967-1973.

TABLE 16: Percent mortality of CLB and *T. julis* determined from examination of pupal cells collected from oat fields at Gull Lake.

Year	$°D_{85}$[1]	Rain[2]	Percent mortality CLB	Percent mortality *T. julis*	n[3]
1970	3	3.62	15.4	--	10
1971	23	1.63	49.2	58.9	12
1972	0	2.70	10.3	6.7	9
1973	1	3.63	6.0	2.1	12

[1]Accumulated $°D_{85}$ by June 30.

[2]Inches during June.

[3]Number of fields sampled.

clear plastic. However, such manipulations enable control over the time of *T. julis* emergence in the spring, depending on the degree to which the soil was heated. From such information, the previous section showed how some of these treatments affected the time of emergence. (These emergence curves were standardized to cumulative percent for comparative purposes). This section shows to what degree the various treatments affected the number of individuals per yd^2.

Table 17 shows the number of *T. julis* trapped. In 1971, the density per yd^2 in each treatment can be compared to the standard or natural stubble from which the parasites normally emerge. Here, some qualifying statements are necessary to explain the different methods used in the 3 years. In 1971, the clear plastic was placed over the stubble on April 9, whereas in 1973, the clear plastic was placed over the stubble in November 1972. Therefore, the clear plastic had a different effect in each year. The opposite was done for black plastic. In 1971 and 1973 the black plastic was placed over oat stubble in November; but, in 1971, the black plastic was spread over late oat stubble and in 1973 it was spread over normally planted oat stubble which produces more parasites. Examination of these data (Table 17) shows differences in the number of parasite adults trapped from oat stubble which was plowed and disked and untreated oat stubble. In 1971, about 81% of the parasites were killed by plowing and disking the soil; in 1972, 89% were killed. In 1973, a surprising number of adult *T. julis* were trapped from the black plastic treatment compared to the other treatments. The biological or physical reason for this is not apparent but this treatment obviously protected the parasites from overwintering mortality. In addition, advanced emergence of

TABLE 17: Mean number of *T. julis* adults per yd^2 trapped from different oat stubble treatments ($\bar{X}$ ± SE).

Year	Treatment	Female	Male	Σ Female, Male	n
1971	Control stubble	15.2±4.0	3.8±1.1	19.0± 5.0	12
	Straw	14.3±8.5	4.3±2.3	18.7±10.7	3
	Snowfence	15.7±6.8	3.3± .3	18.0± 7.8	3
	Mowed	22.0±7.9	8.7±3.5	30.7±11.4	3
	Clear plastic	14.0±4.0	3.3±2.3	17.3± 6.2	3
	Plowed-disked	3.7± .7	0.0	3.7± .7	3
	Winter wheat	3.7±1.8	4.0±2.6	7.7± 4.2	3
	Black plastic	6.0±3.5	1.3± .9	7.3± 4.1	3
1972	Control stubble	14.4±5.2	4.7±1.5	19.1± 6.4	11
	Straw	16.6±4.4	1.0± .4	17.6± 4.8	5
	Plowed-disked	2.2±1.4	0.0	2.2± 1.4	5
1973	Light manure	16.8±3.5	4.1± .8	20.9± 4.1	10
	Heavy manure	9.4±1.9	2.7±1.0	12.1± 2.6	10
	Straw	6.7±3.2	2.5± .5	8.3± 3.9	3
	Clear plastic	1.7± .7	1.0± .6	2.7± .9	3
	Black plastic	33.3±8.4	13.7±1.8	47.0± 9.6	3

T. julis did not occur from the black plastic treatment as it did from clear plastic covered oat stubble.

Another factor, which was not controlled but has implications from practical management of oat stubble, was the application of manure onto the oat stubble in 2 adjacent fields which had similar overwintering parasite population densities as measured in July (79.4 and 75.4 diapausing T. julis larvae per yd^2). Emergence, measured in the spring of 1973 and labeled light and heavy manure (Table 17), indicated that this treatment had an effect on total emergence.

Local differences in the distribution of T. julis within a field may account for the difference in number of parasites caught but the most important treatment, in view of practical management, is that of plowing the stubble and preparing it for another crop. This practice has serious implications because it increases T. julis mortality significantly and must be carefully considered in any management plan for CLB populations if biological control using larval parasites is to be one of the options.

Cereal leaf beetle larval population trends at Gull Lake 1967-1973). This section describes the general population trends of CLB larvae during all years that populations were measured at Gull Lake. In addition, the synchrony of these populations is also examined because of the importance of timing in a pest management strategy with respect to cultural control, pesticide applications, the release of biological control agents, sampling, and other practices useful for measuring and manipulating CLB populations. T. julis was released in 1967 but was not recovered until 1969. Therefore, the examination of these population densities before and after the buildup of T. *julis* is useful to help determine the effect of this parasite.

Population densities of cereal leaf beetle larvae have been measured in specific areas at Gull Lake between 1967-1973. Helgesen and Haynes (1973) developed a within-generation population dynamics model for the years 1967-1969 and the Gull Lake site was included in this analysis. Their model showed density dependent mortality in the fourth instar in winter wheat, and the first and fourth instar in spring oats. Gage (1972) presented the dynamics of larval feeding using CLB population data from Gull Lake.

Estimates of the population densities (1967-1969) were made by pre-selecting a winter wheat and spring oat field and dividing the field into 10 sub-plots Helgesen (1969). Within each of these plots a number of two linear ft. sub-samples were clipped at the soil surface from the grain rows, placed in plastic bags and taken to the laboratory for counting and instar determination. Eggs and larvae were counted and the number of samples taken from each crop depended on a combination of CLB density and resources. The number of samples within a field ranged between 15 and 30; the number of days within a year at which samples were taken ranged between 5 and 16.

To determine the synchrony of the egg and total larval populations, the mean densities at each time sampled were plotted over $°D_{48}$ (Figure 20a-b). The initial, peak, and end points of each curve for eggs and total larvae were estimated from CLB population estimates made in Spring oats (1968-1973). Table 18 shows the $°D_{48}$ at which first, peak, and last eggs and larvae of the CLB occurred. If sampling was not initiated early enough or continued late in the season, the lines

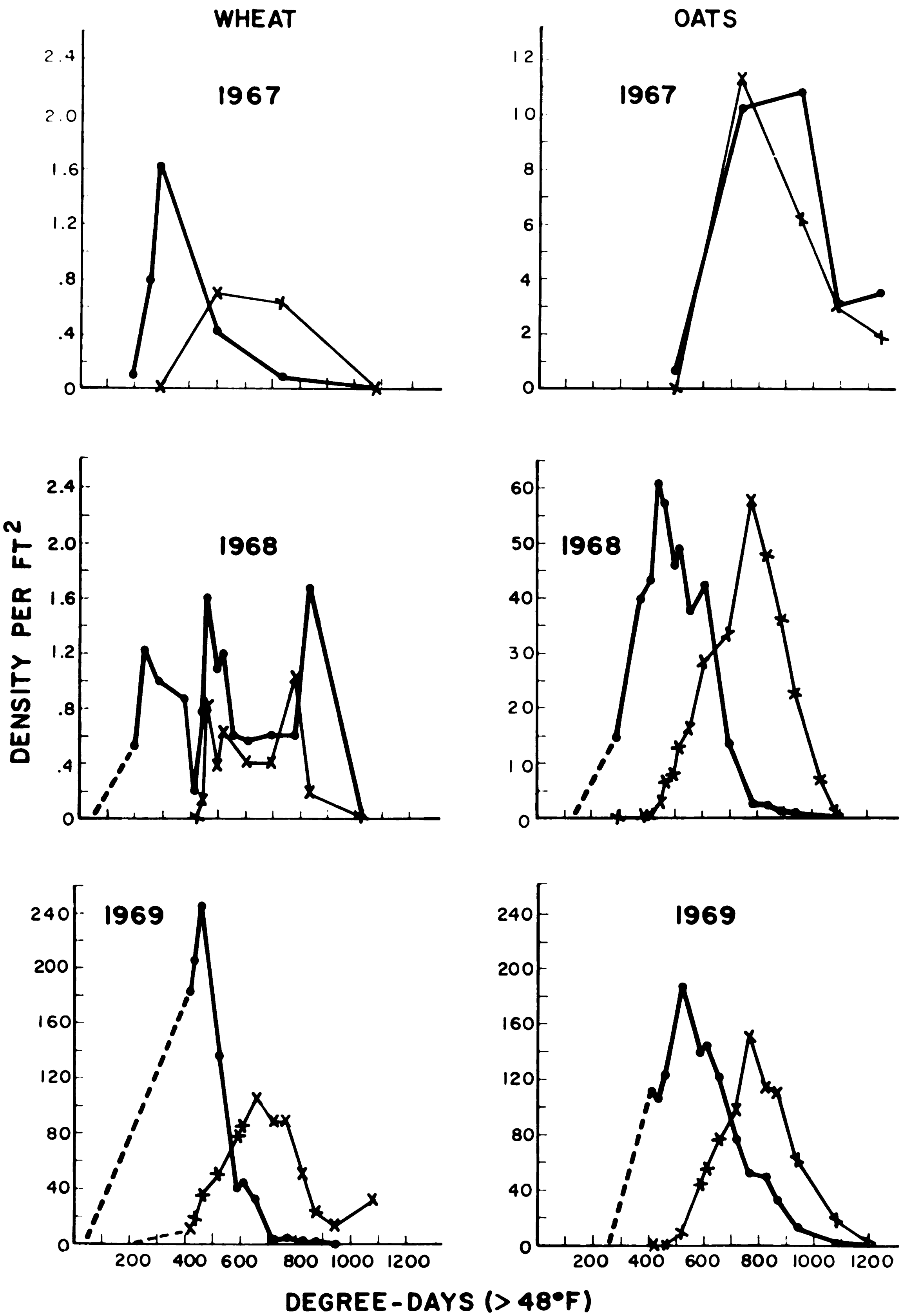


Fig. 20a. Cereal leaf beetle egg and total larval densities in winter wheat and spring oats, 1967-1969.

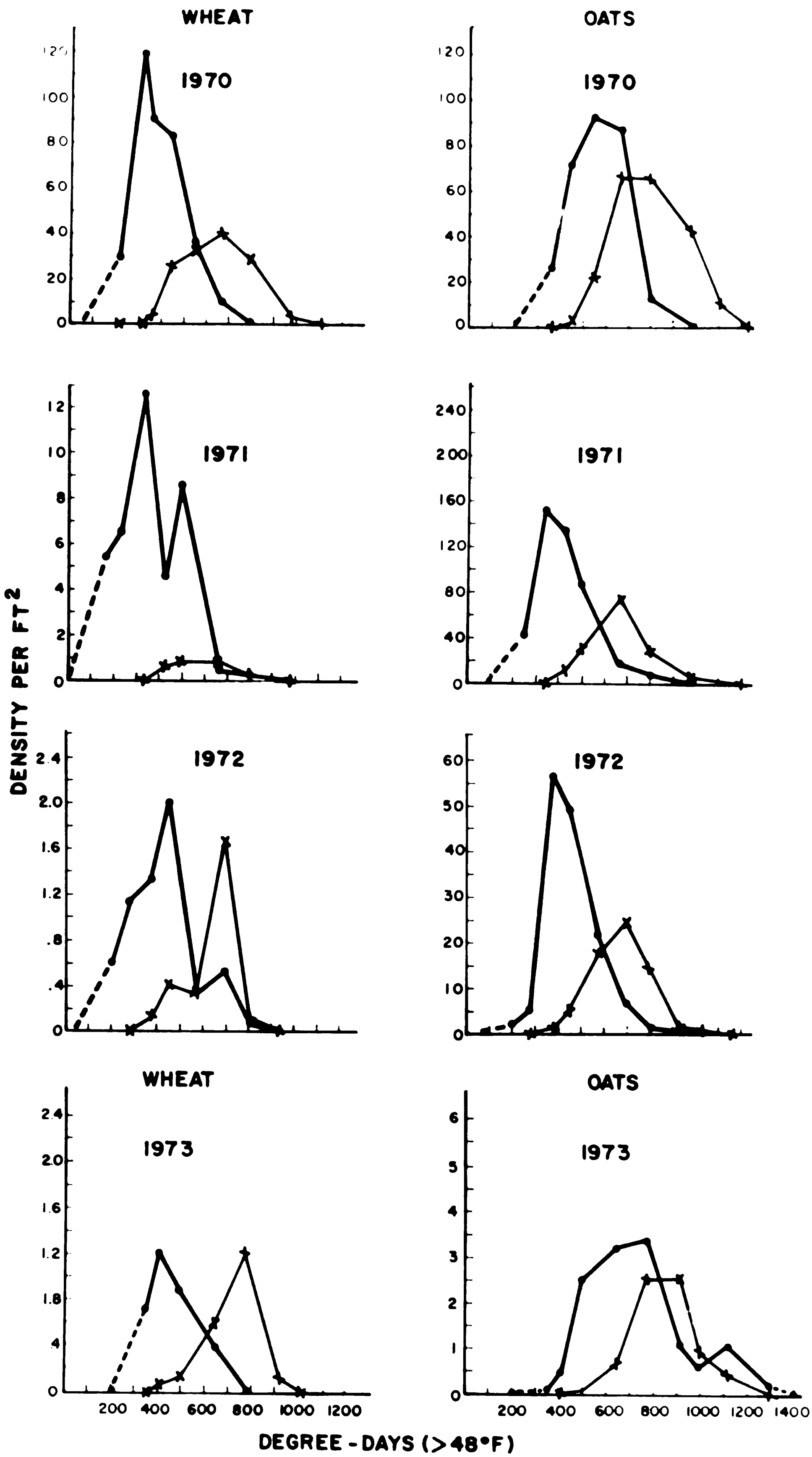


Fig. 20b. Cereal leaf beetle egg and total larval densities in winter wheat and spring oats, 1970-1973.

TABLE 18: The initial, peak, and last CLB egg and larval populations in spring oats with respect to $^{\circ}D_{48}$.

Year	Area	Spring Oats					
		Eggs			Larvae		
		First	Peak	Last	First	Peak	Last
1967*	9--E**						
1968	9--E	200	441	1000	400	780	1150
1969	9--E	256	519	1100	425	767	1225
1970	9--E	225	546	990	400	750	1225
1970	8--E	200	550	1000	400	790	1225
1971	9--E	150	330	970	350	660	1200
1971	5--E	172	425	1100	350	660	1300
1971	8--E	172	330	1100	350	590	1200
1972	9--E	100	380	1000	300	690	1150
1972	9--L	150	450	1100	375	690	1200
1973	9--E	300	700	1200	400	850	1300
$\bar{X}$±SE		193±18	467±36	1056±24	375±12	723±25	1218±16

*Insufficient number of times sampled.

**Numbers refer to management plan maps in Figure 4 and E or L specifies early or late planting of the crop.

were extrapolated to the initial and/or end points. The means ($°D_{48}$) from Table 18 provide estimates of $°D_{48}$ for sampling CLB eggs and larvae in spring oats, or for manipulating the population in various ways depending on management objectives. Differences in $°D_{48}$ accumulated before eggs or larvae are in the field may tend to cause variability between years (i.e., $°D_{48}$ accumulated during March). Peak to peak differences reduce the variability but are not particularly useful for predicting when to begin sampling the populations.

To quantify the seasonal population densities of eggs and larvae (Figure 20) the area under each of the population curves was determined by calculating the area between each sampling point and summing these areas for the season. The approximation used for determining each component area was Simpson's Rule (Crowe and Crowe 1969). The result from this integration gives the total number of individuals for the season on a $°D_{48}$ basis. To correct for the developmental time of an egg or a larva, the total area was divided by the appropriate number of $°D_{48}$ necessary for an individual egg ($160°D_{48}$) or all larvae ($220°D_{48}$) to complete development. This technique was given in Southwood (1966) who coined the term "total incidence method" for the analysis. The total area under the curves of eggs and larvae sampled at successive degree-day intervals during the season, divided by the appropriate developmental times, gives the number of eggs and larvae produced per ft^2 during the season (Ni).

$$Ni = \frac{\text{total incidence}}{\text{developmental time}} = \frac{\int_{t_i}^{t_n} D(x)\ (dx)}{\text{developmental time}}$$

where Ni is the number of individuals produced, t_1 to t_n are the times at which the population was sampled, d_x is the number of individuals at each sample time, and developmental time is the number of degree-days it takes an individual to pass from one stage to the next at some threshold temperature. To define the population curves of eggs and larvae it is necessary to sample at frequent intervals throughout the season. This is useful to examine synchrony of the populations in different crops, etc., but not practical if many fields in many different areas must be sampled. However, if eggs and larvae can be sampled during peak densities, the total incidence can be predicted. Results from the analysis of CLB density measurements taken in a field of winter wheat and a field of spring oats each year from 1967-1973 in section 9 at Gull Lake are graphed in Figure 20a and 20b. Calculations made on these data are presented in Table 19a. Peak population densities occurred in 1969 for both spring oats and winter wheat, and only in 1969 did densities of eggs in wheat occur in greater numbers than in spring oats. Larval population densities have been decreasing since 1969 and have reached densities in 1973 below those in 1967 when densities were first measured at Gull Lake. These population data are given in Helgesen (1969) for 1967-1969 and in Gage (1972) for 1970. Appendices I-VI summarize the CLB population data collected during this study (1971-1973). Changes in larval population densities are expressed in column I_L in Table 19a which is calculated by:

$$I_L = NL_{(t+1)}/NL_{(t)}$$

where I_L is an index of the change in larval density, NL is the number of larvae per sq. ft., and t is time in years. The trend in larval density has been generally decreasing in oats but erratic in wheat, especially between 1968-1969 when larval densities increased 140 fold.

TABLE 19a: Population density in spring oats and winter wheat per ft^2 per season of CLB eggs and larvae (total area under seasonal population curve ÷ developmental time), trend index of larval density ($NL_{(t+1)}/NL_{(t)}$) and the ratio of eggs per ft^2 to larvae per ft^2 in the same section in different years at Gull Lake.

Year	No. Samples	Ft^2 sampled	Eggs/ft^2	Larvae/ft^2	I_L	$\frac{Larvae/ft^2}{Eggs/ft^2}$
			Spring Oats			
1967	5	30	31.7	19.4		.612
					3.97	
1968	16	30	110.0	77.1		.701
					2.57	
1969	13	30	378.6	197.9		.523
					0.66	
1970	8	30	203.4	130.2		.640
					0.74	
1971	7	15	275.0	95.9		.349
					0.35	
1972	10	15	86.8	33.7		.388
					0.12	
1973	9	30	10.1	4.0		.396
			Winter Wheat			
1967	6	30	2.7	1.4		.519
					0.86	
1968	14	30	4.5	1.2		.267
					140.4	
1969	12	30	412.8	168.5		.408
					0.43	
1970	8	30	198.1	72.6		.366
					0.02	
1971	8	15	24.1	1.4		.058
					1.00	
1972	6	15	3.7	1.4		.378
					0.86	
1973	6	30	2.0	1.2		.60

Densities of eggs and larvae are shown graphically in Figure 20a and 20b and the larval trend index I_L is shown in Figure 21. The ratio of total eggs to total larvae (S_L) is shown in Figure 22.

Figure 23 illustrates the changes in egg and larval densities in oats in the phase plane by plotting successive densities (total incidence) over the following year's estimate. The trajectory of the population is in the direction of the arrows on the lines in Figure 23. This illustration is useful in depicting the course of the densities from 1967-1973. The level of the CLB density in 1972-1973 is at its lowest point since sampling began and the next few generations will determine if the CLB will respond positively (densities will increase) or not. A positive response is indicated by egg densities from 1970-1971 but this response was not reflected by the larval population which responded negatively during the same time interval.

