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EFFECTS OF MOLDBOARD PLOWING AND ATRAZINE ON ACARINA AND COLLEMBOLA

By

David Mallow

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ABSTRACT

THE EFFECTS OF MOLDBOARD PLOWING AND ATRAZINE ON ACARINA AND COLLEMBOLA

By

David Mallow

The effects of tillage and Atrazine upon soil Acarina and Collembola populations were evaluated.

Soil core samples were taken regularly during one growing season, and the fauna were extracted with Tullgren funnels. Statistical analyses were performed to determine if any quantitative changes occurred in treated plots compared to populations from grassland controls.

All treatments yielded similar results: populations of Acarina and Collembola were significantly reduced. Collembolan populations recovered during the growing season, while Acarina did not.

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INTRODUCTION

Studies which involved the role of soil microarthropods in organic decomposition, nutrient cycling, and soil humification, have shed light on their importance in soil ecology (Thompson, 1924; Engelman, 1961; Kevan, 1962; Frantz, 1962; Witkamp and Crossley, 1966; Butcher et al., 1971; and Lebrum, 1979). Cognizance of this importance has necessitated more precise investigations of current agricultural practices and their effects on soil microarthropod populations.

The objectives of this study were to determine the effects of conventional tillage and Atrazine on populations of soil Acarina and Collembola. Quantitative comparisons were made between field populations in grass control plots and treated plots.

Summarized below are the treatments evaluated in this study:

(I) Conventional tillage, using the moldboard plow, is the principal tillage method in Michigan. This plow breaks soil, turns it over, and completely reorganizes the surface materials. It is usually the deepest and most disruptive tillage practice used in agriculture. When used at medium soil moisture levels, it surpasses all other implements in loosening soil, while incorporating crop residues, manure, fertilizers or lime. Energy requirements are relatively high because of the large volume of soil it moves (Robertson et al., 1977a).

(II) This treatment combined conventional tillage (moldboard plow), with cultivation methods. These methods were used after seeds were planted, or young plants had emerged. The results of cultivation include: break up of crusts, weed control, increased water infiltration, erosion control and facilitation of harvests. With crops of high economic value, cultivation remains a significant input in crop production costs (Robertson et al., 1977b).

These treated plots were sampled only the last three sampling dates. The decision to take samples from these plots was made after the first five sample dates.

(III) This treatment combined conventional tillage (moldboard plow), cultivation and applications of Atrazine (AAtrex®). The general use of Atrazine is to control broad leaf and grassy weeds in corn, sorghum, sugarcane, and turf grass sod. It is absorbed through the roots and foliage, translocated acropetally in the xylem, and accumulates in the apical meristems, and leaves of plants. It acts as a photosynthetic inhibitor, affecting the photochemical activity of the chloroplasts (Hill reaction) (Audus, 1964).

The term "cultivation" is used vaguely in the literature. Hence, "cultivation" as used in this thesis is defined as any mechanical manipulation of soil for agricultural purposes.

This study was part of a larger effort investigating tillage and herbicide effects on soil fauna at Michigan State University.

LITERATURE REVIEW

Cultivation Effects

The effects of cultivation on soil fauna are more easily recognized by comparing grassland and arable land (Tischler, 1955). Arable land is poorer in soil fauna than uncultivated land in numbers of individuals and species (Buckle, 1921; Kevan, 1962; Burnett, 1968; Edwards and Lofty, 1969; and Edwards and Thompson, 1973). However, certain soil animals, such as Symphyla, Protura, Diplopoda, Rhodacaridae (Mesostigmata), sminthurid Collembola, and prostigmatid mites are more abundant in agricultural soils than elsewhere (Edwards and Lofty, 1969).

An important reason for this difference is that grassland supports vegetation during a period when arable land is fallow. The presence of vegetation ensures that a food source is always available for a large majority of soil species (Buckle, 1921).

Vertical distribution of soil animals in grassland and arable land also differs. In grassland, most animals are within the upper 5.08 cm of the surface, while in arable soils, animals are more evenly distributed through the upper 15 cm (Edwards and Lofty, 1969).

Tischler (1955), Sheals (1956), and Edwards and Lofty (1969, 1975) reported reduction of soil animal populations immediately following cultivation. Some taxa are affected more than others. Edwards and Lofty (1969) report Prostigmata, Mesostigmata and

Symphyla are least affected, while Cryptostigmata, hemiedaphic Collembola and Pauropoda are reduced after plowing. Burnett (1968) claims that cultivation increased Collembola and mite populations. Aleinikova and Utrobina (1975) report that the method of cultivation has no appreciable effect on the total numbers of group diversity, but considerably effects the ratio of individual groups.

Cultivation effects have both advantages and disadvantages. The disadvantages are destruction of soil structure by deep plowing and extensive soil movement. An overall dilution of soil nutrients may also occur when deeper, less nutrient-rich soil is brought to the surface, mixing with, and diluting the nutrient-rich upper layers (Burnett, 1968). Water retention and heat conducting capacity also are affected (Tischler, 1955). The moldboard plow also acts as a forceful disturbance on soil structure, particularly if it is too wet during plowing, thus causing compaction. Another disadvantage of conventional tillage is that when soil is overturned, it becomes susceptible to drying, and vulnerable to wind and water erosion. Also soil organisms brought to the surface become exposed to harsh climatic conditions. In addition, repeated cultivation removes organic matter from the surface and decreases fauna populations by mechanical damage (Edwards and Lofty, 1969).

Conventional tillage incorporates and distributes organic matter, making it more readily available to organisms feeding below the soil surface. It also opens up soil, improving aeration and drainage, and increases the volume of a "favorable zone" for soil animals (Burnett, 1968; Edwards and Lofty, 1969). Tillage also reduces crop residues, weeds, and root masses, which become subject to more rapid decomposition (Tischler, 1955). According to Tischler (1955) and Kevan (1962), the moldboard plow is less injurious to soil animals than rotary or surface scraping cultivators.

An important indirect effect of cultivation is the change it causes in plant cover. Altering the vegetative cover can greatly change the structure of soil animal populations within one horizon and soil type (Block, 1966; Edwards and Thompson, 1973). Strickland (1947) showed that considerable differences exist between qualitative populations on two plots of similar soil type, largely due to different plant associations on the plots. Changing the vegetative cover will change the type of litter produced, which causes a corresponding change in soil organic matter. This in turn effects the faunal composition. Changes in fauna may affect the quality of humus produced, thus effecting soil fertility (Kevan, 1962; Edwards and Thompson, 1973).

Edwards and Lofty (1969) reported that after six months, numbers of soil animals in treated and untreated plots differed only slightly, indicating cultivation effects may not persist into a second growing season. Sheals (1956) showed that reseeding cultivated land resulted in rapid decolonization by Collembola, but populations of Cryptostigmata and Mesostigmata remained low over a period of 17 months. Cultivated land left fallow may result in persistent reduced numbers of soil animals (Sheals, 1957; Edwards and Thompson, 1973). Effects of cultivations on soil animals may persist up to three years (Butcher et al., 1971). Microarthropods with short life cycles become fewer when soil is first cultivated, but they usually recover within a single growing season. By contrast, arthropods that live longer than a year may be affected by cultivation longer than one growing season (Edwards and Lofty, 1969; Edwards and Thompson, 1973).

Herbicide Effects

Increased use of herbicides to control weeds in agricultural systems has necessitated investigations of their side effects on soil animal populations. Their use can exert considerable effects by diminishing or increasing numbers of both beneficial and harmful soil animals (Fox, 1964). Rapoport and Canglioli (1963), Edwards and Arnold (1964), and Davis (1965) found MCPA (4-chloro-2-methylphenoxy-acetic acid) had no effects on numbers of mites in treated and untreated plots. Edwards (1965) found 2,4-D (2,4-dichlorophenoxacetic acid) reduced populations of soil animals one-half to one third compared to untreated soil, predatory mites and isotomid Collembola were most effected. Rapoport and Canglioli (1963) found no differences in mite populations in 2,4-D treated plots. Prasse (1975) reported populations of mites and Collembola increased following 2,4-D application. These discrepancies in the results of 2,4-D effects may be explained by several factors. For instance, effects of herbicides on mites and Collembola are proportional to the concentration used (Popovici et al., 1977). Also many studies done on pesticide effects on microarthropods are done in the summer when their populations are low, minimizing effects (Edwards and Thompson, 1973).