Population densities were measured in different areas at Gull Lake within the same year. A similar analysis was performed on these data to enable comparisons within years to show differences or similarities in density between fields with a year (Table 19b). One feature which is significant is the low larval/egg ratio in 1971 compared to years preceeding 1971 for oats and in all years for wheat (Table 19a). An attempt to explain this is important because mortality due to parasitism by T. julis does not occur during the larval stages but during pupation; and T. julis was operating in 1971. Theoretically, four factors could cause unusually high mortality of the CLB in the larval stage: (1) lack of food, (2) environmental phenomena (e.g., extreme heat), (3) high egg mortality, or (4) changes in population quality. Because densities were higher in earlier years with a correspondingly

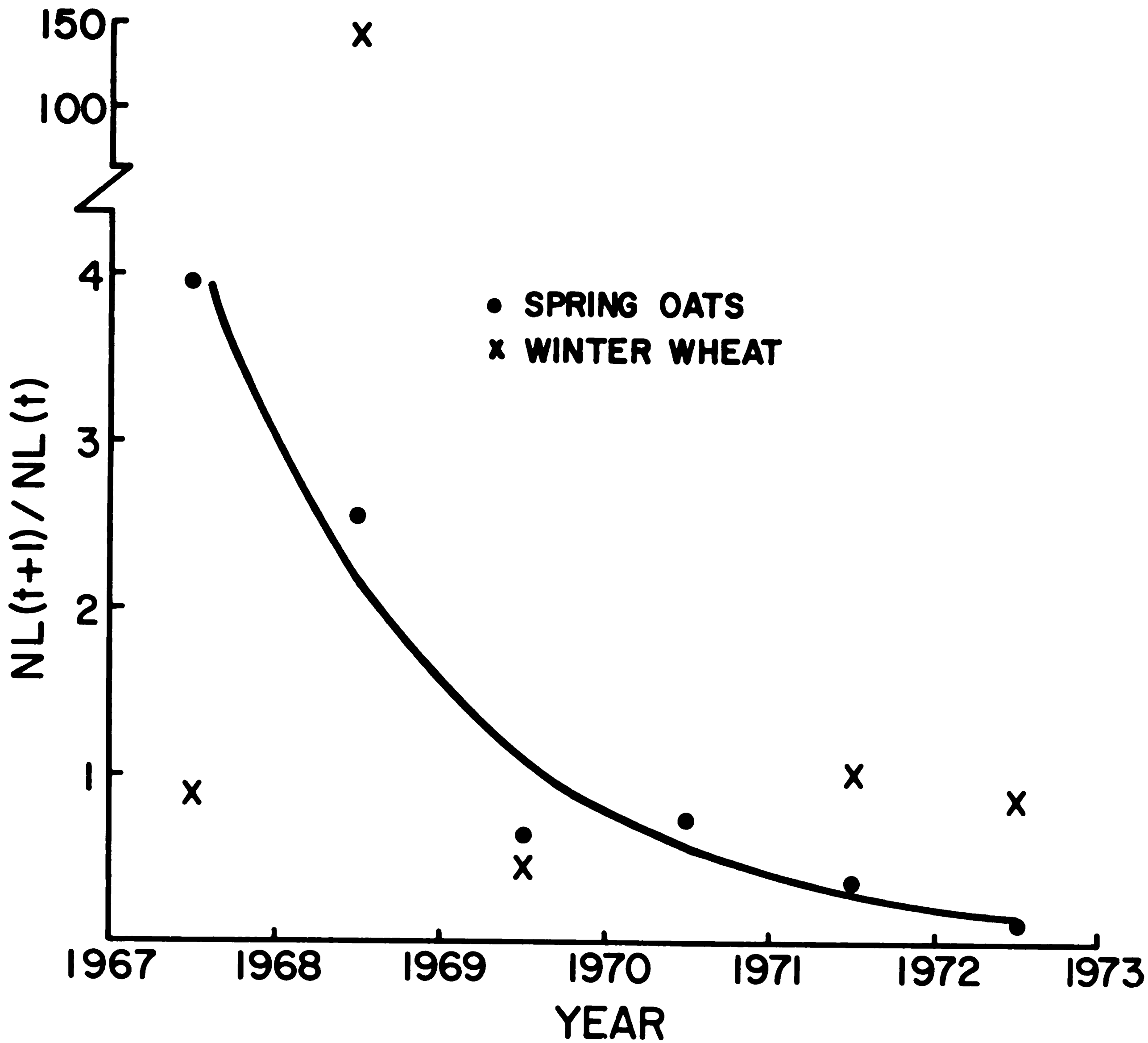


Fig. 21. Cereal leaf beetle larval trend index in winter wheat and spring oats.

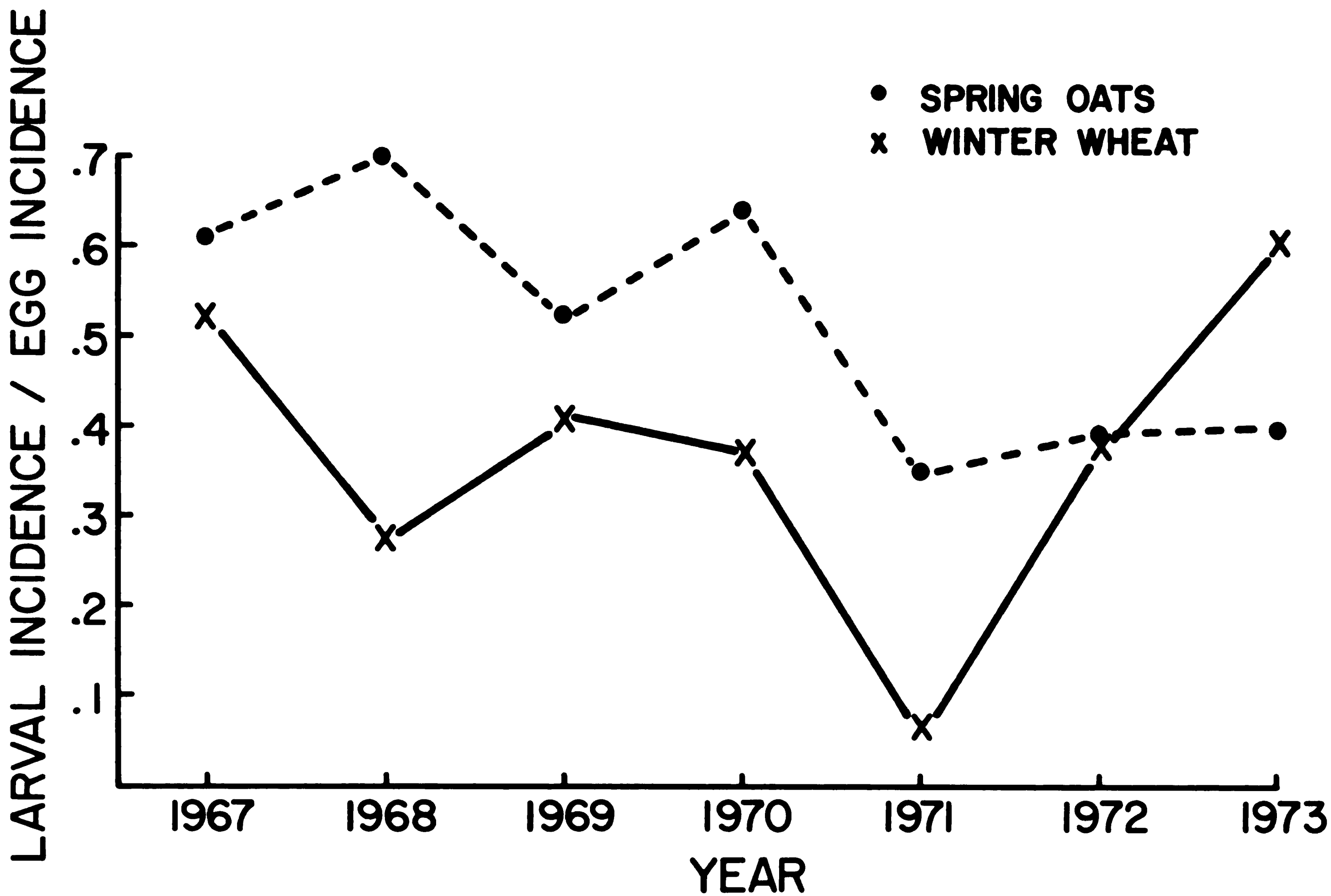


Fig. 22. Ratio of cereal leaf beetle larval incidence to egg incidence in winter wheat and spring oats.

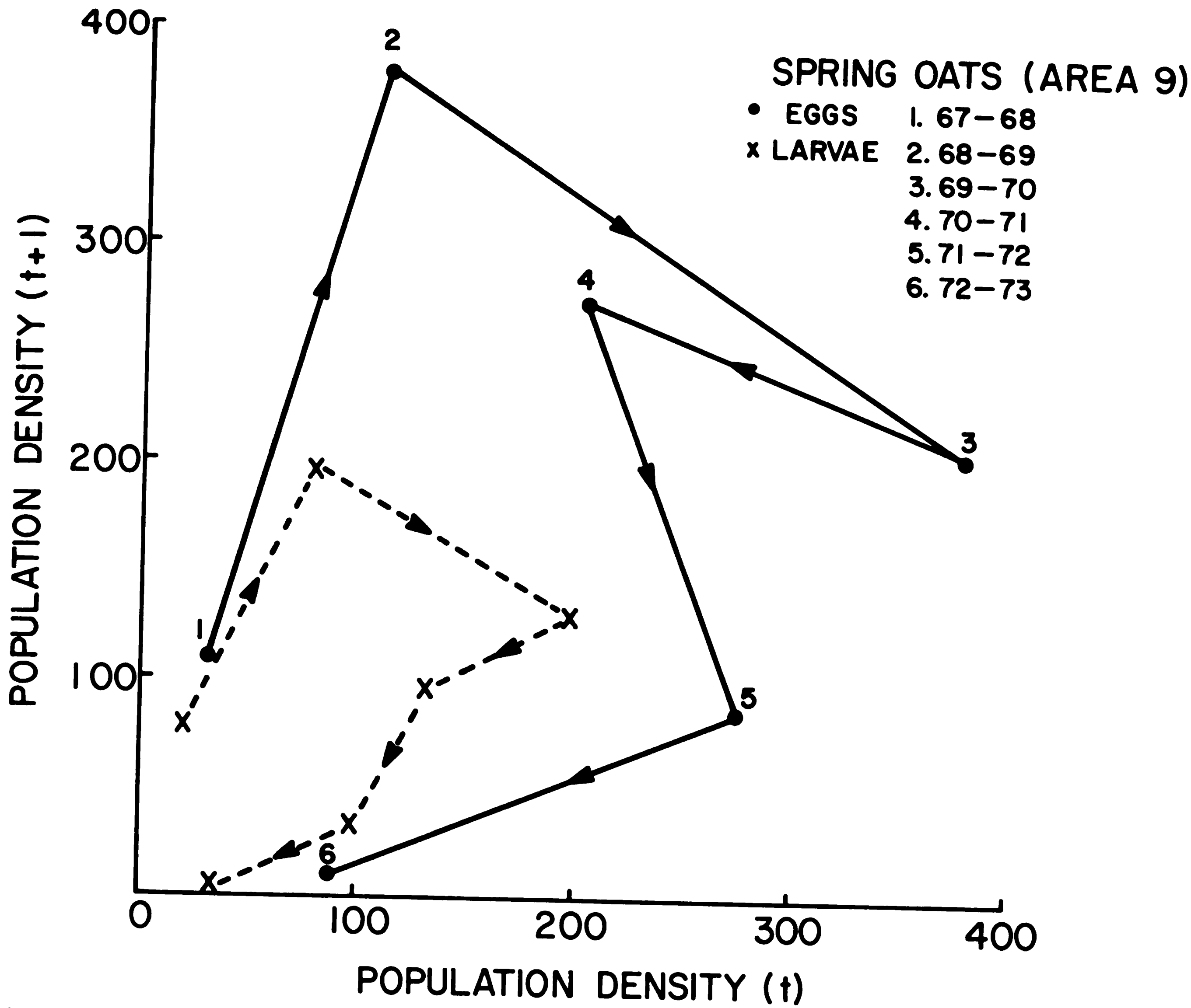


Fig. 23. Phase plot of cereal leaf beetle total egg and larval density per ft^2 in spring oats, 1967-1973.

TABLE 19b: Population density in spring oats and winter wheat per ft^2 per season of CLB eggs and larvae (total area under seasonal population curve ÷ development time) and the ratio of eggs per ft^2 to larvae per ft^2 in different sections and years at Gull Lake.

Year	Area	Eggs/ft^2	Larvae/ft^2	$\frac{Larvae/ft^2}{Eggs/ft^2}$
		Spring Oats		
1970	9	203.4	130.2	.640
1970	8	368.1	199.4	.542
		Winter Wheat		
1970	9	198.1	72.6	.366
1970	8	211.6	112.1	.530
		Spring Oats		
1971	9	275.0	95.9	.349
1971	8	86.0	30.2	.351
1971	5	125.7	50.3	.400
		Winter Wheat		
1971	9	24.1	1.4	.058
1971	8	19.3	2.5	.130
1971	5	10.8	1.2	.111

higher larval survival, food alone is not likely the cause of the high mortality in 1971. High egg mortality had not been observed and Helgesen and Haynes (1972) indicated that egg mortality was constant. These factors, especially environmental phenomena and changes in population quality, need to be investigated thoroughly in subsequent research programs.

Regional surveys are an important component of population studies on the CLB. Since densities of the CLB were measured several times during each season for a number of years in both winter wheat and spring oats at Gull Lake, it is useful to consider relationships which would enhance predictability of the occurrence of the CLB regionally, and enable prediction of total incidence from surveys of peak population density. This data could then be applied to regional survey data where sampling occurs less frequently. At the present time, attempts are being made to develop techniques for sampling peak larvae through use of on-line weather data. From such an estimate, seasonal CLB larval population curves can be constructed (Fulton personal communication). To test the ability to predict total incidence from peak density, 25 different populations of eggs and larvae in spring oats and winter wheat at Gull Lake (Table 20) were tested using this hypothesis. The relationships were linear and significant.

$$\text{Egg Incidence} = 3.51 + 1.85\ (\text{peak eggs}) \quad r^2 = .98$$

$$\text{Larval Incidence} = 1.63 + 1.51\ (\text{peak larvae}) \quad r^2 = .96$$

Although the total numbers of eggs and larvae are highly predictable from the respective peaks, the value of this predictability in a control-management strategy is questionable because by the time peak larvae are determined, damage has already been done. However, the

TABLE 20: The relationship between peak egg and peak larval density per ft^2, and the corresponding total incidence of eggs and larvae per season in spring oats and winter wheat at Gull Lake.

Year	Section	Age	Peak egg density	Egg incidence	Peak larval density	Larval incidence
			Spring Oats			
1967	9	E	10.8	31.7	11.3	19.4
1968	9	E	60.7	110.0	57.7	77.1
1969	9	E	185.7	378.6	152.0	198.0
1970	9	E	91.7	203.4	65.2	130.2
1970	8	E	176.6	368.1	106.0	199.3
1971	9	E	151.8	275.0	72.8	95.9
1971	5	E	58.2	125.7	32.7	50.3
1971	8	E	57.9	86.0	24.2	30.2
1972	9	E	56.2	86.8	24.3	33.7
1972	9	M	30.3	78.2	11.5	22.1
1973	9	E	3.4	10.1	2.6	4.0
1973	9	L	1.5	4.8	0.7	0.8
			Winter Wheat			
1967	9	E	1.6	2.7	0.7	1.4
1968	9	E	1.6	4.5	0.8	1.2
1969	9	E	245.6	412.8	106.3	168.5
1970	9	E	118.8	198.1	39.6	72.6
1970	8	E	103.3	211.6	70.9	112.1
1971	9	E	12.6	24.1	0.8	1.4
1971	5	E	4.5	10.8	0.4	1.2
1971	8	E	4.9	19.3	1.5	2.5
1972	9	E	2.0	3.7	1.7	1.4
1972	9	M	5.2	10.3	2.8	4.3
1972	9	L	21.9	33.3	6.5	10.9
1973	9	E	1.2	2.0	1.2	1.2
1973	9	L	1.1	2.1	1.3	4.0

predictability of total larvae from peak eggs allows some management action to be taken. The regression equation for this relationship is:

$$\text{Larval Incidence} = .90 + .87 \text{ (peak eggs)} \quad r^2 = .88$$

The distribution of *T. julis* at Gull Lake. Initial releases of *T. julis* were made in section 9, field 13 and in section 5 (Figure 4) (Stehr, personal communication). In 1967, 148 *T. julis* were released in an oat field in section 9; and in 1968, 430 *T. julis* were released in the same area. No parasites were released in 1969 (Stehr 1970). Since the initial establishment-recovery of *T. julis* in 1969, many of the fields in the Gull Lake area have been monitored for adult *T. julis* using emergence cages, and for overwintering larvae of *T. julis* by sampling soil and extracting and counting CLB pupal cells in which *T. julis* overwinter as larvae. Additionally, a sweep-survey was developed to monitor population densities in different fields at Gull Lake and to assess the impact of parasites in each of the fields sampled. Historically, this study began in the fall of 1970. Emergence of the spring and summer generations of *T. julis* adults was recorded in 1971-1973. The rate of emergence was measured during these years and was reported earlier, but additional information on total number of *T. julis* adults emerging per yd^2 from the previous year's oat stubble is provided from other oat fields which were measured in the area.

The build-up of *T. julis* densities after the original recovery in 1969 was very rapid, but it occurred only locally. Table 21 shows the maximum numbers of adult *T. julis* caught in emergence traps from oat stubble and the oat crop for the spring and summer generations, respectively. The changing *T. julis* densities in the sections which had

TABLE 21: Mean number of spring and summer generation *T. julis* adults and CLB summer adults emerging per yd^2 from several oat fields sampled in the three sections at Gull Lake. These estimates show the highest densities from the oat fields sampled in each section.

Year	Section	No.* fields	Spring generation/yd^2	No. fields	Summer generation/yd^2	CLB adults/yd^2
1971	9	5 (31)	20.9	3 (25)	66.4	79.9
1971	5	5 (21)	0.2	4 (12)	0.0	--
1971	8	3 (14)	0.2	2 (8)	0.0	--
1972	9	5 (70)	22.0	5 (45)	13.9	41.6
1972	5	3 (30)	0.0	1 (5)	0.8	--
1972	8	2 (20)	0.2	2 (10)	4.6	--
1973	9	3 (30)	20.9	3 (34)	15.6	2.1
1973	5	4 (40)	1.5	4 (20)	12.4	--
1973	8	3 (30)	6.4	3 (15)	18.0	--

*( ) = no. sq. yds. sampled.

low densities in 1971 (sections 5 and 8) can also be observed in Table 21. This is evident from examination of the numbers of T. julis trapped during the summer generation in each section from 1971-1973. Also note that CLB densities declined significantly during these three years (see CLB adult production in section 9; Table 21). Production of T. julis never reached densities in sections 5 and 8 comparable to those in section 9 in 1971 because of the decline in CLB density; but, by the summer generation of 1973, production in the three areas was comparable, indicating that parasite dispersal and build-up in the three areas had been accomplished by 1973.

Crop age has significant impact on the production of CLB and T. julis. Table 22 summarizes emergence data taken from crops of different ages which were planted side by side. In spring oats, more parasites are produced from the earliest planted crop, with production decreasing as the age of the crop decreases. The opposite relationship is true in winter wheat where the later the crop is planted, the higher the production of parasites as well as CLB adults.

The complete set of emergence data collected in 1973 is given in Table 23 and Table 24 to show the present densities of T. julis and variability within each field sampled. By 1973, the parasite densities apparently became more uniform due to dispersal from the original release site and build-up within each of the sections sampled.

Additional information on distribution of T. julis at Gull Lake was obtained by sampling soil, extracting the pupal cells of the CLB, and determining the number of parasites which overwinter. This method of determining population density is useful in that it is an accumulation of the CLB population which completed feeding, and of parasitism at the

TABLE 22: The effect of crop and crop age (early or late) on production* of T. *julis* (summer generation) and CLB adults.

Year	Crop	Age[1]	*T. julis*/yd^2 Female	*T. julis*/yd^2 Male	CLB/yd^2	n/field
1971	Oats	E	8.7±8.7	1.3±1.3		3
1971	Oats	M	1.7± .9	0.0		3
1971	Oats	L	0.0	0.0		3
1972	Wheat	E	.7± .4	0.0	1.5± .4	15
1972	Wheat	M	3.7±1.2	.5± .2	8.0±1.7	15
1972	Wheat	L	7.7±1.5	.9± .4	21.3±2.8	15
1972	Oats	E	14.5±3.4	2.1± .4	12.8±2.0	15
1972	Oats	M	12.6±3.1	1.1± .3	12.7±2.0	10
1972	Oats	L	4.2±1.8	.2± .2	8.6±2.2	5
1973	Wheat	E	1.8± .4	.8± .4	1.4± .5	5
1973	Wheat	L	7.4±1.6	2.3± .7	1.0± .2	20
1973	Oats	E	13.3±3.3	2.3±1.2	2.1± .8	10
1973	Oats	L	2.2± .7	.6± .2	.2± .2	5

*$\bar{X} \pm SE/yd^2$.

[1]E = Early planted oats or wheat
M = middle planted oats or wheat
L = late planted oats or wheat.

TABLE 23: Mean number of *T. julis* trapped from stubble at Gull Lake in different sections during spring emergence, 1973.

Section	Stubble field	Crop	No. sq. yds. sampled	*T. julis*/yd^2 Female	Male
9	12	Wheat (E)	10	1.5± .6	1.6± .8
9	8	Oats (E)	10	16.8±3.5	4.1± .8
9	18	Oats (L)	10	2.3± .7	0.5± .3
9	10	Oats (E)	10	9.4±1.9	2.7±1.0
5	53	Oats (E)	10	0.2± .1	0.2± .1
5	55	Oats (L)	10	1.1± .5	0.7± .3
5	60	Oats (E)	10	1.4± .6	0.1± .1
5	63	Oats (L)	10	0.8± .4	0.4± .2
8	11	Oats (L)	10	0.6± .2	0.2± .1
8	9	Oats (E)	10	5.4±1.4	1.0± .2
8	13	Oats (E)	10	2.6±1.0	0.2± .2

TABLE 24: Mean* number of *T. julis* and CLB adults trapped at Gull Lake in different sections during the summer generation, 1973.

Section	Field no.	Crop	No. sq. yds. sampled	*T. julis*/yd^2 Female	*T. julis*/yd^2 Male	Adult CLB /yd^2
9	13	Oats (E)	19	5.5±1.4	1.3± .4	1.4± .3
9	15	Oats (E)	10	13.3±3.3	2.3±1.2	2.1± .8
9	9	Oats (E)	5	2.2± .7	.6± .2	.2± .2
9	7	Wheat (E)	5	1.8± .4	.8± .4	1.4± .5
9	11	Wheat (L)	20	7.4±1.6	2.3± .7	1.0± .2
5	54	Oats (E)	5	7.2±3.1	.8± .4	2.2± .9
5	61	Oats (E)	5	10.0±1.5	2.4±1.7	3.4±1.8
5	51	Oats (L)	5	.2± .2	0.0	.6± .2
5	59	Oats (L)	5	0.0	.4± .4	.8± .5
5	56	Wheat (L)	5	7.6±3.6	1.2± .8	4.0±1.5
5	62	Wheat (L)	5	4.8±1.2	.6± .4	4.4±2.4
8	7	Oats (E)	5	14.0±5.4	4.0±2.8	5.0±1.9
8	11	Oats (E)	5	2.4±1.0	.4± .2	6.6±2.3
8	9	Oats (L)	5	.4± .2	0.0	1.2± .5
8	13	Wheat (L)	5	2.4±1.9	1.2± .8	1.0± .6

*$\overline{X}$ ± SE.

end of the season. It also provides an estimate of the parasite population to emerge the following spring (after overwintering mortality). The soil samples do not account for the number of cells that were parasitized early in the season by T. julis which emerge as the non-diapausing component of the parasite population. Attempts were made to categorize cells which had parasite emergence holes to account for the parasitism during the first generation. This point will be discussed later.

During the investigation, several methods of soil sampling were attempted to determine the best method to use. Also, due to variability in elevation within some of the areas sampled, the distribution of the CLB within the crop would affect soil sample estimates of parasite density. To test for a difference in CLB density, samples were taken on a hill top, a slope, and in a low area (Table 25). The variation in the numbers of cells is high due to the small number of samples taken, but the decrease in density on the slope was indicative of low plant density due to low moisture in this area in 1970. To account for these differences it was necessary to sample these areas within a field (if they existed) to account for the distribution of the CLB. It was also important to examine the difference in crop age on the number of cells found in the soil, which reflects the production of CLB and parasites (Table 26). More CLB and parasites were produced in the middle (M) aged oats compared with early (E) or late (L) planted oats during high CLB population densities in 1970.

Different methods of sampling were tested in 1971 in early and late planted oats to determine which was the best method of sampling. One method consisted of scooping soil along the grain row to a depth of about 3 inches in 2 rows for 24 inches; the other method was to drop a

TABLE 25: Differences in CLB production within a field depending on elevation differences (1970).

Crop	Hill top	Slope	Valley	n
Winter wheat	35.7± 9.0*	21.0±13.2	55.7±19.3	3
Spring oats	42.7±24.6	12.0± 3.5	58.0± 8.0	3

*Total pupal cells/$\frac{1}{2}$ yd^2 ($\overline{X}$ ± SE)

TABLE 26: Difference in crop age on the number of CLB and parasites produced (1970).

Crop	Age	Total cells	Parasitized cells	Total *T. julis*	n
Oats	E	74.0± 8.6	7.8±2.0	35.3± 9.4	10
	M	110.0±12.4	12.4±3.3	55.3±13.3	10
	L	25.8± 5.1	9.2±2.3	38.4± 9.4	10

TABLE 27: A comparison of two methods used to remove CLB pupal cells from the soil (1971).

Crop	Method	Total cells	Parasitized cells	Total *T. julis*	n
Oats (E)	Scoop*	30.0±4.8	12.2±1.8	23.2±4.3	5
	1/2 yd^2	47.2±2.8	16.2±1.7	29.4±4.6	5
Oats (L)	Scoop	8.6±1.7	3.4±0.7	11.0±1.9	5
	1/2 yd^2	6.2±2.1	2.6±0.7	9.4±1.9	5

*Soil scooped to a depth of 3 in. in 2 grain rows for 24 in.

$1/2\ yd^2$ frame at random in the field (Table 27). Although similar production was estimated by the two methods, the more quantitative $1/2\ yd^2$ method was continued for population samples. However, since the "soil scoop" method required less effort, it was used to collect parasitized cells for rearing purposes.

The difference between the numbers of CLB and parasites produced in and outside of the emergence traps was examined to determine if the effect of the cage was important. Soil samples ($1/2\ yd^2$) were taken after summer emergence was completed. Table 28 shows that parasite mortality was significantly affected in 1971 due to the emergence trap because plant growth within the traps was greater than in the uncovered crop, especially during dry periods (June 1971) when the crop was protected from direct sunlight and therefore less moisture was lost.

The relationship between the mean number of pupal cells recovered per $1/2\ yd^2$ from 24 fields of oats between 1970 and 1973, and the corresponding standard error is shown in Figure 24. This relationship indicates that on the average the standard error was slightly above 10% of the mean. The average sample size for these estimates was 10.2 one-half sq. yds. per field.

Table 29 summarizes the estimates of the number of CLB pupal cells and the number of parasitized pupal cells per $1/2\ yd^2$ from oat fields in the areas sampled between 1970 and 1973. In 1969, Stehr (1970) estimated that there were 0.25 parasitized cells per $1/2\ yd^2$ (1 per 2 yd^2). If this estimate is accurate, the parasite population increased 57 fold in one year (1969-1970), although the build-up in 1970 was localized around the original release fields in section 9. In 1970, low numbers of parasites were estimated from section 8 which is

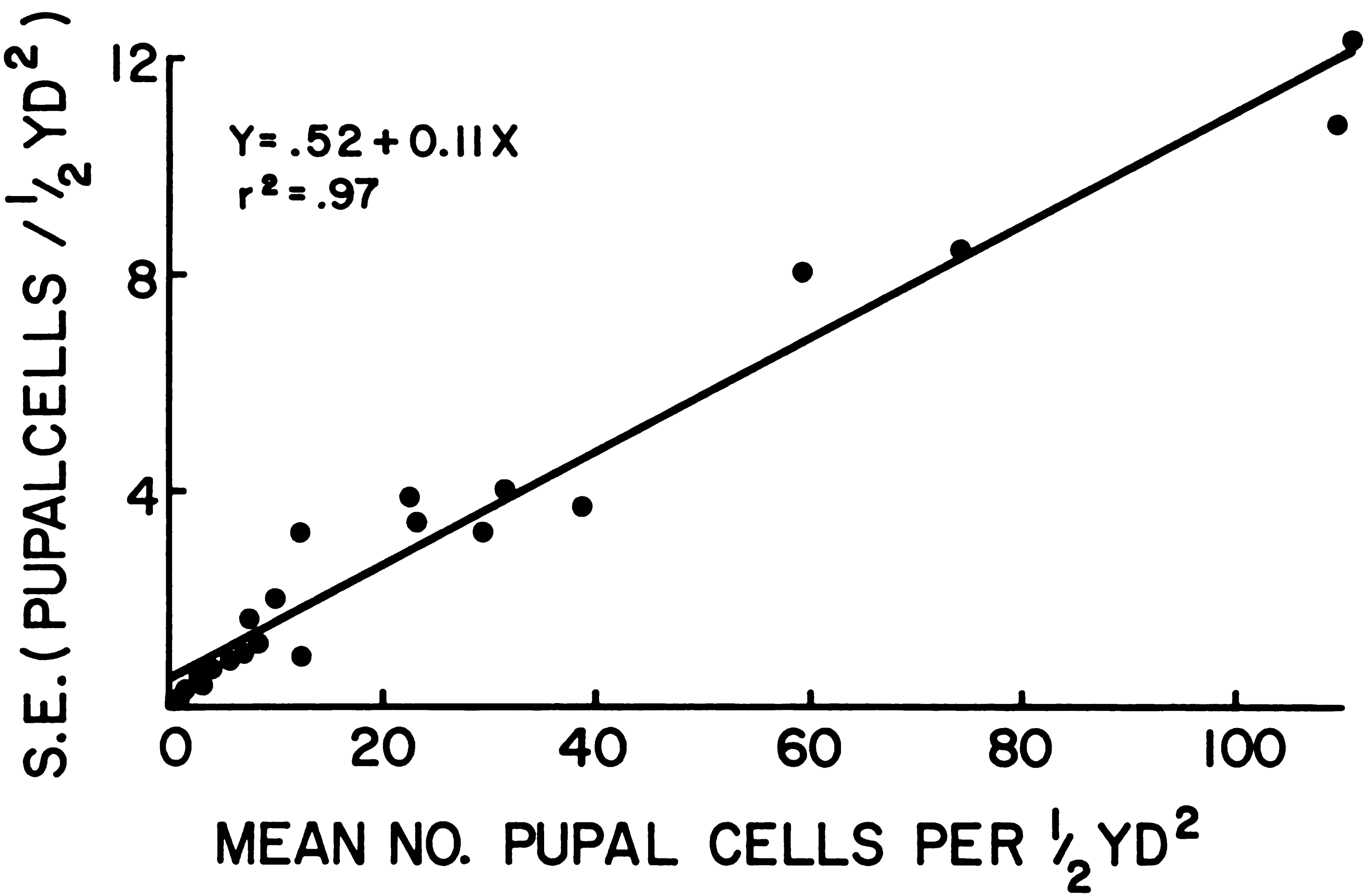


Fig. 24. The relationship between mean number of pupal cells per ½ yd^2 and the standard error of the mean.

TABLE 28: Differences in mean number and mortality of CLB and *T. julis* during drought conditions when 1/2 yd^2 soil samples were taken inside and adjacent to emergence traps in 1971.

Condition	Total cells	Parasitized cells	Live *T. julis*	Dead *T. julis*	Dead CLB
Within trap	22.6±5.0	3.4±0.9	12.4±4.1	1.0±0.6	1.8±0.7
Outside trap	18.0±4.1	3.4±0.9	3.4±1.4	11.4±5.7	5.4±2.1

TABLE 29: Mean number per 1/2 yd^2 of CLB cells and mean number of cells containing diapausing _T. julis_ larvae in samples taken from representative fields of normally planted oats in different years in each of three sections at Gull Lake.

Year	Section	Crop	CLB cells	Parasitized cells	n
1970	9	Oats	97.3± 5.6*	14.3±1.5	30
1970	8	Oats	109.5±11.0	.2± .2	10
1971	9	Oats	59.1± 8.1	4.9±1.0	10
1971	8	Oats	23.2± 3.8	.2± .2	5
1971	5	Oats	51.7±13.8	1.0± .7	6
1972	9	Oats	31.6± 4.0	8.4±1.3	10
1972	8	Oats	24.6± 3.3	1.3± .5	9
1972	5	Oats	7.4± 1.6	1.8± .6	9
1973	9	Oats	5.1± .9	2.5± .6	14
1973	8	Oats	8.0± 1.3	2.8± .5	14
1973	5	Oats	12.3± .9	4.1± .9	14

*$\bar{X}$ ± SE / 1/2 yd^2.

about 1/4 mile from the release site. An increase in parasite densities was expected in 1971, but estimates of diapausing *T. julis* larvae showed that the population decreased from 14.3 to 4.9 per 1/2 yd^2. Earlier, Table 16 indicated the effect of high temperatures on *T. julis* and CLB survival in the soil. Increases in the other sections were not significant for the same reason. In 1972, the diapausing parasite density nearly doubled even though the CLB population decreased by 1/2 in the release area (59.1 to 31.6). Parasite densities also increased in 1972 in the other sections and by 1973 the proportion of the cells which were parasitized in each of the three sections was high.

Table 30 shows fields which were sampled in the three sections in 1973. The number of total cells produced is low, but the proportion parasitized is generally high compared with the total number of CLB per field. In 1973, the soil samples were taken in seven pairs down the field strips. These pairs were tested (paired-t) for significant differences of pupal cell density per 1/2 yd^2 within each field. Only two fields of 14 oat fields sampled were significantly different at the 5% level. The same test was performed on the numbers of diapausing *T. julis* larvae and there was no significant difference at the 5% level within these fields.

The impact of *T. julis* on the CLB population. The increase in density of *T. julis* between 1969 and 1970 was very rapid in the original release site. Optimal conditions prevailed during this period due to high CLB populations which provided abundant hosts. In 1970, CLB densities were measured in the parasite release area and larvae were dissected to determine percent parasitism. Similar population density

TABLE 30: Density of CLB cells and density of parasitized cells per 1/2 yd^2 sampled in July, 1973 in three sections at Gull Lake.

Section	Field	Crop	CLB* cells	Parasitized* cells	n/field
9	9	Oats (L)	1.3± .4	.6±.2	14
9	13	Oats (E)	5.1± .9	2.5±.6	14
9	15	Oats (E)	7.7±1.4	2.4±.6	14
9	25	Oats (E)	6.9±1.0	1.3±.5	14
8	7	Oats (E)	8.0±1.3	2.8±.5	14
8	9	Oats (L)	1.9± .5	.4±.1	14
8	11	Oats (E)	2.7± .6	.9±.3	14
8	32	Oats (E)	12.1±3.2	1.1±.4	14
8	34**	Oats (E)	3.6± .7	.9±.3	14
5	51	Oats (L)	.9± .2	.2±.1	14
5	59	Oats (L)	2.0± .5	.9±.3	14
5	61	Oats (E)	12.3± .9	4.1±.7	14

*$\overline{X}$ ± SE.

**Sprayed.

estimates were obtained in the primary release area in 1971 and, in addition, estimates of CLB densities and percent parasitism were made in sections 5 and 8 (see Figure 4). In 1972, similar estimates were made but an effort was placed on examination of the effect of crop age on CLB density and percent parasitism in section 9, rather than sample specific fields in sections 5 and 8 using the weekly foliage collection method. To examine CLB density and parasitism in these areas, a survey was conducted which allowed estimates of the above from several fields rather than concentrating on one or two fields in each section. In 1973, detailed population density estimates were obtained in section 9 in 2 wheat and 2 oat fields of different ages, as well as conducting an extensive survey in the 3 sections.

A summary of within-generation CLB egg and larva population data collected at Gull Lake in section 9 is given in Figures 25a and 25b and in Tables 19a and 19b. Fields in which parasitism was estimated by larval dissection are considered in this section. Two aspects concerning parasitism by _T. julis_ became evident. First, parasitism was variable from year to year because of the changing state of the CLB population and _T. julis_ densities; second, point estimates of parasitism within a season by _T. julis_ was not useful because of the dynamic interactions between the host and parasite. For example, percent parasitism reaches near 100% during the second generation of _T. julis_. At this point, larval densities are low and effective parasitism can only be reflected by examining the number of larvae parasitized per ft^2. To determine the within season impact of _T. julis_ on the CLB population, the area under the total CLB larval curve must be compared to the area under the parasitized CLB larval curve.

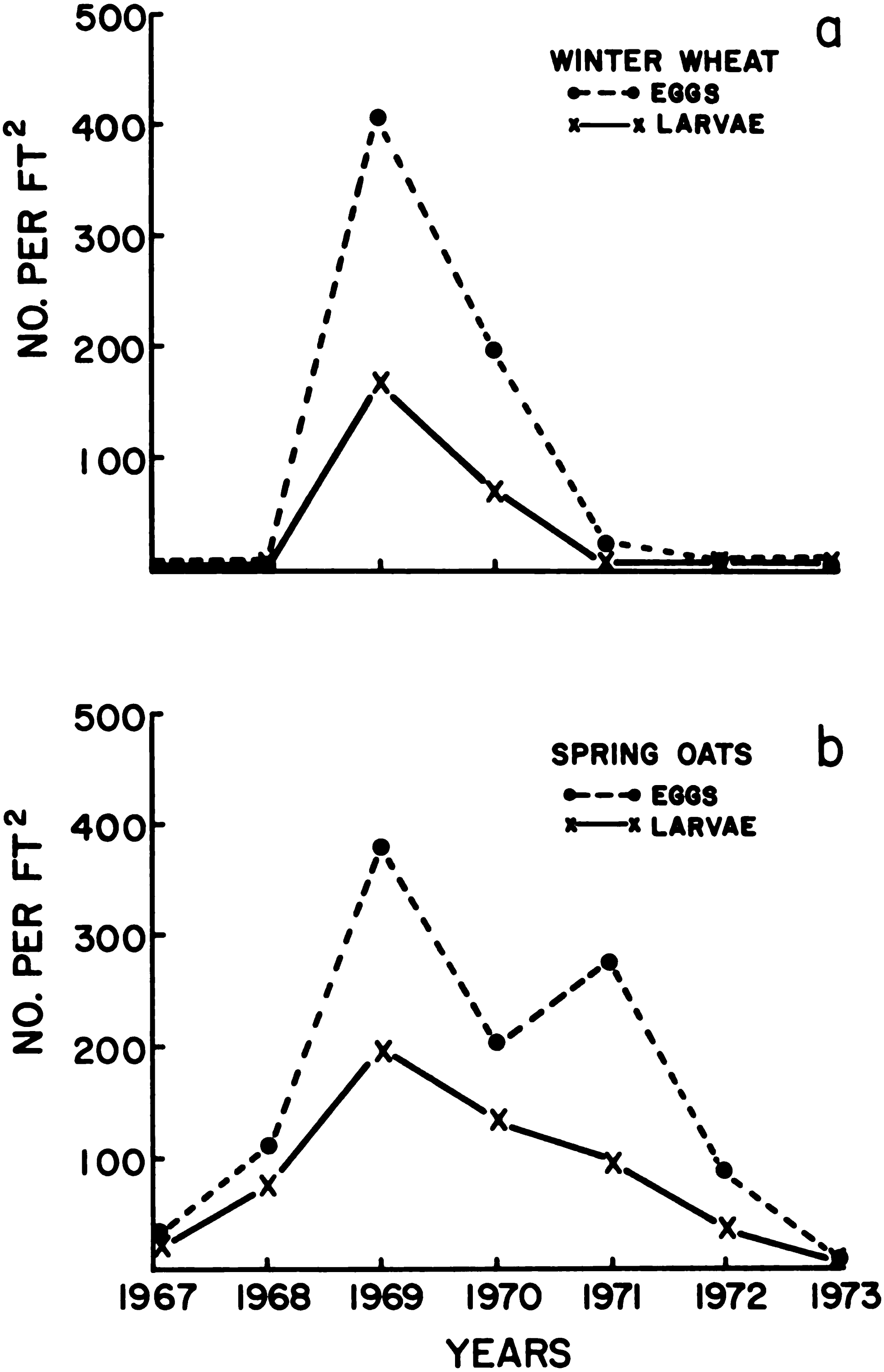


Fig. 25. Total incidence of cereal leaf beetle eggs and larvae in winter wheat (a) and spring oats (b).