Experiments with Atrazine show pronounced sensitivity of the soil fauna to the action of this herbicide (Popovici et al., 1977). Subagja and Snider (1981, in press) found that Brewers yeast treated with Atrazine, and fed to Folsomia candida and Tullbergia granulata caused significant mortalities at 5000 ppm. It also caused longer instar duration and reduced egg production. Fox (1964) and Edwards and Thompson (1973) showed Atrazine decreased numbers of Collembola and mites. They also reported Collembola were less susceptible to herbicides than mites.

Changes in vegetative cover resulting from herbicide application causes indirect effects on the structure of soil animal populations (Fox, 1964). Unlike the blanket destruction that cultivation has on vegetative cover, herbicide effects are often more selective of the plant species it eradicates. This selectivity may diminish the numbers of species of soil animals, but not necessarily the total number of animals (Edwards and Thompson, 1973). Herbicides that effect saprophagus soil animals, which are essential in the breakdown of litter into its organic and inorganic constituents, may ultimately alter soil fertility and structure. The higher susceptibility of predatory mites to herbicides (Edwards, 1965) may positively affect nutrient cycling by freeing saprophagus animals from predation, thus permitting an increase in breakdown of litter and liberation of nutrients (Butcher et al., 1971).

An important consideration in herbicide usage is its ability to degrade, and thereby its mode of degradation. The fate of herbicides applied to soil is largely governed by four factors: placement (dominant factor); sorption equilibria; inherent phyto-toxicity; and microbiological effects (Upchurch, 1966). Atrazine degradation is dependent on soil type, concentration, and moisture content (Skipper and Volk, 1972). Harris and Warren (1964) reported Atrazine adsorption depends on soil type. They found a direct correlation between adsorption and content of organic matter, clay, and cation exchange capacity. McCormick and Hiltbold (1966) and Roeth, Lavy and Burnside (1969) found that Atrazine degradation increased two-to-three-fold for each 10^{o}C temperature increase (from 15^{o}-35^{o}C). The exact process of degradation has three major pathways: hydrolysis at the number two carbon (most predominant); N-deakylation of side chains; and ring cleavage (Kaufman and Kearney, 1970).

Accumulation and persistence of herbicide residues in the soil may endanger soil animal biotic processes (Popovici et al., 1977). Considerable changes in community composition of microarthropods persisting for more than a year could be attributed to weed control worsening the living conditions of most soil inhabiting species (Prasse, 1975). Persistent herbicides do not always effect soil animals the most. Simazine (2-chloro-4,6,-diethylamino-s-triazine) may persist from six months to more than a year, but it is only slightly toxic to soil animals. D-D mixture (1,3-dichloropropene and 1,2-dichloropropane) persists only a few weeks, yet it is extremely toxic to all soil animals and may decrease numbers of them for two to three years (Edwards and Thompson, 1973). Burnside et al. (1965) found that herbicide carry-over is a greater problem in arid regions than humid regions of the U. S. Popovici et al. (1977) report that reduction of Atrazine effects on soil animals after four months is significant for restoring their equilibrium.

METHODS AND MATERIALS

The study area is located off Jolly and College Roads, on the north end of section "C" of the new Crops and Soils Science farm at Michigan State University.

Samples were taken from a series of plots, each 6.1m x 15.2m, on which corn was grown. The plots comprised seven treatments in four replicates. Each replicate had a grass control (Figure 1). The soil is classified as Celina loam (soil management group 2.5a) and supported grass for the past eight years. This soil tends to be high in fertility and available water capacity. Runoff is slow to medium, and permeability moderately slow. There are no limitations that seriously affect its use for farming. Treatments were initiated May 1979 (plowed-May 11, planted-May 15). Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) was applied June 12, at a concentration of .47 cc/m^2 and cultivation was done June 22. During the investigation, water was supplemented by sprinkler irrigation five times; 12.7 mm-June 26; 25.4mm-June 28, July 10, July 18; and 38.1mm-July 27 (Figure 2).