The dynamics of parasitism by T. julis is best illustrated by population data collected in 1972. This data set provides information on the temporal attack of CLB larvae by T. julis in different ages of wheat and oats planted side by side (see Figure 4d, section 9 fields 12-13). Figure 26 shows the effect of crop age on population levels of the CLB as well as the proportion of the population parasitized by T. julis in each crop. Population measurements of CLB eggs, larvae, associated parasite densities, and the proportion of the larvae parasitized were made in three ages of winter wheat, one age of mixed winter wheat and spring oats (Figure 26; oats a), and 2 ages of spring oats. Associated plant biomass information was also collected (Appendices I-VI). In the wheat-oat mixture, accomplished by disking a late-planted winter wheat strip and replanting to spring oats, CLB eggs on wheat and oats were counted and kept separate.

The temporal occurrence of the populations of larvae and parasitism by T. julis in different ages of winter wheat and spring oats is shown in Figure 26. Several features can be observed from this series of figures. First, the peak larval densities in wheat increase as crop age decreases. Also, in wheat, only the first generation of T. julis parasitizes CLB larvae. This is due to the drop in larval densities between 800-900$^\circ D_{48}$ and the initiation of the second generation of T. julis which occurs at 900-950$^\circ D_{48}$. Second, peak larval densities in oats tend to decrease with a decrease in crop age. Parasitism by T. julis adults occurs in oats during both generations (Figure 26). Percent parasitism in oats increases rapidly at the end of the larval population. The significance of this increase is not related to the number of larvae that are parasitized because the actual

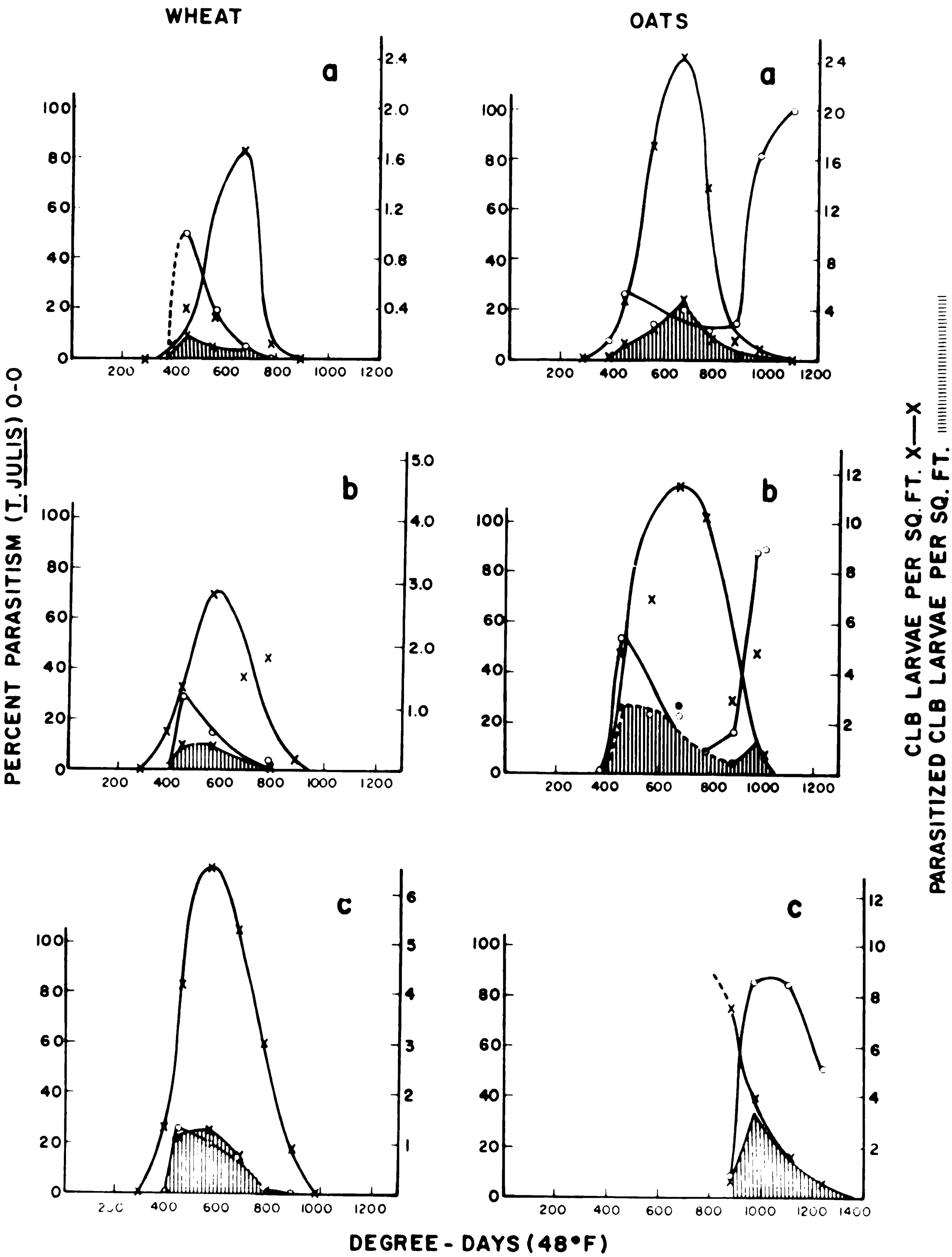


Fig. 26. Total cereal leaf beetle larvae per ft^2 in three ages of wheat and oats in 1972, with corresponding percent parasitism by *T. julis*. Hatched areas indicate parasitized larvae per ft^2.

number parasitized is small when compared to the total density per sq. ft. The importance is that the larvae parasitized during the second generation constitute a significant component of the parasites produced which enter diapause and overwinter.

Figure 26, oats b represents the characteristic trend of parasitism by T. julis in normally planted oats. The level that parasitism reaches depends on the adult parasite density searching for and attacking CLB larvae in the crop as well as the density of CLB larvae. The management plan at Gull Lake optimized the spacial arrangement of the crops with respect to the distance that T. julis had to travel from its overwintering site to the crop. Therefore, T. julis females began to attack larvae in oats soon after initial emergence of the spring generation. Also, attack by the first generation of T. julis was most important because of the number of hosts available during the first generation attack phase (400-700°D) (Figure 26).

The emergence of the second parasite generation does not occur until the CLB larvae attacked by the first generation have pupated and the parasites within the cells develop. Second generation emergence begins at about 900°D and may not be completed until 1200°D. By 1200°D almost all larvae in oats have completed feeding and have pupated. Peak CLB larval density occurs between the two parasite generations.

Adult parasite densities were monitored using a D-vac to define the period when adults are searching in the crop and to establish the number of individuals searching. Adults are found searching in the crop as soon as they emerge from oat stubble. This situation was optimized at Gull Lake by planting crops in strips adjacent to the overwintering sites of *T. julis* (oat stubble).

The period of peak density of adult *T. julis* during the first parasite generation in oats occurs just as CLB larvae are increasing; but, adult *T. julis* densities decrease prior to peak larval density. Adult *T. julis* densities increase again due to second generation emergence as indicated by the curves of percent parasitism in Figure 26.

In 1972, adult parasite density estimates were taken daily during the first and second generations of *T. julis* in a field of mixed wheat and oats and in late wheat (oats "a" and wheat "c", Figure 26). The other two wheat fields were sampled only during the first parasite generation for adult *T. julis*, and the late oat field was not sampled until the second generation (wheat "a-b" and oats "c", Figure 26). In each field, adult *T. julis* densities were estimated from twenty ft^2 samples. Density estimates of *T. julis* sampled on a particular day were averaged and plotted over $°D_{48}$ (Figure 27). In each case, *T. julis* adults were already in the fields when the first sample was taken, as sampling was done just prior to peak emergence from the soil. The dotted line in Figure 27 depicts the average incidence of larvae in oats and shows that the first generation of *T. julis* occurs prior to peak larvae and the second generation attacks only late CLB larvae. This compares with percent parasitism curves shown in Figure 26. The mean maximum *T. julis* density in each field sampled in 1972 and 1973 is shown in Tables 31a and 31b. Note that peak parasite densities were higher in 1972. However, CLB larval densities were lower in 1973; so, to place adult *T. julis* density in perspective, the ratio of CLB larvae to *T. julis* adults was calculated at peak parasite density to

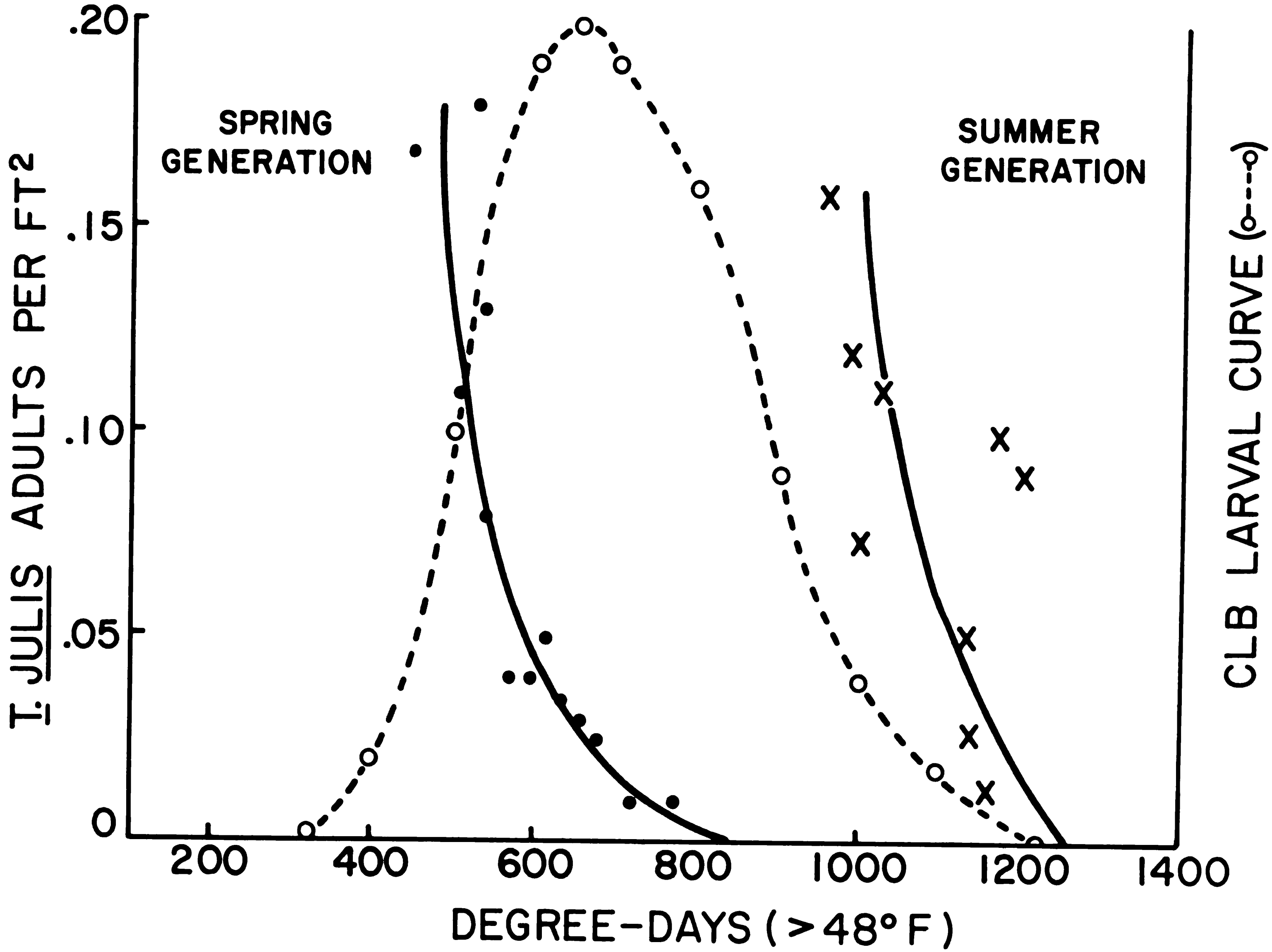


Fig. 27. Mean daily *T. julis* adult density per ft^2 in winter wheat and spring oats, and mean occurrence of cereal leaf beetle larvae.

TABLE 31a: Mean maximum number of *T. julis* adults per ft^2 in 3 different ages of oats and wheat during the first and second generations in 1972 (n = 20).

	Oats			Wheat		
	E*	M	L	E	M	L
1st generation	.40	.40	--	.15	.15	.20
2nd generation	.35	.35	.30	--	--	.35

TABLE 31b: Mean maximum number of *T. julis* adults per ft^2 in 2 different ages of oats and wheat during the first and second generations in 1973 (n = 20).

	Oats		Wheat	
	E	L	E	L
1st generation	.16	--	.12	.20
2nd generation	.08	.04	.04	.12

*E = early planting
M = medium planting
L = late planting.

show the number of CLB larvae for each adult parasite (Tables 32a and 32b). These estimates show that to parasitize all CLB larvae in oats in 1972, about 12 larvae would have to be attacked per ft^2 by an adult, first generation T. julis at peak parasite density. In 1973, less larvae were present, but less larvae needed to be attacked because of the proportionately higher parasite density in that year. This has important management as well as survival implication for T. julis. The assessment of the impact of the parasite population on the CLB population is also made more difficult because of the two attack periods, especially when attempting to use percent parasitism determined from larvae sampled in different areas of a region where differences in temperature affect the occurrence of CLB larval populations.

To quantify the effect of parasitism by T. julis on the CLB in fields at Gull Lake where weekly population estimates were made in 1970-1973, the area under the population curves of unparasitized and parasitized CLB larvae was calculated and is given in Table 33. Effective parasitism (P) is determined by:

$$P = \frac{\int PL/D}{\int TL/D} \times 100$$

where TL is total CLB larvae per ft^2, PL is the number of parasitized CLB larvae per ft^2, and D is the developmental time of larvae in $°D_{48}$. Since no difference in D was determined for parasitized larvae, D cancels out. Using this incidence method, the effect of crop age on CLB density and parasitism by T. julis is shown in Table 34. Accurate estimates of CLB population densities and the proportion parasitized at any one sampling date became more difficult in 1973 due to the low densities of the CLB. To account for this, the number of samples taken at each time was increased from 15 ft^2 in 1972 to 30 ft^2 in 1973. To

TABLE 32a: Number of CLB larvae per adult *T. julis* based on peak *T. julis* density per ft^2 in 1972 in three ages of oats and wheat in section 9 at Gull Lake.

	Oats			Wheat		
	E*	M	L	E	M	L
1st generation	12.0	12.0	--	2.7	3.0	20.5
2nd generation	2.6	14.0	13.0	--	--	1.4

TABLE 32b: Number of CLB larvae per adult *T. julis* based on peak *T. julis* density per ft^2 in 1973 in two ages of oats and wheat in section 9 at Gull Lake.

	Oats		Wheat	
	E	L	E	L
1st generation	4.4	--	5.0	3.0
2nd generation	5.0	2.5	.3	.8

*E = early planting
M = middle planting
L = late planting.

TABLE 33: Population density in spring oats per ft^2 per season of CLB larvae and larvae parasitized by T. julis (total area under seasonal population curves ÷ developmental time) and effective parasitism by T. julis determined from weekly population samples in three sections at Gull Lake.

Year	Section	Larvae/ft^2	Parasitized larvae/ft^2	% Parasitism (Effective)	n/week
1970	9	130.2	7.62	5.9	30
1971	9	95.9	4.70	4.9	15
1971	8	30.2	.27	.9	15
1971	5	50.3	.16	.3	15
1972	9	34.0	5.97	17.6	15
1973	9	4.0	1.62	40.5	30

TABLE 34: Population density in different ages of winter wheat and spring oats per ft^2 per season of CLB larvae and larvae parasitized by T. julis (total area under seasonal population curves ÷ developmental time) and effective parasitism by T. julis determined from weekly population samples in section 9 at Gull Lake.

Crop	Larvae/ft^2	Parasitized larvae/ft^2	% Parasitism (Effective)	n/week
1972				
W (E)	1.36	.36	26.5	15
W (M)	4.17	.42	10.1	15
W (L)	10.90	1.61	14.8	15
O (E)	34.01	5.97	17.6	15
O (M)	22.11	6.98	31.6	15
1973				
W (E)	1.23	.26	21.1	30
W (L)	1.49	.70	47.0	30
O (E)	4.02	1.62	40.3	30
O (L)	.77	.31	40.3	30

supplement estimates obtained from detailed weekly samples for population estimates in 1973, small collections of larvae (25 larvae/field) were taken from fields in each of the 3 sections at Gull Lake and dissected to estimate percent parasitism at key times in the seasonal domain of _T. julis_. These data (Table 35) show that percent parasitism is quite variable between fields and between areas depending on crop age; but, they also show that _T. julis_ is generally distributed in the fields sampled. Also note the characteristic decline in parasitism between the first and second generations of _T. julis_ in 1973 (Table 35) when parasitism was very low in sections 5 and 8.

Effective parasitism cannot be calculated using percent parasitism data without some estimate of CLB larval densities on a per unit area basis. A sweep survey was implemented to accomplish an estimate of larval densities because of the impossibility of collecting weekly population samples using the foliage sample method from a large number of fields. The survey was designed after the method used by Ruesink and Haynes (1972) to measure adult CLB densities. The conversion from number of adults/sweep to density per unit area involves a model which takes into account several meteorological parameters, as well as crop height, because of adult mobility. Ruesink and Haynes (1973) indicated that a conversion from larvae per sweep to larvae per ft^2 was not necessary and that the conversion was direct (i.e., larvae per sweep is approximately equal to larvae per ft^2). They estimated this during high larval densities.

To check this conversion at low densities, the sweep survey was conducted in 1973 in two winter wheat and two spring oat fields the same day when detailed weekly population samples were taken. The

TABLE 35: Percent parasitism on different dates determined from collection of 25 late instar larvae from early and late oat fields in 3 sections at Gull Lake (1973).

Crop	Section	Field	Date	$^{\circ}D_{48}$	Percent parasitism
Oats (E)	9	13	6/11	745	76
	9	13	6/16	868	56
	9	13	6/25	1065	100
	8	11	6/11	745	68
	8	11	6/16	868	20
	8	11	6/25	1065	80
	5	54	6/11	745	56
	5	54	6/16	868	36
	5	54	6/25	1065	88
Oats (L)	9	9	6/11	745	88
	9	9	6/16	868	100
	9	9	6/25	1065	100
	8	9	6/11	745	28
	8	9	6/16	868	12
	8	9	6/25	1065	92
	5	59	6/11	745	29
	5	59	6/16	868	60
	5	59	6/25	1065	92
Wheat (L)	9	11	6/11	745	84
	9	11	6/16	868	36
	8	13	6/11	745	68
	8	13	6/16	868	16
	5	56	6/11	745	52
	5	56	6/16	868	12

sweeping was not done within the plots delineated for the detailed sampling but in the same fields. To check the conversion, a regression analysis was performed on the total larvae taken by each method whenever larvae were encountered by both methods in any of the four fields. The analysis showed that the sweep method underestimated the total larvae per ft^2 taken by the detailed sampling method (Figure 28). The following equation can be used for the conversion of the sweep method to total number of larvae ft^2:

$$y = .26 + 2.6\ x \quad (r^2 = .82)$$

This relationship may be used to convert total catch/sweep to total larvae/ft^2 and can be used as a reasonable index of total CLB larvae at low densities. However, caution must be exercised in using this method to predict number of larvae per ft^2 at low densities until a better model is developed. Further examination of this data revealed that very few first instar larvae were caught in the net. Therefore, in the following results pertaining to sweep survey data, the information is presented using larvae per sweep rather than larvae per ft^2.

In 1972, 9 fields of oats and 6 fields of wheat were included in the survey. A standard sample of 100 sweeps was taken in each field at weekly intervals. A similar but expanded survey was conducted in 1973, which included crop as well as non-crop areas, to determine the general distribution of T. julis in the Gull Lake region. Up to 100 CLB larvae were dissected from each field if more than 100 larvae were collected, and all larvae were dissected from fields where larval densities were less than one larva per sweep. Instar determinations were made on each larva dissected as well as documenting the frequency of numbers of parasite eggs and larvae within each larva.

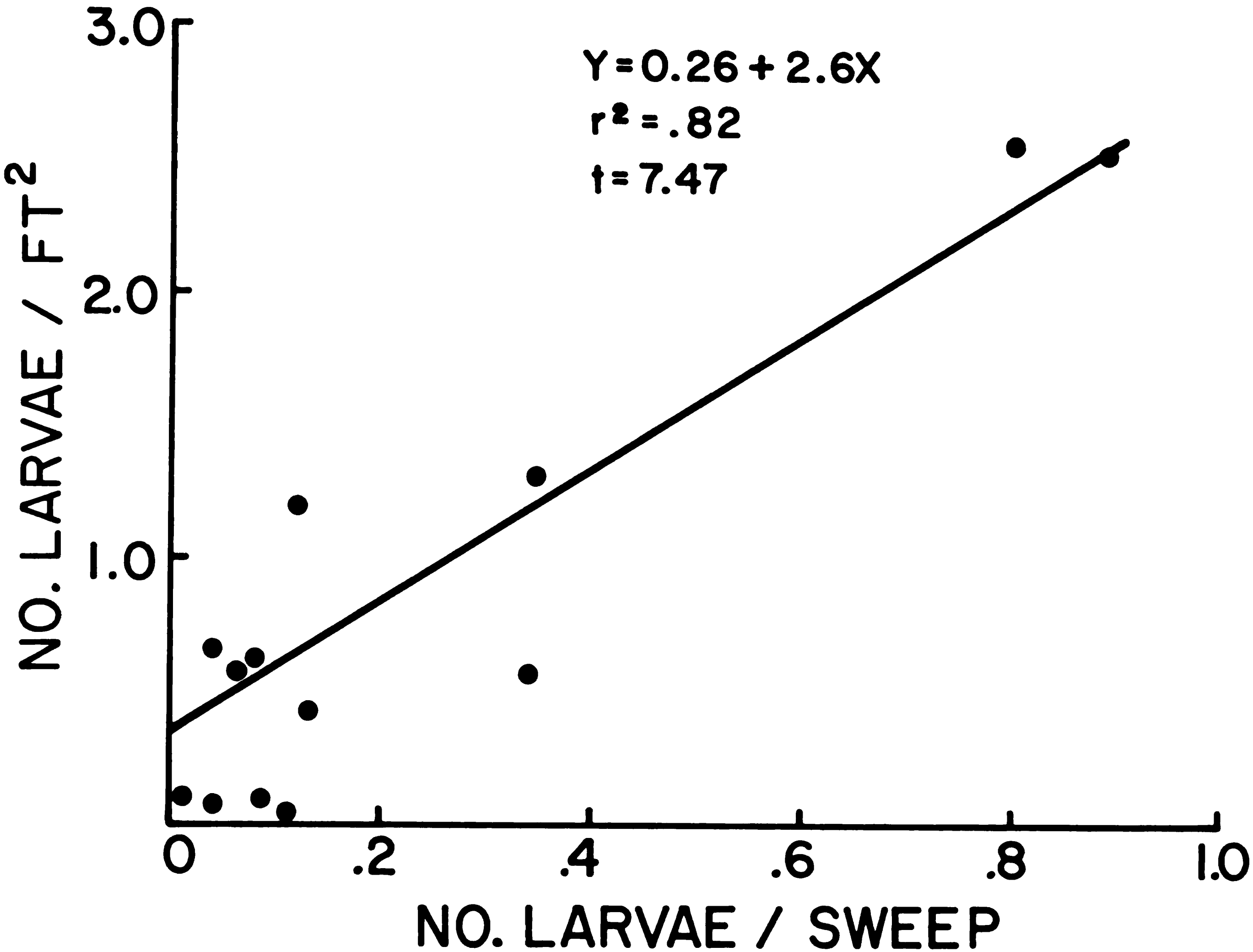


Fig. 28. The relationship between the number of cereal leaf beetle larvae per sweep and number per ft^2.

The most useful method of summarizing the data was to determine the number of CLB larvae and parasitized larvae per sweep per season by integrating the area under each of the population curves, as was done for the weekly population estimates. In cases where not all larvae were dissected, percent parasitism was used to estimate the number of parasitized larvae per sweep. Table 36 shows the CLB larval density, parasitized larval density, and effective parasitism for each of the fields sampled in 1972.

In 1972, the numbers of *T. julis* collected during the spring emergence period indicated that few *T. julis* adults were produced in sections 5 and 8 (Table 21). This was substantiated by estimates of low overwintering densities of *T. julis* determined by soil samples in July 1971 in these areas (Table 29). The relatively high levels of effective parasitism shown in Table 36 suggest that a significant movement of *T. julis* adults took place from fields in section 9, which produced as many as 20 *T. julis* adults per yd^2 during the spring generation, to sections 5 and 8. In addition, during the period when parasitism began to increase in sections 5 and 8 (June 22-July 10) large catches of *T. julis* in flight traps indicated that dispersal of adults to these sections was occurring.

In 1973, a similar survey was conducted, but this survey was expanded to include stubble fields from the previous year as well as other field classes of interest to other workers on the project. In comparing densities of CLB larvae in oats and wheat in 1972 and 1973 (Tables 36 and 37 a-b) a general reduction in population density is apparent. *T. julis* was removing significant numbers of larvae from the population in 1972. Adult CLB immigration into the Gull Lake

TABLE 36: Density in different ages of spring oats and winter wheat per sweep per season of CLB larvae and larvae parasitized by T. julis (total area under seasonal curve ÷ developmental time) and effective parasitism by T. julis in three different sections at Gull Lake in 1972.

Crop	Section	Field	Larvae /sweep*	Parasitized larvae/sweep	% Parasitism (effective)
Oats (E)	9	8	44.3	13.3	30.0
(E)	9	10	57.3	13.0	22.7
(L)	9	18	2.3	1.1	47.8
Oats (E)	8	9	88.9	21.1	23.7
(L)	8	11	13.7	2.4	17.5
(E)	8	13	53.4	6.6	12.4
Oats (E)	5	53	11.2	1.1	9.8
(L)	5	55	6.1	2.3	37.7
(L)	5	63	0.84	0.36	42.9
Wheat (L)	9	9	3.4	0.33	9.7
(L)	9	15	1.9	0.34	17.9
Wheat (L)	8	7	3.2	0.29	9.1
Wheat (L)	5	51	4.7	0.19	4.0
(E)	5	54	0.07	0.03	42.9
(L)	5	59	2.1	0.21	10.0

*Estimates based on 100 sweeps/field/sample date.

TABLE 37a: Density in different ages of spring oats per sweep per season of CLB larvae and larvae parasitized by *T. julis* (total area under seasonal curve ÷ developmental time) and effective parasitism by *T. julis* in different sections at Gull Lake in 1973.

Crop	Section	Field	CLB larvae /sweep	Parasitized larvae/sweep	% Parasitism (effective)
Oats (L)	9	9	0.24	0.21	87.5
(E)	9	13	1.31	0.74	56.5
(E)	9	15	2.16	1.27	58.8
(E)	9	17	3.97	0.53	13.4
(E)	9	25	5.30	1.99	37.5
Oats (E)	8	7	3.52	0.56	15.9
(L)	8	9	0.85	0.20	23.5
(E)	8	11	4.35	0.56	12.9
(E)	8	34	1.89	0.21	11.1
Oats (L)	5	51	0.06	0.0	0.0
(E)	5	54	1.15	0.36	31.3
(E)	5	61	5.63	1.40	24.9

TABLE 37b: Density in different ages of winter wheat per sweep per season of CLB larvae and larvae parasitized by _T. julis_ (total area under seasonal curve ÷ developmental time) and effective parasitism by _T. julis_ in different sections at Gull Lake in 1973.

Crop	Section	Field	CLB larvae /sweep	Parasitized larvae/sweep	% Parasitism (effective)
Wheat (E)	9	7	0.20	0.06	30.0
(L)	9	11	0.46	0.29	63.0
(E)	9	19	0.34	0.16	47.1
Wheat (E)	8	8	0.70	0.31	44.3
(L)	8	13	1.32	0.75	56.8
Wheat (E)	5	52	0.29	0.06	20.7
(L)	5	56	0.67	0.24	35.8
(E)	5	58	0.41	0.03	7.3
(L)	5	62	1.58	0.33	20.9

region was obviously not a factor between 1972 and 1973 because this would have been reflected in increased larval densities in 1973 but emigration could have been a factor. The increased removal of individuals by T. julis from the population in 1973 further reduced population levels and, unless immigration into the area becomes a factor, populations should be extremely low in 1974.

The impact of T. julis on the CLB population can best be summarized by examining the information contained within data collected from soil samples after CLB pupation occurred: Table 38 shows the ratio of cells containing diapausing T. julis larvae to total CLB cells per 1/2 yd^2 sampled from normally planted oat fields from the 3 sections examined during this investigation. In 1969, Stehr (1970) reported a density of .25 parasitized cells per 1/2 yd^2, and Helgesen (1969) estimated a density of 34.3 ± 3.6 CLB pupal cells per 1/2 yd^2 in an oat field where Stehr's samples were taken (section 9). Using these estimates, the ratio of parasitized cells to total cells is .007 for that field. The estimate for 1970 in section 9 (Table 29) shows a 21-fold increase in the proportion of cells parasitized by T. julis between 1969-1970. Mortality of non-diapausing and diapausing T. julis as well as CLB prepupae, pupae, and CLB adults caused by high soil temperatures in 1971 showed a decrease in the proportion of CLB cells parasitized between 1970-1971 in section 9. Parasitism by T. julis has been increasing at different rates in three sections because of differences in CLB densities in the fields sampled, and because of the dynamics of the crop. For example, the total number of CLB cells in 1972 was 7.4 in normally planted oats in section 5, compared to 31.6 and 24.6 cells per 1/2 yd^2 in sections 9 and 8 respectively (Table 29).

TABLE 38: Ratio of CLB cells parasitized by *T. julis* to the total number of CLB pupal cells per 1/2 yd^2, determined from soil samples taken in early planted oat fields.

	Percent CLB cells parasitized ÷ 100		
Year	Section 5	Section 8	Section 9
1969	NS	NS	.007*
1970	NS	.002	.147
1971	.019	.009	.083
1972	.243	.053	.266
1973	.333	.350	.490

NS = not sampled

*See text.

The total number of cells parasitized by T. julis in sections 5 and 8 (1.3 and 1.8) was similar; but, because CLB densities were greater in section 8, the proportion parasitized was much lower. In 1973, the proportion parasitized continued to increase, whereas CLB density continued to decrease. The mortality attributed to different factors, including parasitism by T. julis, is shown in Table 39a and b where Table 39a shows the numbers per 1/2 yd^2, and Table 39b the percent mortality attributed to each component. T. julis actually contributes twice to mortality because more than one generation may be produced during a season. The contribution to mortality attributed by the non-diapausing generation was estimated by counting cells with T. julis emergence holes, even though this estimate is difficult because some cells are broken during pupal sampling. In these oat fields, about 30% of the mortality caused by T. julis can be attributed to the non-diapausing component of the parasite population. The non-diapausing parasites continue to attack CLB larvae and contribute to the non-diapausing mortality. Soil sampling also revealed that Diaparsis sp. and Lemophagus curtus have been operating at a low but relatively consistent level. Density estimates (Table 39a) reveal that although the populations of these parasites have not increased as rapidly as T. julis, relative mortality caused by these parasites has increased due to the decrease in CLB density. These two ichneumonids have been included together. Detection of these parasites by methods other than soil sampling has not been fruitful because densities have been too low to adequately monitor the populations at Gull Lake. Changes in total mortality caused by these ichneumonid parasites are shown in Table 39b. In 1973, the contribution of T. julis amounted to 74.5% of CLB pupal

TABLE 39a: Classification of CLB pupal mortality due to undetermined death and parasitism between 1970-1973 from oat fields in section 9 at Gull Lake. Density estimates are for 1/2 yd^2 samples.

Year	Mean no. cells	Dead CLB	*T. julis* Non-Diapausing	*T. julis* Diapausing	*D. carinifer* and *L. curtus*	n
1970	97.3±5.7	13.2±1.2	(6.81)	14.3±1.5	.03± .2	30
1971	59.1±8.1	12.9±2.6	1.9± .5	4.9±1.0	.1 ± .2	10
1972	31.6±4.0	3.5± .8	4.7± .7	9.5±2.0	.4 ± .1	10
1973	5.1± .9	.1± .1	1.3± .3	2.5± .6	.4 ± .1	14

TABLE 39b: Percent mortality ÷ 100 due to each of the components from density estimates given in Table 39a.

Year	Dead CLB	*T. julis* Non-Diapausing	*T. julis* Diapausing	*D. carinifer* and *L. curtus*	Σ M	% T.j.
1970	.135	(.070)	.147	.0003	.352	61.6
1971	.218	.032	.083	.0017	.335	34.3
1972	.111	.149	.301	.013	.574	78.4
1973	.020	.255	.490	.078	.843	88.4

() = estimated.

mortality or 88% of the total mortality for the combined effect of these components. *Diaparsis* sp. and *L. curtus* contributed 9.3% of the combined mortality. The distribution, density, and mortality attributed to these factors in 1973 are shown in Table 40a and 40b.

Interaction of T. julis with A. flavipes. *A. flavipes*, a mymarid parasite of CLB eggs, was the first biotic agent brought to North America for the purpose of biological control of the CLB. Its establishment in the U.S. was reported by Maltby *et al*. (1971). Early in this effort, Anderson and Paschke (1968) noted that the numbers of *A. flavipes* did not build up within a season until late in the CLB egg population. This observation was confirmed in Michigan by Morris and Moorehead (1971). Gage and Miller (unpublished m.s.) showed this to also be true in southwestern Ontario in 1973. The significance of this delay in build-up, due to low overwintering densities of *A. flavipes*, and the subsequent rapid increase in parasitism of CLB eggs by *A. flavipes* at the end of the CLB egg population, has led to potential interaction between *A. flavipes* and *T. julis*.

This interaction is best illustrated by data collected from normal oats during the course of this study. The sequence of events, derived from population samples of CLB eggs, and the percent parasitism of CLB eggs by *A. flavipes* shows that egg parasitism builds up after peak egg density (Figure 29). The effectiveness of *A. flavipes* as a method for biological control of CLB populations is reduced due to this slow rate of increase during peak oviposition by CLB adults. The substantial increase in parasitism by *A. flavipes* after peak CLB egg density indicates that this mymarid is removing CLB eggs and, subsequently, larvae from the population within the same season. This

TABLE 40a: Classification of CLB pupal mortality due to undetermined death and parasitism in 1973 from oat fields in three sections at Gull Lake. Density estimates are from 14-1/2 yd^2 samples per field.

Section-Field	Mean no. cells	Dead CLB	*T. julis* Non-Diapausing	*T. julis* Diapausing	*D. carinifer* and *L. curtus*
9- 9	1.29	0.0	.43	.64	0.0
9-13	5.29	.07	1.29	2.57	.43
9-15	7.71	.29	2.86	2.50	.57
9-25	6.79	.21	3.14	1.29	0.0
8- 7	8.00	.71	2.00	2.86	0.0
8- 9	1.93	.07	1.00	.36	0.0
8-11	2.71	.29	.93	.86	0.0
8-32	11.79	1.29	3.21	1.21	.07
8-34	3.64	.07	.24	.86	.07
5- 2	6.50	0.0	1.29	1.14	0.0
5-51	.86	.07	.36	.21	0.0
5-54	2.14	0.0	.57	1.14	0.0
5-59	2.00	.14	.57	.77	0.0
5-61	9.21	.07	.64	4.00	0.0
KRE*	6.80	.10	1.40	1.30	0.0

*A field 1/2 mile outside the boundary of the Kellogg Farm.

TABLE 40b: Percent mortality ÷ 100 due to each of the components from density estimates given in Table 40a.

Section-Field	Dead CLB	Non-Diapausing	Diapausing	*D. carinifer* and *L. curtus*	Total: Σ M	Total: % T.j.
9- 9	0.0	.333	.496	0.0	.829	100
9-13	.013	.244	.486	.081	.824	88.6
9-15	.038	.371	.324	.056	.789	88.1
9-25	.031	.462	.190	0.0	.683	95.5
8- 7	.089	.125	.358	0.0	.572	84.4
8- 9	.036	.109	.187	0.0	.332	89.2
8-11	.107	.133	.317	0.0	.557	80.8
8-32	.109	.272	.103	.07	.554	67.7
8-34	.019	.236	.236	.07	.561	84.1
5- 2	0.0	.198	.175	0.0	.373	100
5-51	.081	.419	.390	0.0	.890	80.9
5-54	0.0	.266	.533	0.0	.799	100
5-59	.070	.285	.244	0.0	.530	99.8
5-61	.008	.069	.434	0.0	.511	98.4
KRE*	.015	.206	.191	0.0	.412	96.4

*A field 1/2 mile outside the boundary of the Kellogg Farm.

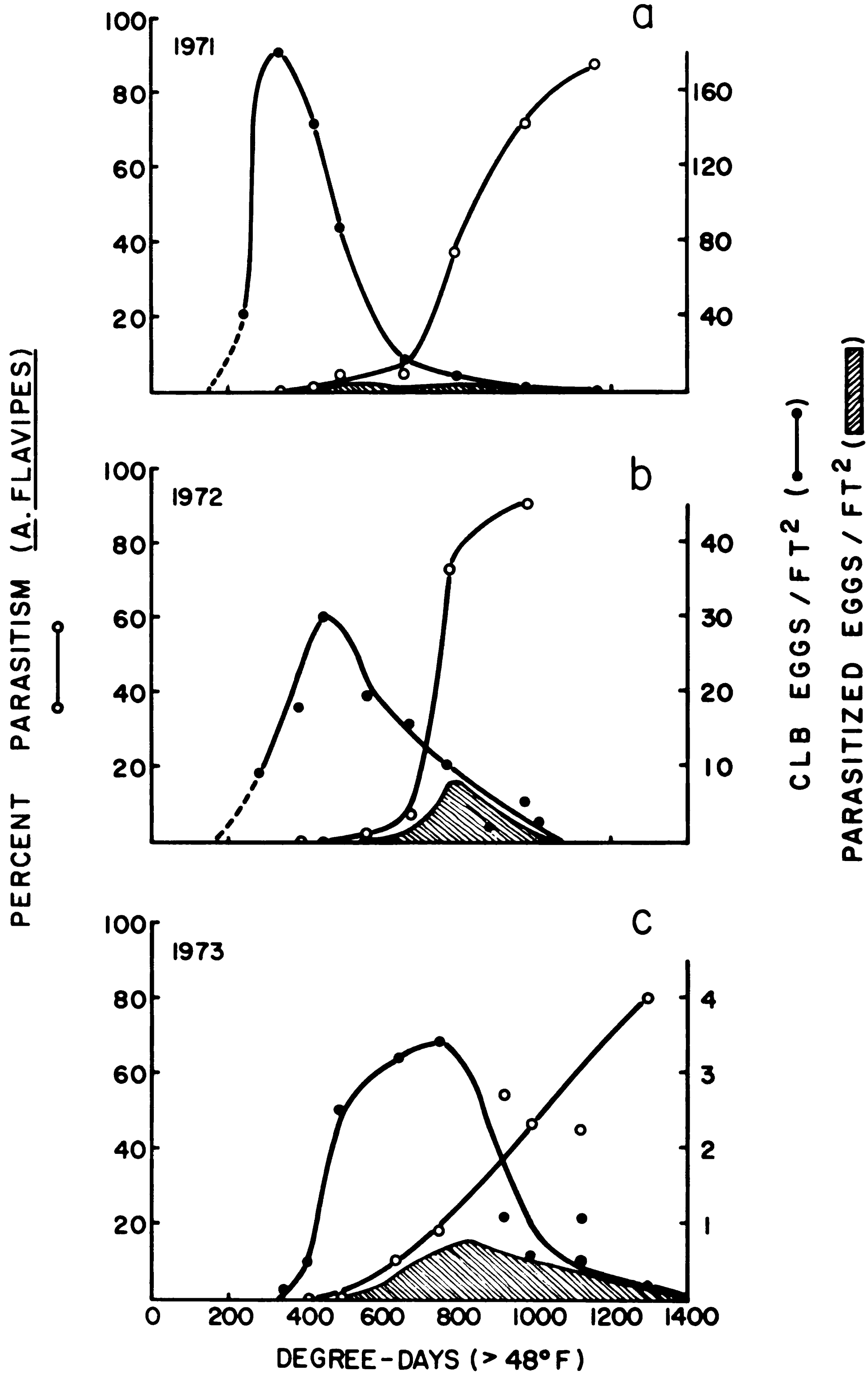


Fig. 29. The relationship between cereal leaf beetle egg density per ft^2 and percent parasitism by A. flavipes. The hatched area is number of parasitized eggs per ft^2.

population reduction caused by *A. flavipes* is not likely to be significant as a mechanism for controlling damage caused by the CLB population because of the delay in population build-up by *A. flavipes*. The removal of eggs laid late in the season by *A. flavipes* will produce the effect of fewer late CLB larvae. This will not reduce damage significantly; but, because *T. julis* has a partial second generation which is not optimally synchronized with the CLB larval population (Figure 29), the removal of eggs laid late in the season reduces the potential number of hosts available to the searching second generation *T. julis* adults. Since it is largely the parasite's second generation progeny which enter diapause and serve as the source population of the following spring, the removal of late larvae by *A. flavipes* reduces the numbers of *T. julis* which will be produced. This may have important consequences with respect to the numbers of CLB larvae parasitized during the first generation of *T. julis* which is, at present, the most effective generation for CLB population reduction. *A. flavipes* will undoubtedly reduce the response rate of *T. julis* to changes in CLB densities, and may also induce sufficient selection pressure against the second *T. julis* generation to eventually cause *T. julis* to have a single generation. Carl (1972) indicates that *T. julis* has only one generation in Switzerland, though in other European countries *T. julis* has two generations (Hodson 1929). It is unknown whether or not these differences in the number of *T. julis* generations are caused by pressure from *A. flavipes*, but it is important to investigate this possibility.