Samples were taken approximately every three weeks from the following plots (Figure 1):

Control-Grass

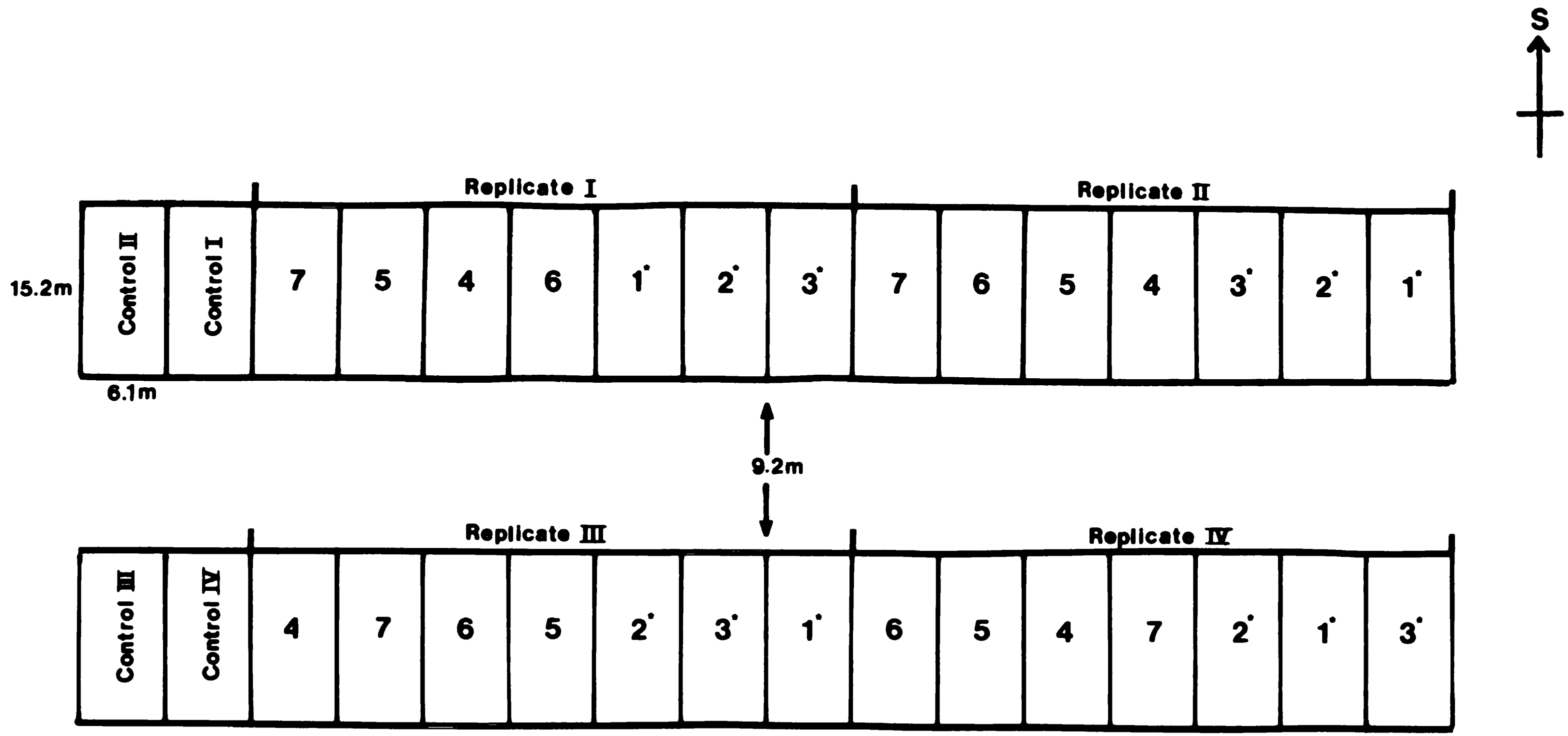
I. Plowed

II. Cultivated

III. Herbicide

Samples, in the form of soil cores were collected using a 15cm deep core device of 6cm diameter (Figure 3). Five cores were taken from each treated and control plot in all four replicates. Cores were taken in-row between plants, in the central portion of each plot to avoid edge effects. Samples were placed in plastic bags and taken to the laboratory. Microarthropods were extracted by using Tullgren funnels.