DISCUSSION

Some general management considerations. To place these quantitative descriptions of the interaction of parasites with the CLB in perspective, it is useful to represent these interactions in a conceptual framework. Figure 30 shows an initial attempt by members of the CLB research group to depict these interactions and some of the important parameters associated with them. Not all of these interactions have been fully evaluated, but sufficient understanding of the system has begun to evolve such that management of the CLB on a regional basis can be initiated while results from these preliminary efforts are further evaluated. The dark arrows in Figure 30 indicate specific locations where man-induced management strategies are feasible. For example, within the *T. julis* component, control of overwintering parasite survival depends on the degree of control over the disturbance of oat stubble prior to spring emergence. If stubble is plowed and disked, survival will be reduced significantly. The application of insecticides for control of CLB larvae feeding on the host plants will also determine whether or not *T. julis* will become an important factor in CLB management strategies. If CLB larvae are sprayed during peak parasitism, *T. julis* populations will be drastically reduced.

In addition to representing the CLB ecosystem in block diagram (Figure 30), it is essential to develop a general conceptualization of the time domains when specific interactions are occurring. When

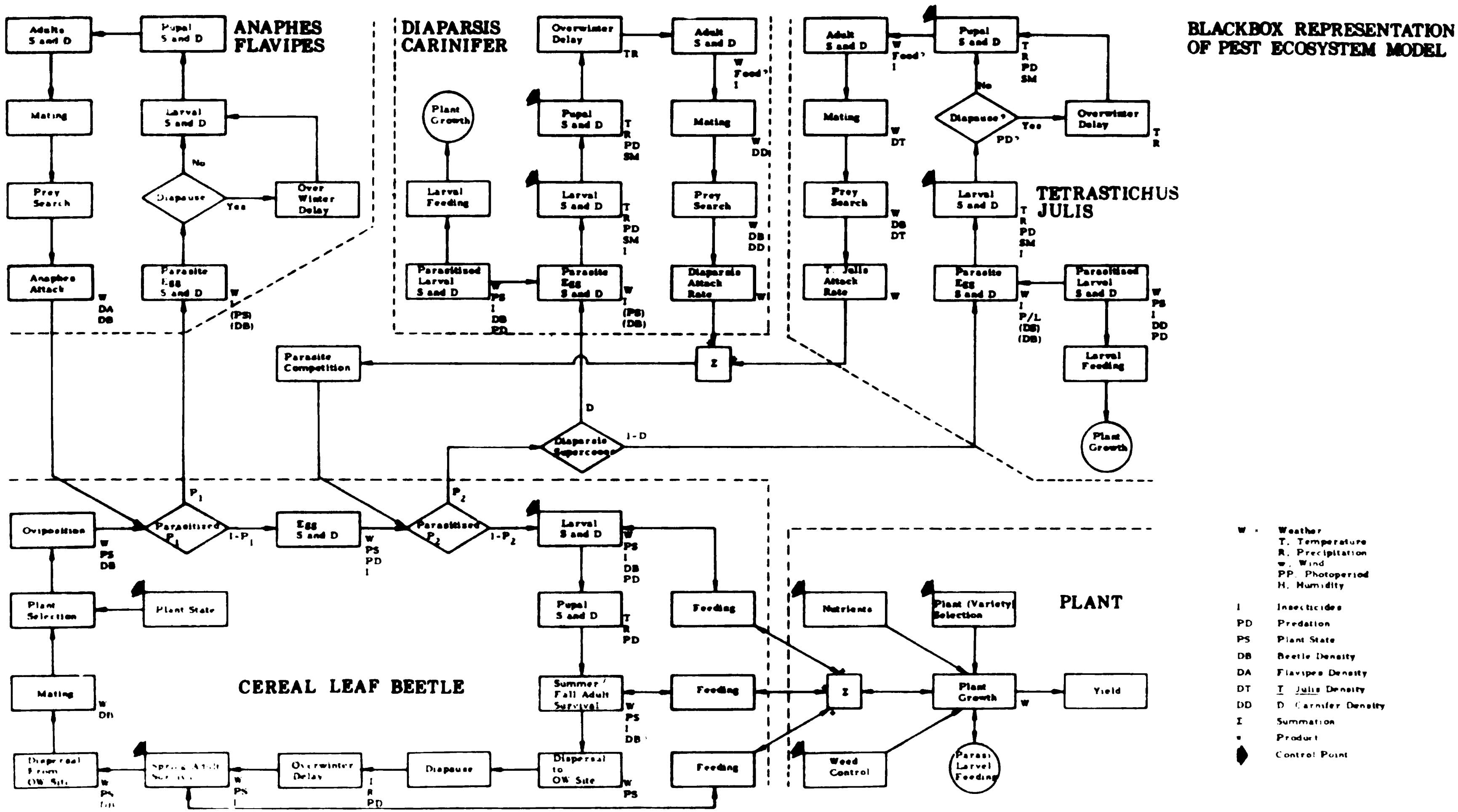


Fig. 30. A schematic representation of the cereal leaf beetle life system indicating mortality parameters and some potential control points.

specific actions need to be accomplished at certain times on CLB populations occurring in a region, these actions must be optimized depending on specific management objectives. The seasonal occurrence of the different interactions measured during this study are represented by a series of general figures showing the interrelationships of parasite dynamics with the CLB population. The values are based on the average conditions measured at Gull Lake, and each component is plotted over $°D_{48}$ so that this information can be applied regionally.

Figure 31 a-d represent parasitism of eggs and larvae by A. flavipes and T. julis respectively. Both the egg and larval population curves are represented by a maximum density of 100 per ft^2 for convenience. Egg parasitism is shown in Figure 31a where egg density is represented by open circles, percent parasitism by solid circles, and the number of eggs parasitized per ft^2 by the hatched area. Parasitism by A. flavipes begins about $400°D_{48}$ and does not begin to remove a significant number of eggs from the population until the end of the oviposition period. The removal of eggs from the population is shown in Figure 31b where the hatched area shows the number removed subtracted from total eggs available. To enhance the efficiency of A. flavipes, initial attack should begin about $200°D_{48}$ earlier, or at about the time when eggs are first oviposited. Parasitism by T. julis occurs early in the larval population. Figure 31c indicates that the overwintering generation removes the most significant number of larvae from the population, even though parasitism may approach 100% during the second generation. The number of larvae removed from the population is represented by Figure 31d. CLB larvae are not actually removed by T. julis because larvae are not killed until the pupal cell is formed in the soil.

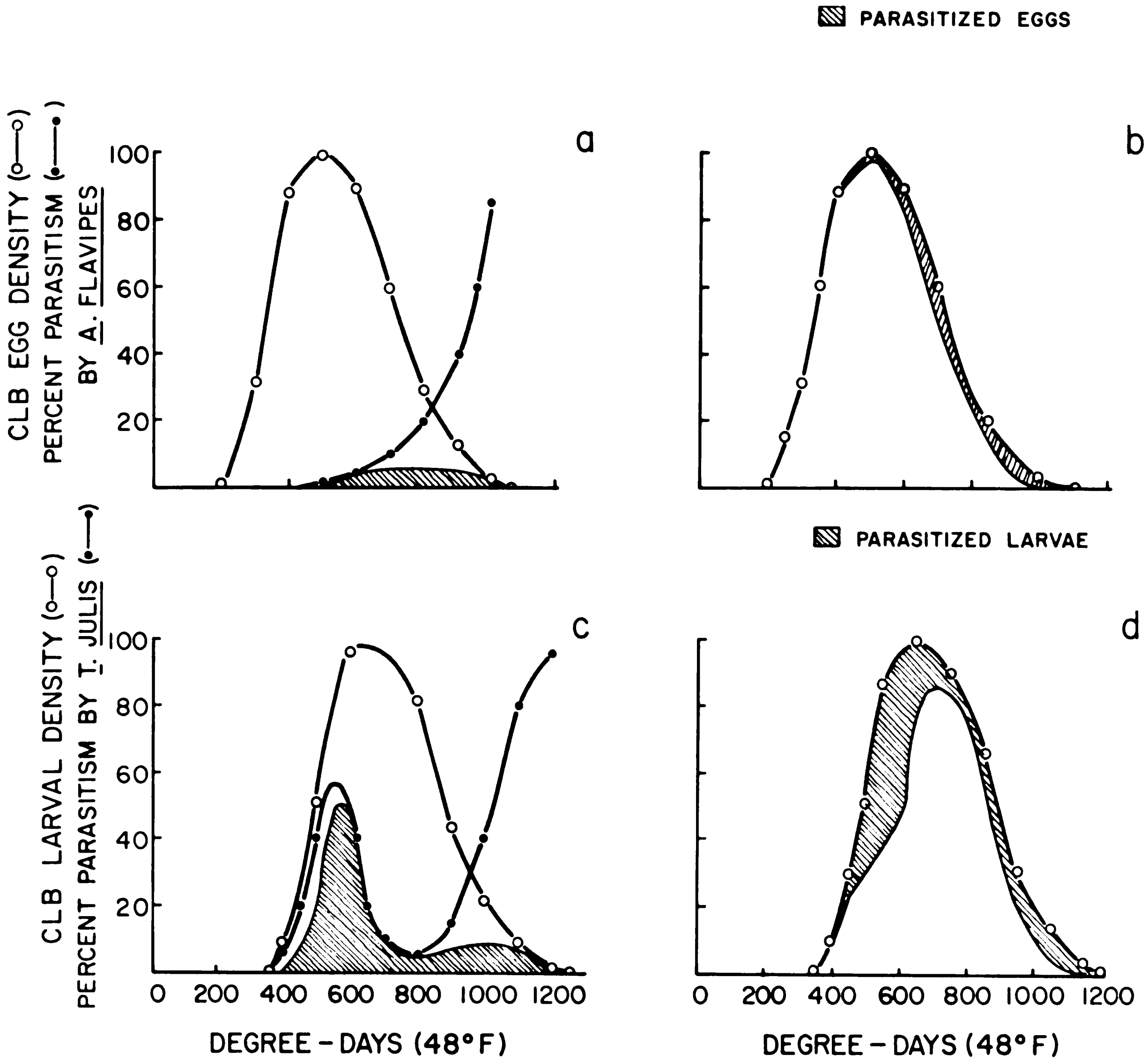


Fig. 31. General curves of cereal leaf beetle egg and larval densities and corresponding parasitism by A. flavipes and T. julis. Hatched areas show the numbers of individuals per ft^2.

With information on the seasonal dynamics of the CLB and *T. julis*, some management strategies can be formulated to enhance the survival of *T. julis*. The 3 principle considerations are as follows: (1) do not disturb the previous year's oat stubble until about 80% of *T. julis* emergence is completed (600°D_{48}); (2) encouarge the practice of seeding oats and alfalfa together so that a crop can be obtained; and (3) if CLB densities are sufficiently high to warrent control using pesticides in areas where *T. julis* is operating reduce egg input by spraying adult beetles in the crop before 350°D_{48}. Perhaps seeding oats and alfalfa together will have the most important impact on increasing parasite populations, since oat stubble would be protected from plowing until after parasites have emerged. This practice involves planting oats and alfalfa at the same time. The oats grow more rapidly and can be harvested. The following years alfalfa can be harvested. Caution must be exercised because problems may arise due to damage caused by alfalfa weevil and to protect the alfalfa, application of insecticide may be necessary for alfalfa weevil control. Spraying should occur prior to *T. julis* emergence in the spring (300°D_{48}).

Regional management of the CLB using *T. julis* as the principle biological control component. One of the principle objectives of this study was to learn enough about the biology of *T. julis* and its impact on CLB populations so that it could be used as one of a number of strategies for CLB control on a regional basis. *T. julis* populations increased rapidly during 1970 and by the fall of that year, overwintering density of *T. julis* was locally high in a few oat strips near the original release site (Section 9: fields 9-13). To capitalize on these high densities, a plan was envisioned to distribute *T. julis* throughout Michigan with help from the Agricultural Extension Service. Information on the CLB and its parasites was presented to county agents who were invited to attend a "biological control day" at Gull Lake. Under the direction of Drs. F. W. Stehr, R. J. Sauer, D. L. Haynes, and other Michigan State University personnel, the county agents were shown the methods for collection and release of CLB larvae parasitized by *T. julis*. In 1971, each participating county agent collected larvae from a specific oat field which was sampled prior to the collection date to determine the proportion of the CLB larvae parasitized. The collection date was estimated about 3 weeks in advance from *T. julis* emergence information and parasitism by *T. julis* on the collection day was 40-50%. This procedure was repeated in 1972; but, by 1973 the CLB population was low and mass collecting was difficult. In addition to collections made by county agents for distribution in Michigan, U.S.D.A. personnel collected CLB larvae weekly from the same fields at Gull Lake for distribution to other states (Table 41).

An integral part of this release strategy is the necessity of surveys to determine establishment of the parasite and its success in the management of the CLB population. The current method (R. J. Sauer and F. W. Stehr, personal communication) is sweep sampling of oat fields near release sites by county agents and the return of the samples to M.S.U. for dissection. One of the difficulties in accomplishing this task is determining the optimum sampling time for peak parasitism on a statewide basis. Regional variability in temperature on a north-south gradient affects development of both the CLB and parasite populations. Unfortunately, it is not possible to monitor the parasite populations

TABLE 41: Total number of CLB larvae collected by U.S.D.A. personnel at the Gull Lake field insectary and estimates of total parasitized CLB larvae by *T. julis*.

Year	No. CLB larvae collected	No. CLB larvae parasitized
1971	70,913	26,354
1972	108,800	58,752
1973	60,000	42,090

in each release site to determine when to collect larvae during peak parasitism. Accurate assessment of the collection time is important because of the short time interval during which the first generation of T. julis attacks CLB larvae in oats (400-800°D_{48}). This degree-day interval represents the span of attack during the first generation; but, to estimate when the maximum number of parasitized larvae occur in the field, a more precise estimate is necessary.

One of the primary components for estimating the occurrence of T. julis, and its subsequent attack of the CLB in oats, is the definition of a general emergence curve. The emergence curve in Figure 10 was generated from daily emergence measured at Gull Lake (1971-1973) and represents an average emergence of the T. julis population from oat stubble at Gull Lake. This curve can now be used as a regional estimator of emergence of T. julis in Michigan in any year if temperature information is available from sites where T. julis emergence may occur. To illustrate this, 18 temperature recording sites in Michigan were used to map emergence at 5-day intervals during the parasite emergence period. The rational for using only 18 stations was (1) to illustrate the procedure (2) to provide hourly on-line temperature information since these 18 stations are airport weather stations (3) the degree of resolution necessary for estimating emergence on a regional basis has yet to be tested, and (4) models are presently being developed to relate these on-line stations to other stations in Michigan (Fulton, personal communication).

Parasite emergence classes in °D_{48} determined from the cumulative percent emergence curve (Figure 10) are listed in Table 42. Corresponding to each class is the symbol used to map emergence at 5-day

TABLE 42: Symbolic reference table for decision making maps of first generation *T. julis* emergence (Figures 32 and 33).

Emergence class (°D_{48})	Percent cumulative emergence	Symbol
0 - 373	0 - 5	....1.... ....
374 - 452	6 - 25	+++++++++ +++++++++ ++++2++++ +++++++++ +++++++++
453 - 505	26 - 50	000000000 000000000 000030000 000000000 000000000
506 - 557	51 - 75	θθθθθθθθθ θθθθθθθθθ θθθθ4θθθθ θθθθθθθθθ θθθθθθθθθ
558 - 637	76 - 95	ΠΠΠΠΠΠΠΠΠ ΠΠΠΠΠΠΠΠΠ ΠΠΠΠ5ΠΠΠΠ ΠΠΠΠΠΠΠΠΠ ΠΠΠΠΠΠΠΠΠ
above 638	96	HHHHHHHHH HHHHHHHHH HHHHNHHHH HHHHHHHHH HHHHHHHHH

intervals using a computer mapping package written by the Harvard School of Graphics and Design and described by Fulton (in preparation). Figures 32 and 33 (A-I) show a chronological sequence of _T. julis_ emergence classes and a comparison of 1971 and 1972 emergence patterns in Michigan. These maps can be used for decision making as soon as capabilities for on-line access of temperature information from the weather stations is available. Between-year differences in air temperature, reflected by accumulation of $^{\circ}D_{48}$ at each of the 18 temperature collecting stations indicate dynamic shifts that are important in management decisions concerning CLB populations. Care must be taken to avoid pesticide use during critical periods that would eliminate parasite populations. An important period of _T. julis_ emergence occurs when between 25-50% of the adults have emerged. This period occurs between 452-505$^{\circ}D_{48}$ and is represented in Figures 32 and 33 as an open circle (O). In 1971, Figure 32 shows that this emergence period had not yet occurred in the lower portion of Michigan by day 150, but by the same day in 1972 (Figure 33) this emergence period had occurred. By day 165 the heat accumulated in 1971 was similar to that accumulated in 1972 indicating a "hot spell" during mid-June in parts of the lower peninsula of Michigan. If decision making or sampling depended on accurate assessment of the adult parasite between 25-50% emergence, and if the sampling was done on day 150 in both years in the southern third of Michigan, the 1971 sample would have been too early (5-25%) compared to 1972 (25-50%). This example is one of many that can be used to illustrate the importance of accurate assessment of the occurrence of _T. julis_ on a regional basis. Each of the parasite release locations are indicated on each map with a small asterisk (*). These dynamic

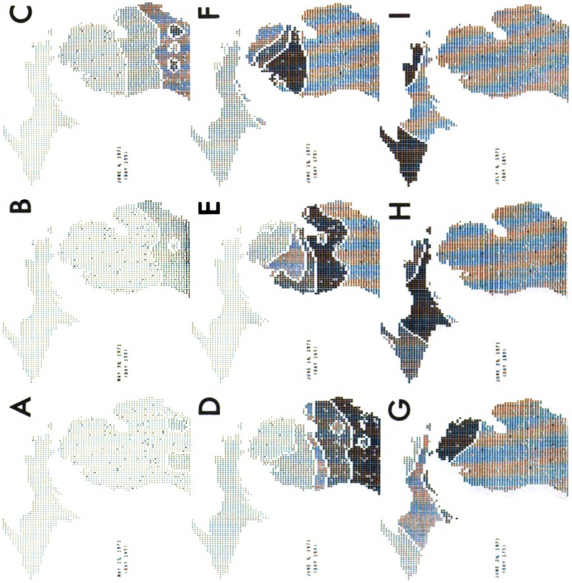


Fig. 32. Regional emergence of first generation T. *julis* adults at five-day intervals in 1971. (See Table 42 for emergence class intervals).

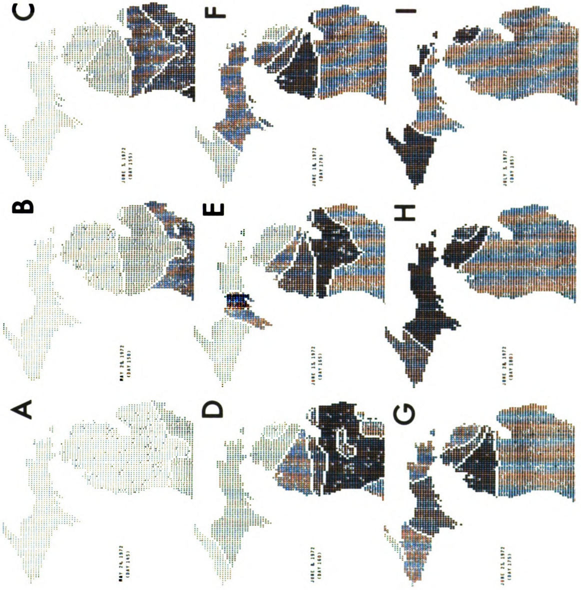


Fig. 33. Regional emergence of first generation T. julis adults at five-day intervals in 1972. (See Table 42 for emergence class intervals).

maps can guide researchers in making decisions concerning location of resources for evaluation of parasite influence on CLB populations.

Another approach that can be taken to enhance practical recommendations and decisions made for control of CLB populations is to provide information pertaining to biological windows. These windows are time areas within the seasonal population cycles when decisions can be made which may reduce damage to the crop, while avoiding interference with the biological control entities which are operating on the population. One example that has been examined recently at Gull Lake is that of optimal timing of alfalfa harvest (Casagrande and Stehr 1973). The seasonal occurrence of the CLB and the interaction of specific life stages with T. julis offer an examination of this concept. Current control recommendations are directed against CLB larvae. These recommendations are in direct conflict with T. julis as it attacks CLB larvae at about the same time when pesticide application is recommended. We obviously must examine these procedures in view of the efforts placed on biological control of the CLB using T. julis by the same extension personnel who are encouraged to recommend specific pesticides and the timing for their application by farmers. Until biological control was introduced into the CLB life system, there was little need for a critical examination of the recommendations except for changing pesticides to comply with current regulations. The options at the present time are to recommend not to use pesticides where T. julis is present, or to spray when the parasite is not present. The first option is not very feasable because, in certain cases, CLB populations must be reduced below levels which may cause economic damage. The second option entails applying pesticides to adult beetles when they are ovipositing in the oat crop. The rational behind this suggestion is to reduce adult populations prior to oviposition and prior to initial emergence of the T. julis population. By directing control against adults when adult densities are high enough to warrant control, populations will be reduced, but a portion of the population will survive because the currently recommended treatment (malathion) does not kill eggs. This may be beneficial because T. julis requires CLB larvae to parasitize. To illustrate the dynamics of directing control at a biological window, Figures 34 and 35 (a-f) represent the period when the first eggs begin to appear in oats until the initiation of emergence by T. julis (173-300°D_{48}). The maps in Figures 34 and 35 show the appearance of this window throughout Michigan at 5-day intervals starting at day 130. The areas indicated by (x) on the map represent the area where control could be directed, at that time, if CLB density warrants it. Between-year differences indicate that weather information must be taken into account. For example, by day 140 in 1971 (Figure 34c) control activities should have ceased in the lower third of the state to avoid destruction of the parasite population. On the same day in 1972 (Figure 35c) only a small area in the southern third of the state showed that spraying should stop to avoid killing parasites. Changes in the opening and closing of this window are caused by the dynamics of temperature which influence the dynamics of the insect population.

These examples of decision-making maps are based on historical data using only 18 weather stations in Michigan. They show that many management decisions are possible using the proper kind of biological information coupled with environmental data from throughout the region

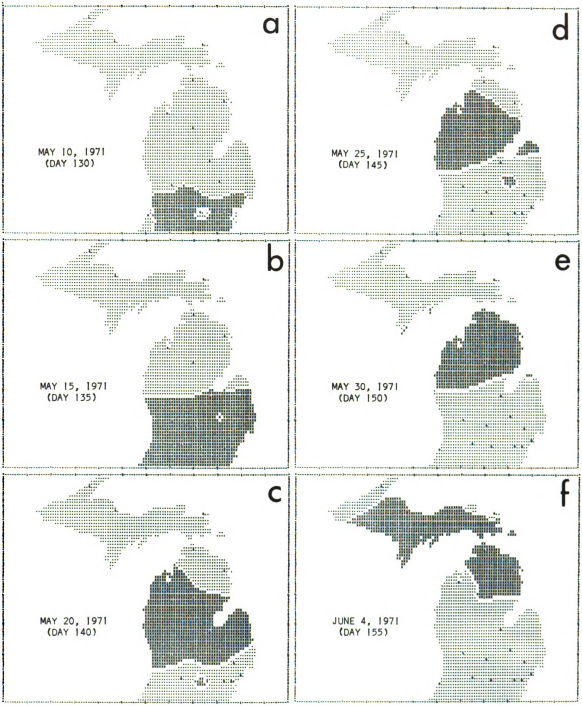


Fig. 34. Illustration of the concept of a biological window. The dark portion (x) indicates the region in Michigan in 1971 where control of adult cereal leaf beetles could be initiated using a short-lived pesticide (malathion) without killing _T. julis_ adults.

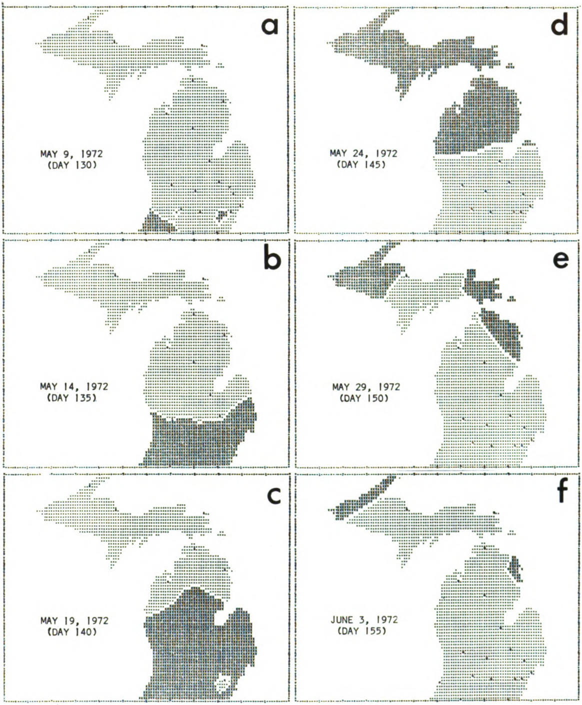


Fig. 35. Illustration of the concept of a biological window. The dark portion (x) indicates the region in Michigan in 1972 where control of adult cereal leaf beetles could be initiated using a short-lived pesticide (malathion) without killing <u>T. julis</u> adults.

where decisions are to be made. For such decision making to be useful on a real-time basis, on-line weather data is necessary. To date, researchers have not had this information and, therefore, have not been able to address themselves to real-time decision making. Such communication networks are available, and they will be operating shortly in Michigan (Haynes, personal communication).

Expansion of data collected at Gull Lake to a regional basis for interpretation of CLB and *T. julis* population interaction and management. Gull Lake is situated in northeastern Kalamazoo County, adjoining Barry and Calhoun Counties. These three counties represent the general area, with respect to oats, which produces the principle host crop of the CLB. Calhoun County produced about 35% more oats than did Kalamazoo or Barry, which together produced an average of 7,800 acres of oats or about 1.7% of the total oat crop harvested in Michigan during 1967-1972 (Woods *et al*. 1974). The major spring oat and winter wheat growing area in Michigan is shown in Figure 36 where the color gradient represents the average number of acres of oats harvested per county in Michigan in 1964 and 1970 per 1000 acres of land area.

The average number of acres of oats harvested is misleading because Michigan has been producing less oats each year since 1961 (Woods *et al*. 1974). This trend in reduced oat acreage is reflected in the average yearly production of oats in the three counties surrounding Gull Lake from 1967 to 1972 (Figure 37). It is interesting to compare this decline with the decline in CLB density over the same time span (Figure 25), but no attempt was made to derive any functional relationship between decrease in crop harvested and CLB population decline at Gull Lake.

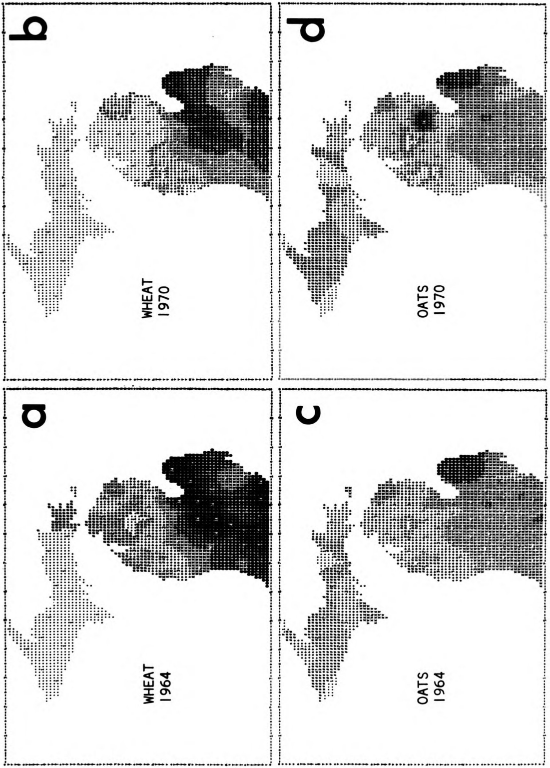


Fig. 36. Spring oat and winter wheat acres harvested in 1964 and 1970.

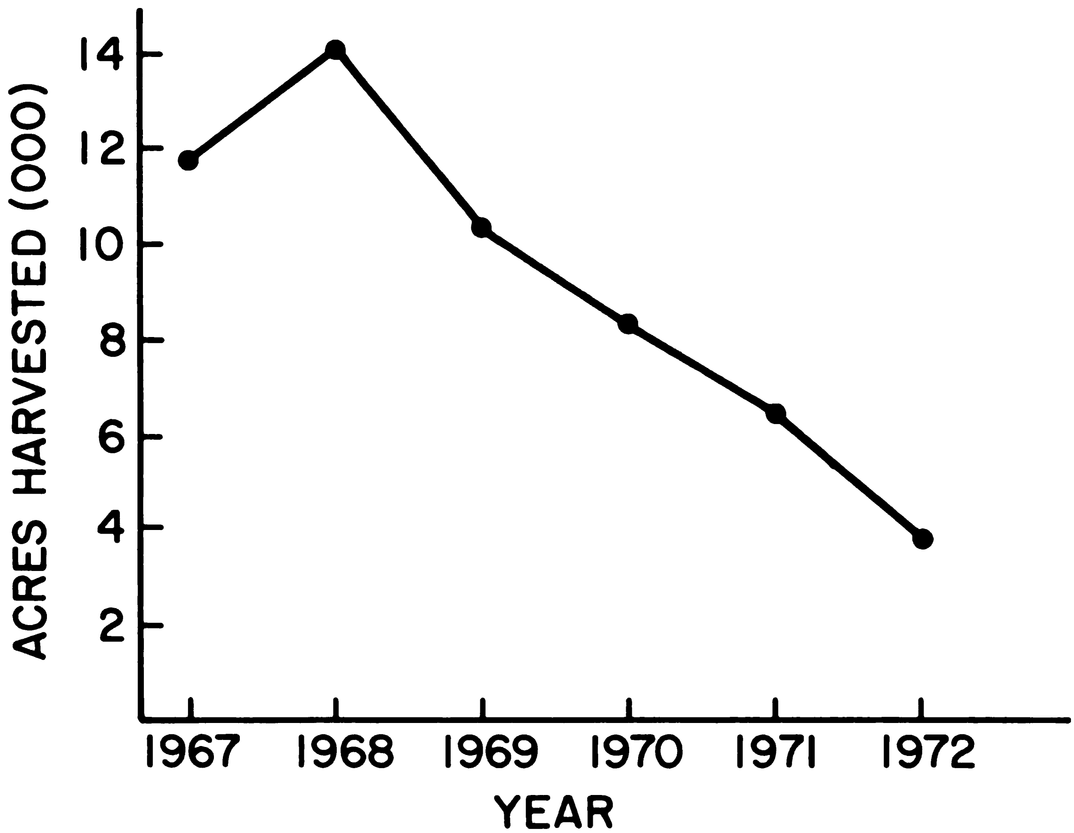


Fig. 37. Average acres of spring oats harvested in three counties surrounding Gull Lake, 1967-1972.

Information on crop yield is also available on a per county basis (Woods et al. 1974). The average oat yield per acre in Kalamazoo County from 1967-1972 indicated a significant reduction in oat yield in 1971 (Table 43). Environmental conditions in 1971 contributed to CLB and T. julis mortality (Table 15) and these same conditions may account for the poor oat yield. Using a combination of accumulated rainfall during May and June and heat at Gull Lake during June (RAIN/°D>85° F: Table 43), one can detect the importance of low rain and high heat in determining the low oat yield experienced in 1971. Although this analysis is not intended to be an explanation of the variability of oat yield, similar environmental parameters (rainfall and high temperatures during June) are important indicators of grain yield and CLB and T. julis mortality. The variability in levels of precipitation in Michigan for 10-day intervals during June for 1971 and 1972 is shown in Figure 38 (a-f). The increasing intensity of the overprint in Figure 38 indicates higher precipitation in each 10-day interval. Rainfall during mid-June best illustrates differences between 1971 and 1972 (Figure 38c and d).

This technique helps lead to some understanding of the various factors that may unfold within a season in a region, although there is little that can be done to manage rainfall or high temperatures that affect crop yield or CLB and T. julis mortality. However, these illustrations show that information derived from a detailed research program in a particular locality can provide some insight into what is occurring regionally. Of course, these extrapolations must be carefully examined.

TABLE 43: Total rainfall during May and June, $°D_{85}$ during June at Gull Lake, and average oat yield (bu./acre) in Kalamazoo Co. from 1967 to 1972.

Year	June ($°D_{85}$)	May + June Rain (in.)	$\frac{\text{May-June rain}}{°D_{85}\text{ June}}$	Kalamazoo Co. (bu./acre)
1967	2	8.46	4.23	48.4
1968	3	9.84	3.28	55.0
1969	2	8.39	4.20	53.9
1970	3	7.10	2.36	48.0
1971	23	3.96	.17	32.9
1972	0	6.49	6.49	52.6

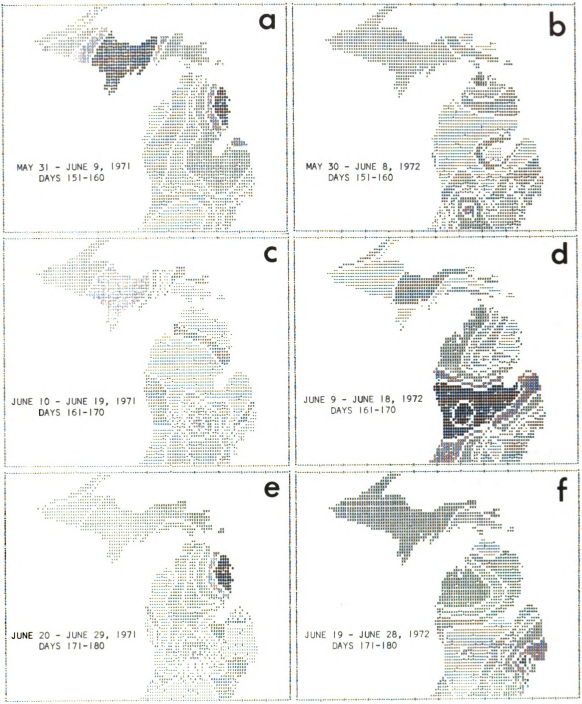


Fig. 38. Precipitation during ten-day intervals in June in 1971 and 1972. Darker areas represent increased amounts of rain.

One interesting feature was the cyclical nature of the CLB population measured in section 9 (Figure 23). T. julis was obviously inflicting significant mortality on the population at Gull Lake (Table 40a and b), but regional surveys (Haynes, personal communication, and Wilson, 1974) indicate that CLB densities have been declining. The parasite release program in Michigan began in 1971 and although recoveries of T. julis were obtained in about 40% of the release sites after one year (Stehr, personal communication), parasites did not have sufficient time to initiate the regional CLB decline which was first detected in 1970. The CLB larval population densities measured in oats at Gull Lake are compared with a regional estimate of the CLB population measured from about 30 oat fields in Jackson County (Table 44). The trend is similar in both populations. At Gull Lake, attempts were made to provide optimal conditions for the CLB by providing side-by-side plantings of different aged crops. Another factor, which cannot be discounted, is the effect of pesticides on the population in Jackson County. Indications are that the CLB population is increasing again in Berrion County where the original infestation started (Webster, personal communication). From these indications it is not clear what role parasites will play in regulating CLB populations on a regional basis. If T. julis builds up regionally as it has at Gull Lake, this parasite will obviously have an impact on the rate of build-up and decline of CLB populations. The reasons for the present cycle are not yet clear, but Haynes (personal communication) has suggested that genetic changes in the CLB population could account for the cycle.

TABLE 44: A comparison of CLB larval population densities per ft^2 at Gull Lake and in Jackson County.

Year	CLB larval incidence/ft^2	
	Gull Lake	Jackson Co.*
1967	19.4	11.8
1968	77.1	19.8
1969	197.9	115.6
1970	164.8	65.9
1971	58.8	16.2
1972	42.4	5.0
1973	3.6	5.7

*Peak larvae/sweep corrected to total incidence using two correction equations: one to correct larvae/sweep to larvae/ft^2, ($y = .26 + 2.6x$) and the second to correct peak larvae/ft^2 to total incidence per season ($y = 1.63 + 1.51x$).

It is hoped that researchers will use information from this study to continue examining the role of T. julis in the population dynamics of the cereal leaf beetle on a regional basis, and to develop management plans to optimize natural enemies like T. julis.

CONCLUSION

This study has been an attempt to piece together some of the biological phenomena that occur within and between two interacting insect species, a herbivore and one of its predators (parasites), within a three season interval in a limited area. There are drawbacks to limited area investigations because extrapolations to regional inferences about population behavior are often unwarranted. However, without detailed studies in some location, it is unlikely that realistic questions about host-parasite dynamics and regulation potentials could be asked, let alone answered, by regional surveys. One might argue that regulation would or would not occur whether or not such detailed studies were done. This may be true, but many of the observations were made around manipulation and this aspect of management must not be discounted. The particular manipulations attempted, and the results, have helped in the understanding of CLB-*T. julis* interaction and have also assisted in the guidance of the release program which resulted in considerable success, and may inevitably be a principle factor in the future reduction of CLB populations.

One of the major limitations encountered was the lack of information about the biology of *T. julis*. Although some initial surveys and observations were done by Dysart *et al.* (1973) on *T. julis* in Europe, these observations were limited. Until this study little was known about seasonal dynamics, behavior, diapause, fecundity, mortality, etc., of *T. julis* or whether or not it could potentially regulate CLB numbers, even in a limited area.

Fortunately, this study is not an isolated investigation, but an integral component of a project which also encompasses detailed, dynamic investigations of CLB adults, the host crop, and additional parasites as well as regional and international studies which will eventually be compiled as a model study of the understanding of an introduced pest.

There are several points which warrant specific comment. Biological investigations of the behavior of *T. julis* should be continued. In particular, it would be useful to quantify attack by *T. julis* females under field conditions and develop an attack model for this parasite. Diapause of *T. julis* was described but, because of conflicting information in Europe concerning the number of generations of *T. julis*, the proportion of *T. julis* entering diapause through time should continue to be measured. There may be possible shifts in the diapause curve resulting from pressure from *A. flavipes* and other factors.

Work should also continue on monitoring CLB and *T. julis* populations at Gull Lake. The cyclical nature of the CLB population at Gull Lake indicates that the CLB species is dynamic, and specific experiments should be conducted to determine the cause of the changes in density when food is not limited.

Several procedures have been suggested for optimizing sampling of parasite populations and management of CLB populations with specific reference to *T. julis* populations. This information was extrapolated from Gull Lake data to Michigan. Although the principles are sound, the suggested procedures should be carefully evaluated under field conditions to test projected parasite population synchrony in order that sound management procedures may be put into practice.