Figure 1. Map of Sample Plots



Treatments:

Control- Grass
*1. Mold-board
*2. Mold-board, Cultivation
*3. Mold-board, Cultivation, Atrazine
4. No-till, Atrazine
5. No-till, Paraquat
6. No-till, Atrazine, Paraquat
7. No-till

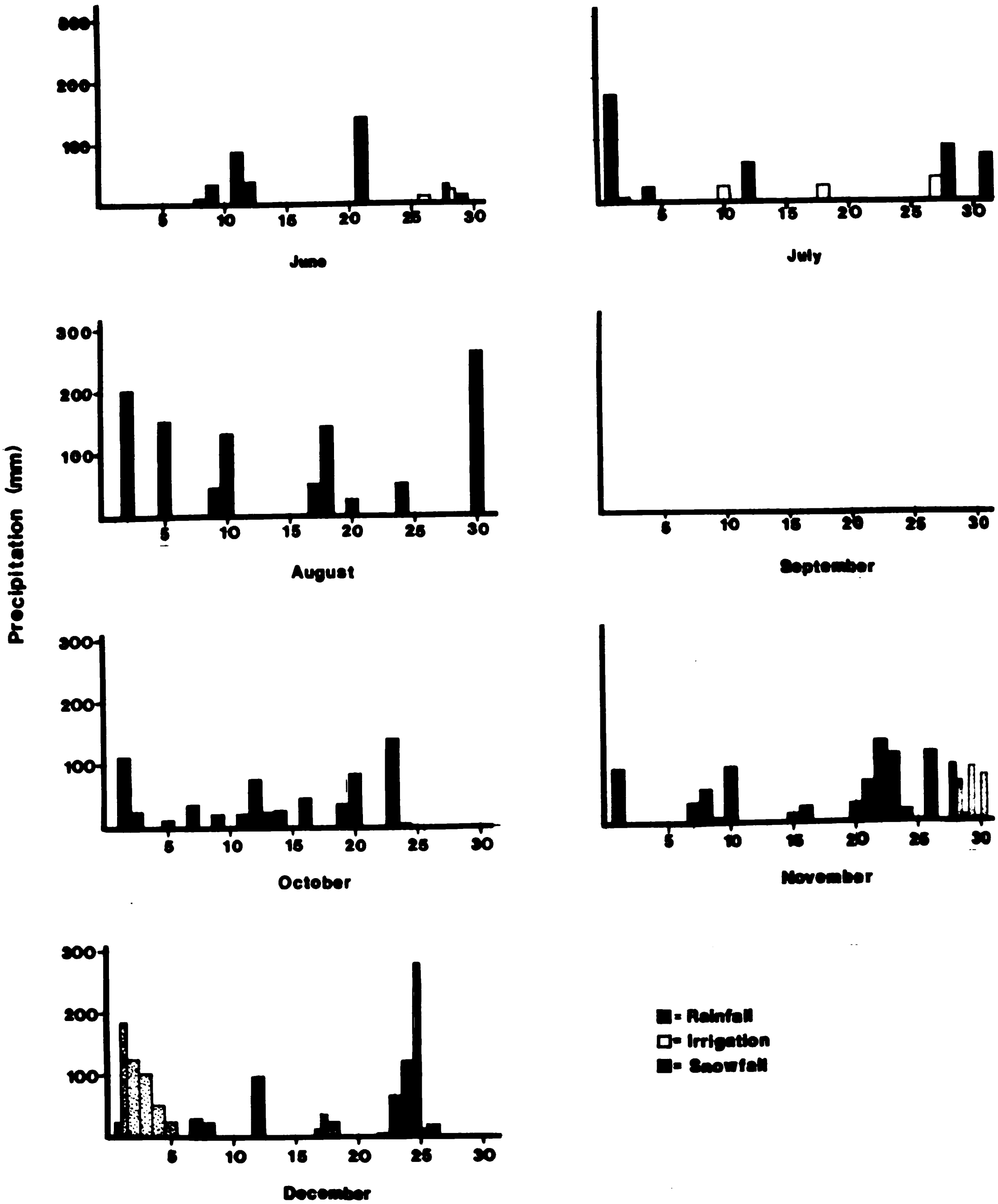


Figure 2. Daily Precipitation.