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APPENDICES

Appendix I: Density per ft.^{2} of cereal leaf beetle life stages in wheat with associated crop biomass information (1971).

Date	DD_{48}	Eggs	Instar I	Instar II	Instar III	Instar IV	Total larvae	No. tillers	Wet weight	Oven dry wt.
					T--WHEAT (E)					
5/ 4	164	7.5±1.7*	0.0	0.0	0.0	0.0	0.0	129.1±6.3	86.3± 4.3	19.9±1.0
5/11	235	9.5±1.2	0.0	0.0	0.0	0.0	0.0	92.4±6.2	104.0± 8.8	21.0±1.4
5/18	332	2.6± .7	0.0	0.0	0.0	0.0	0.0	74.3±5.0	117.8± 5.3	30.6±1.0
5/25	422	3.5±1.0	.9± .3	.1± .1	0.0	0.0	1.0	66.0±4.1	155.4±11.6	32.0±3.1
6/ 1	491	4.9±1.0	.7± .3	.7± .2	.1± .1	0.0	1.5	60.0±3.5	167.5± 9.2	44.1±2.4
6/ 9	660	.5± .2	.1± .1	.1± .1	.2± .1	1.1±.03	1.5	61.5±4.2	161.0±16.1	57.3±4.0
6/15	793	1.3± .7	.2± .2	0.0	.1± .1	0.0	.3	60.7±4.7	172.4±10.2	64.6±3.7
6/22	976	.4± .3	.1± .1	0.0	0.0	0.0	.1	54.1±4.8	137.6±11.0	72.5±5.3
					R--WHEAT (E)					
5/ 4	164	5.4± .1	0.0	0.0	0.0		0.0	189.0±7.0	145.9± 6.5	32.0±1.4
5/11	235	6.5± .1	0.0	0.0	0.0		0.0	145.3±6.3	164.8±12.0	33.2±1.1
5/18	332	12.6±2.6	0.0	0.0	0.0		0.0	102.9±7.7	225.0±13.2	48.7±2.3
5/25	422	4.6± .7	.6± .2	0.0	0.0		.6	86.5±4.9	258.8±19.2	86.5±4.9
6/ 1	491	8.6±2.0	.7± .3	.1± .1	0.0		.8	75.5±3.9	274.9±19.6	62.5±3.1
6/ 9	660	.5± .2	0.0	.3± .1	.2± .1	.3± .1	.8	77.1±2.5	265.3±15.1	79.0±2.1
6/15	793	.3± .2	0.0	.1± .1	.1± .1	.1± .1	.3	62.1±3.0	201.7±11.2	76.1±4.1
6/22	976	0.0	0.0	0.0	0.0	0.0	0.0	61.0±14.1	192.8±16.0	88.1±6.3
					B--WHEAT (E)					
5/ 4	164	3.2± .7	0.0	0.0	0.0	0.0	0.0	153.7±5.7	114.7± 6.4	27.0±1.3
5/11	235	2.7± .4	0.0	0.0	0.0	0.0	0.0	140.3±5.4	140.6± 8.3	31.8±2.7
5/18	332	4.5± .9	0.0	0.0	0.0	0.0	0.0	93.3±5.7	134.1±10.9	34.8±2.6
5/25	422	2.7±1.0	.4± .2	0.0	0.0	0.0	.4	76.1±6.2	203.0±12.3	42.1±2.0
6/ 1	491	2.0± .8	.2± .1	0.0	.1± .1	.1± .1	.4	80.6±3.1	221.0±13.6	52.3±3.2
6/ 9	660	.6± .3	0.0	0.0	0.0	.1± .1	.1	63.7±2.7	162.4± 8.5	57.4±2.6
6/15	793	1.1± .5	.7± .4	0.0	.2± .1	.1± .1	.1	64.0±4.8	209.4±20.1	78.2±7.0
6/22	976	0.0	0.0	0.0	0.0	0.0	0.0	61.0±4.7	151.8±12.8	74.4±5.6

* $\overline{X}$ ± S.E. (n=15)

Appendix II: Density per ft.^{2} of cereal leaf beetle life stages in oats with associated crop biomass information (1971).

Date	DD_{48}	Eggs	Instar I	Instar II	Instar III	Instar IV	Total larvae	No. tillers	Wet weight	Oven dry weight
					T--OATS (E)					
5/18	332	57.9± 5.7*	.1± .1	0.0	0.0	0.0	.1	46.4±2.7	14.3± .8	2.0± .1
5/25	422	29.3± 3.3	10.5±2.3	1.4± .3	0.0	0.0	11.9	52.8±2.9	33.4± 1.8	3.9± .2
6/ 1	491	19.0± 2.0	8.0±1.5	12.3±1.7	3.9±1.1	0.0	24.2	63.8±3.7	79.0± 4.4	10.0± .5
6/ 9	660	5.9± 1.4	.9± .3	3.2± .8	4.4±1.0	13.0±2.0	21.5	53.9±3.5	102.3± 9.6	15.6±1.2
6/15	793	5.5± 1.2	.7± .3	.7± .3	.8± .5	1.8± .3	4.0	42.7±2.8	132.1±11.2	20.1±1.4
6/22	976	.7± .3	0.0	.1± .1	.2± .1	.9± .4	1.2	35.1±1.8	120.0±10.5	32.8±2.3
6/29	1194	.3± .3	0.0	0.0	0.0	.1± .1	.1	32.0±2.7	92.1± 8.9	35.6±3.3
					R--OATS (E)					
5/12	241	41.9± 3.7	0.0	0.0	0.0		0.0	34.0±3.8	4.6± .3	.6± .03
5/18	332	151.8± 7.8	.1± .1	0.0	0.0		.1	49.3±3.2	13.2± .8	1.8± .1
5/25	422	133.8±14.2	9.6±1.7	1.9± .6	0.0		11.5	56.9±2.1	38.2± 1.9	4.8± .2
6/ 1	491	87.6± 9.9	24.7±3.0	13.5±2.3	.4± .2		28.0	59.6±2.9	73.5± 3.9	8.4± .4
6/ 9	660	16.9± 3.1	9.4±3.3	14.4±2.5	22.7±2.2	26.3±3.2	72.8	61.6±2.1	151.8± 6.3	18.3± .6
6/15	793	8.3± 3.4	2.0± .7	6.4±1.5	7.5±1.4	13.0±1.9	28.9	50.1±3.7	164.3±15.9	23.9±1.8
6/22	976	.4± .3	.7± .1	.5± .4	2.7± .6	2.5± .8	6.4	41.9±2.3	113.6± 2.3	30.2±1.5
					B--OATS (E)					
5/18	332	48.0± 7.8	0.0	0.0	0.0	0.0	0.0	23.2±2.4	5.3± .5	.8± .1
5/25	422	58.2± 4.6	1.8± .6	.1± .1	0.0	0.0	1.9	43.5±3.1	24.8± 2.2	2.9± .2
6/ 1	491	53.9± 6.2	8.5±2.0	6.2±2.3	.3± .1	0.0	15.0	43.4±2.8	44.9± 4.1	5.4± .4
6/ 9	660	11.5± 2.1	6.7±1.9	9.4±1.3	8.1±1.5	8.5±1.7	32.7	39.1±2.2	73.2± 4.8	11.0± .6
6/15	793	6.3± 1.5	.5± .5	4.8±1.1	4.0±1.2	5.6±1.1	14.9	29.7±2.2	83.3± 6.5	13.4±1.0
6/22	976	2.2± 1.1	.5± .5	1.4± .5	2.3± .8	4.2±1.0	7.4	30.0±1.8	100.2± 7.5	25.1±1.0

* $\overline{X} \pm$ S.E. (n=15)

Appendix III: Density per ft^2 of cereal leaf beetle life stages in wheat with associated crop biomass information (1972).

Date	DD_{48}	Eggs (crop)	Eggs (grass)	Instar I	Instar II	Instar III	Instar IV	Total larvae	Crop wet weight	Grass wet weight
					WHEAT (A)					
5/10	195	.5± .3*	.1±.1	0.0	0.0	0.0	0.0	0.0	80.9± 5.4	9.7±2.6
5/17	276	1.2± .4	.3±.2	0.0	0.0	0.0	0.0	0.0	135.8± 9.4	21.3±3.7
5/22	376	1.1± .4	.2±.1	.1±.1	0.0	0.0	0.0	.1	180.2±13.6	20.7±3.1
5/25	446	1.5± .5	.5±.3	.1±.1	.2±.1	.1±.1	0.0	.4	187.5±11.6	23.5±6.0
6/ 2	570	.3± .2	0.0	.3±.2	0.0	0.0	.1±.1	.3	230.5±11.8	22.8±5.2
6/ 8	691	.5± .3	0.0	.2±.2	.6±.1	.3±.2	1.7±.4	2.8		
					WHEAT (B)					
5/10	195	1.9± .4	.1±.1	0.0	0.0	0.0	0.0	0.0	44.5± 3.3	1.0± .3
5/17	276	4.5± .6	.1±.1	0.0	0.0	0.0	0.0	0.0	85.2± 2.4	2.5± .9
5/22	376	5.1± .6	.1±.1	.5±.2	.1±.1	0.0	0.0	.6	166.2±19.3	3.4±1.1
5/25	446	3.7± .6	0.0	.4±.2	.8±.3	.1±.1	0.0	1.3	180.4±13.7	4.7±1.3
6/ 2	570	1.5± .4	.1±.1	.5±.2	.9±.3	.7±.2	.6±.2	2.8	190.8±12.4	3.7±1.1
6/ 8	691	.7± .4	0.0	.1±.9	.9±.3	.7±.3	.4±.2	1.5	182.4±11.7	5.1±1.4
6/14	801	0.0	0.0	.3±.1	.2±.1	.3±.2	1.1±.3	1.8	185.5±12.3	7.2±2.2
6/21	930	0.0	0.0	0.0	0.0	.1±.1	.1±.1	.2	184.5±12.1	9.0±2.3
					WHEAT (C)					
5/10	195	2.3± .6	0.0	0.0	0.0	0.0	0.0	0.0	12.7± 1.1	.1± .1
5/17	276	1.3±1.4	.1±.1	0.0	0.0	0.0	0.0	0.0	32.5± 3.5	.4± .1
5/22	376	21.9±1.7	0.0	1.1±.3	.2±.1	0.0	0.0	1.3	63.6± 5.8	.5± .2
5/25	446	15.6±2.2	.1+.1	1.6±.4	2.0±.4	.4±.2	.1±.1	4.1	84.2± 4.3	1.0± .4
6/ 2	570	5.5± .7	0.0	3.3±.5	2.1±.5	.8±.3	.5±.2	6.5	100.3± 8.1	1.1± .3
6/ 8	691	.5± .2	0.0	.9±.3	1.5±.4	1.7±.4	1.3±.3	5.3	128.1± 9.0	1.3± .5
6/14	801	0.0	0.0	.1±.1	.4±.1	.8±.2	1.7±.3	3.0	137.6±16.4	1.3± .5
6/21	930	0.0	0.0	.1±.1	.1±.1	.3±.2	.3±.2	.9	150.4±11.4	2.8±1.1
6/28	1025	.1± .1	0.0	0.0	0.0	0.0	.1±.1	.1	147.5± 8.5	3.1±1.3

* $\overline{X}$ ± S.E. (n=15)

Appendix IV: Density per ft^2 of cereal leaf beetle life stages in oats with associated crop biomass information (1972).

Date	DD_{48}	Eggs (crop)	Eggs (grass)	Instar I	Instar II	Instar III	Instar IV	Total larvae	Crop wet weight	Grass wet weight
					OATS (A)					
5/10	195	W-- 2.1± .8*	0.0	0.0	0.0	0.0	0.0	0.0	3.2± .3	0.0
5/17	276	W-- 5.2± .8	.1±.1	0.0	0.0	0.0	0.0	0.0	2.6± .4	.6± .1
5/22	376	O--53.9±3.9	.2±.2	.5± .2	.7± .3	0.0	0.0	1.2	24.9± 3.3	.3± .1
		W-- 2.1± .9							3.0± 1.2	
5/25	446	O--47.1±4.5	.3±.3	2.9± .9	1.9± .5	0.0	0.0	4.8	34.0± 1.8	.8± .4
		W-- 1.9± .7							7.6± 2.2	
6/ 2	570	O--21.0±2.3	0.0	7.1±1.1	5.7± .9	2.3±.5	.6± .2	17.1	54.1± 3.1	.9± .4
		W-- .8± .3		.7± .3	.3± .2	.3±.3	.1± .1		18.7± 5.0	
6/ 8	691	O-- 6.5±1.7	0.0	2.7± .6	6.7±1.1	8.0±.9	5.8± .5	24.3	101.7±11.2	.1± .1
		W-- .1± .1		.1± .1	.3± .1	.3±.2	.3± .2		14.8± 2.8	
6/14	801	O-- 1.4± .5	0.0	.7± .3	1.6± .3	3.0±.6	8.6±1.6	13.8	91.5± 8.5	1.3± .9
		W-- 0.0							17.2± 3.6	
6/21	930	O-- .6± .3	0.0	.1± .1	.2± .1	.3±.2	1.1± .3	1.7	137.4±16.4	1.3± .5
		W-- 0.0		0.0	0.0	0.0	.1± .1		21.5± 5.7	
6/28	1025	O-- .3± .1	0.0	.1± .1	.1± .1	.3±.1	.3± .1	.9	127.8±12.1	1.7± .8
		W--							12.5± 3.8	
7/ 5	1158	O-- 0.0	0.0	0.0	0.0	0.0	0.0	0.0	164.1±21.9	2.9±2.2
					OATS (B)					
5/17	276	9.3±1.7	.1±.1	0.0	0.0	0.0	0.0	0.0	10.4± 1.1	.2± .1
5/22	376	18.3±1.7	.5±.3	.1± .1	0.0	0.0	0.0	.1	6.4± .6	1.5± .3
5/25	446	30.2±3.7	.1±.1	2.9± .8	1.5± .4	.5±.2	0.0	4.8	15.9± 1.2	1.4± .4
6/ 2	570	19.5±2.4	.1±.1	1.8± .4	3.0± .5	1.7±.5	.5± .2	6.9	30.3± 2.7	1. ± .4
6/ 8	691	15.7±2.4	.1±.1	1.9± .4	3.9± .7	1.9±.4	3.8± .6	11.5	94.8± 9.7	3.8±1.4
6/14	801	10.5±1.4	.2±.1	1.0± .2	3.5± .6	2.9±.6	2.9± .5	10.3	143.9±19.0	10.5±2.7
6/21	930	1.9± .6	0.0	.3± .2	1.2± .2	.7±.3	.7± .2	2.9	245.6±15.8	19.2±3.6
6/28	1025	6.8±1.2	.2±.1	.5± .2	1.3± .4	1.2±.2	1.9± .4	4.9	236.6±18.8	20.8±4.1
7/ 5	1158	2.7± .7	0.0	.1± .1	.3± .2	.3±.1	.1± .1	.8	263.0±29.1	10.3±2.3
					OATS (C)					
6/21	930	14.3±1.6	.9±.4	2.1± .5	2.8± .8	1.3±.4	1.3± .4	7.5	177.9±24.7	40.5±9.7
6/28	1025	7.4±2.1	.5±.3	.5± .3	1.6± .6	1.1±.4	.6± .4	3.9	132.9±24.7	31.7±7.7
7/ 5	1158	1.8± .5	0.0	.1± .1	.2± .1	.7±.1	1.0± .5	1.5	183.6±20.3	25.7±5.2

* $\overline{X}$ ± S.E. (n=15)

Appendix V: Density per ft^2 of cereal leaf beetle life stages in wheat with associated crop biomass information (1973).

Date	DD_{48}	Eggs	Instar I	Instar II	Instar III	Instar IV	Total larvae	Plant height	No. tillers	Wet weight
					WHEAT (E)					
5/16	347	.7±.3*	0.0	0.0	0.0	0.0	0.0			115.6±15.7
5/23	406	1.2±.2	.03±.03	0.0	0.0	0.0	.03	48.6±1.2		155.0± 9.0
5/31	495	.9±.2	.1±.1	0.0	0.0	0.0	.1	74.6±1.4		209.3±12.8
6/ 7	641	.4±.1	.1±.1	.3±.1	.2±.1	0.0	.6	91.9±1.6		281.3±13.1
6/12	775	0.0	.1±.1	.5±.2	.5±.2	.2±.1	1.2	105.9±1.5	49.4±2.3	278.0±14.6
6/18	917	0.0	0.0	.03±.03	.03±.03	.03±.03	.1	109.1±2.0	53.7±2.3	256.8±13.0
					WHEAT (L)					
5/23	406	1.1±.2	.03±.03	0.0	0.0	0.0	.03	32.5± .8		61.8± 4.4
5/31	495	1.1±.3	.3±.1	.03±.03	0.0	0.0	.4	51.2±1.0		113.7± 6.1
6/ 7	641	.2±.1	.1±.1	.2±.1	.2±.1	.03±.03	.6	69.2±1.8	40.5±1.8	195.6± 9.6
6/12	775	.03±.03	.1±.1	.5±.2	.4±.1	.4±.1	1.3	78.2±1.7	47.1±2.2	230.8±11.7
6/18	917	0.0	0.0	0.0	.03±.03	.1±.1	.1	91.7±2.1	35.1±1.6	180.8± 9.2
6/21	991	0.0	0.0	.03±.03	0.0	.1±.1	.1	93.4±1.4	35.9±2.3	183.2± 9.5

* $\overline{X} \pm$ S.E. (n=30)

Appendix VI: Density per ft^2 of cereal leaf beetle life stages in oats with associated crop biomass information (1973).

Date	DD_{48}	Eggs	Instar I	Instar II	Instar III	Instar IV	Total larvae	Plant height	No. tillers	Wet weight
					OATS (E)					
5/16	347	.1±.1*	0.0	0.0	0.0	0.0	0.0			2.4± .4
5/23	406	.5±.2	.03±.03	0.0	0.0	0.0	.03	13.4± .4		7.9± .6
5/31	495	2.5±.5	.1±.1	0.0	0.0	0.0	.1	19.5± .5		22.9± 1.8
6/ 7	641	3.2±.5	.4±.2	.2±.1	.03±.03	0.0	.7	28.8± .9	36.2±1.8	57.6± 4.7
6/12	775	3.4±.6	.4±.1	1.3±.2	.8±.2	.03±.03	2.5	34.5±1.0	37.4±2.5	91.5± 8.6
6/18	917	1.1±.2	.2±.1	.9±.2	.7±.2	.8±.2	2.6	49.5±1.8	36.5±1.4	156.8±10.2
6/21	991	.6±.2	.03±.03	.1±.1	.3±.1	.5±.1	.9	49.4±2.1	47.0±1.9	181.8±10.8
6/27	1119	1.1±.3	.03±.03	.1±.1	.1±.1	.2±.1	.4	61.5±1.1	43.8±3.1	210.8±10.4
7/ 5	1292	.2±.1	0.0	0.0	0.0	0.0	0.0	82.2±1.6	35.2±1.9	199.7±10.8
					OATS (L)					
5/31	495	.2±.1	.03±.03	0.0	0.0	0.0	.03	10.3± .4		3.1± .3
6/ 7	641	.8±.2	.1±.1	.03±.03	0.0	0.0	.1	19.0±1.4	33.8±2.2	18.4± 1.3
6/12	775	1.4±.3	.1±.1	.4±.2	.1±.1	0.0	.6	23.6± .7	37.2±1.6	36.8± 2.8
6/18	917	1.5±.4	.03±.03	.1±.1	.1±.1	.2±.1	.4	32.5±1.0	36.5±1.5	70.9± 5.3
6/21	991	.9±.2	0.0	0.0	.03±.03	0.0	.03	31.9±1.4	31.5±1.3	67.2± 5.8
6/27	1119	.9±.2	.03±.03	0.0	0.0	.1±.1	.1	43.1±1.2	37.4±2.9	114.0± 8.3
7/ 5	1292	.3±.2	0.0	0.0	0.0	0.0	0.0	61.9±1.3	45.6±2.5	167.9± 8.5
7/12	1473	0.0	0.0	0.0	0.0	0.0	0.0	70.9±1.2	48.3±2.6	150.5± 9.5

* $\overline{X}$ ± S.E. (n=30)