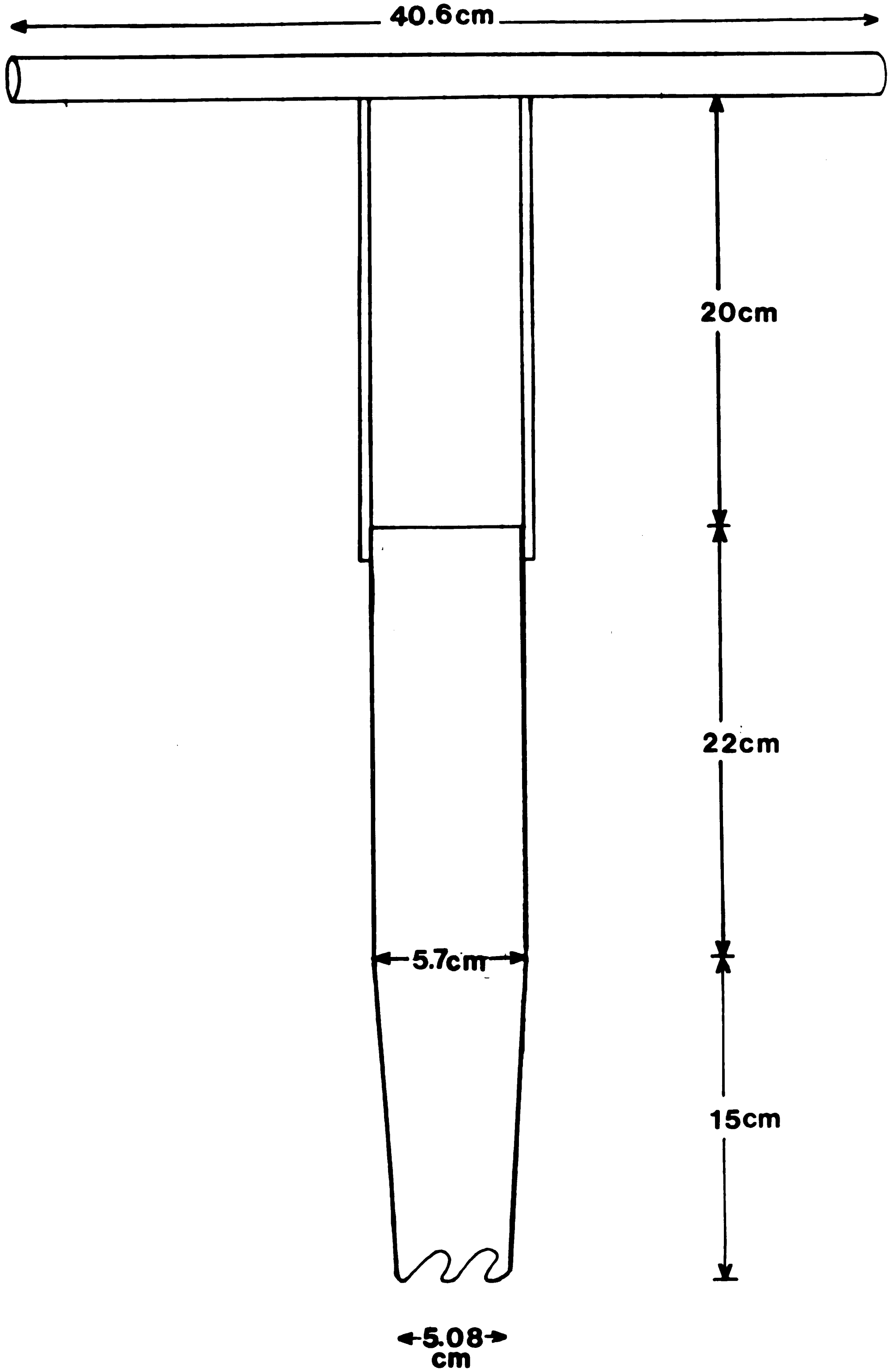


Figure 3. Diagram of Core Device.

The heat source for the funnels were 25-watt bulbs connected to a rheostat. Low settings were used to prevent the soil from drying too rapidly, trapping the arthropods inside the soil. Soil was extracted four or five days, depending on the initial temperature and moisture levels of the soil (soil too moist or cold required lower heat and longer extraction time). Extracted animals were collected and preserved in a solution of 95% ethanol - 1% glycerine.

Inherent biases in the extraction method were considered. Satchell and Nelson (1966) found that the efficiency of Tullgren funnel extraction may vary with the physical characteristics of species, independent of sampled soil type. Haarlov (1962) reported that due to poorly developed locomotory structures, small, slow moving species suffer the greatest losses when extracted with Tullgren funnels. Tamura (1976) found the extraction efficiency of Tullgren funnels to be very low compared with hand sorted samples. He found the deficiency greater in smaller species than larger ones. Satchell and Nelson (1962) found that oribatid mites were extracted more efficiently in Tullgren funnels than by flotation.

Extraction efficiency of the Tullgren funnels was determined using dried, extracted soil from 10 controls taken June 18, 1980 (Table 1). The soil was immersed and remoistened in a saturated sugar solution, causing less dense organic matter to rise to the surface, where it was collected and identified. Taxa not included in Table 1 were collected in numbers too few for valid conclusions.

Air and soil temperatures were taken each sampling date using a Yellow Springs Institute Telethermometer (YSI-42SC) (Table 2). Soil temperatures were measured at a depth of 15cm. No soil temperatures

Table 1. Percent Extraction Using Tullgren Funnels Determined by Flotation.

Animal	% Extracted
Brachystomella parvulis	50.0
Tullbergia granulata	60.0
Lepidocyrtus pallidus	25.0
Scheloribates sp.	45.0
Opiella sp.	89.9
Bakerdania sp.	27.4
Rhodacarellus sp.	60.0
Total Acarina	64.2
Total Collembola	48.2

Table 2. Soil and Air Temperatures from Each Sampling Date.

Date (1979)	Air Temperature (^{o}C)	Soil Temperature (^{o}C) (15.2cm depth)
9 June	20.0	22.5
19 July	24.0	20.0
3 August	25.0	23.1
26 August	23.1	17.5
23 September	19.2	16.5
14 October	11.0	--*
1 November	13.0	9.0
9 December	-11.1	--*

*Temperature meter not functioning.

were taken on October 15 and December 9 due to temperature meter not functioning. Maximum and minimum daily temperatures and precipitation during the study were obtained from the National Weather Service, South Farm Station (Figures 2, 4).

Following extraction, arthropods were identified to species (Collembola), Genus (Acarina), Order (Insecta, Crustacea) and Class (Myriapoda). Collembola were identified according to Snider (1967), and Christiansen and Bellinger (1980). Acarina were identified according to Krantz (1978), and from keys provided at the Ohio State University summer Acarology program 1980 (unpublished).

Statistical analysis of data utilized a two-way, fixed classification model and normal equations. These methods generated F-ratios and confidence intervals (Gill, 1978). The classification model used was:

$$y=u+T_i+S_j+P_{(i)k}+TS_{ij}+e$$

Where:

u = Mean common to all elements

T = Treatment effects; i = 1,2,3,4

S = Season effects; j = 1,2,3,4,5,6,7,8

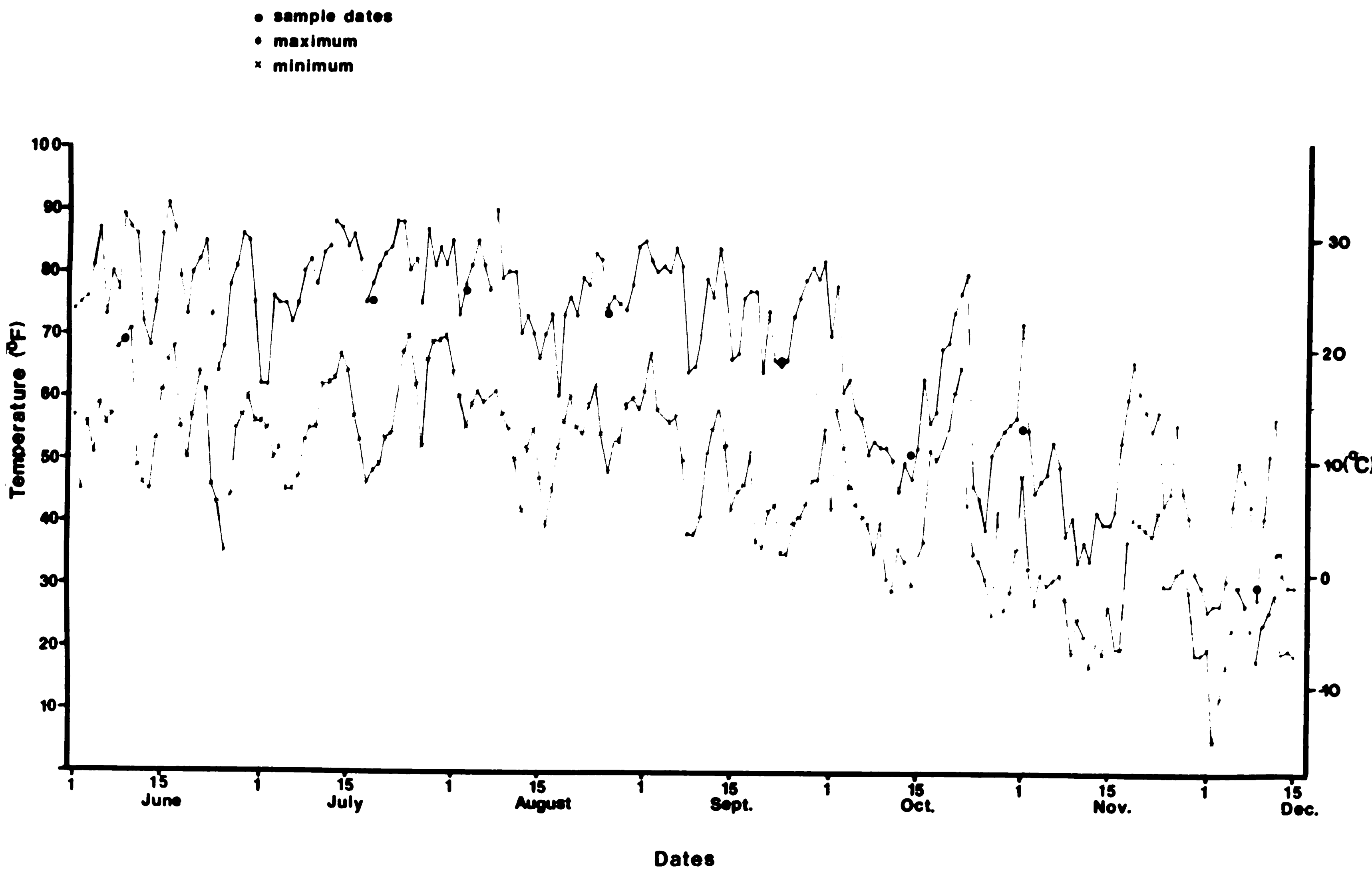
P = Plot replicate effects (nested in treatments); k = 1,2,3, ...15,16

TS = Treatment-season interaction

e = error

All data was processed by computer using the Statistical Analysis System (SAS) program.

Figure 4. Daily Maximum-Minimum Temperatures.


sample dates
maximum
minimum
Temperature (°F)
100
90
80
70
60
50
40
30
20
10
10(°C)
30
20
0
-10
1
15
June
July
August
Sept.
Oct.
Nov.
Dec.
Dates

RESULTS

Quantitative Effects

Quantitative analysis of this study was based on two major microarthropod orders: Acarina and Collembola. Of 51 genera identified, only two Collembola and one genus in each of the three major soil inhabiting sub-orders of Acarina (Prostigmata, Mesostigmata, and Cryptostigmata) were collected in numbers large enough to make any statistically valid conclusions.

Treatment II data was omitted for the following reasons: Only three sample dates were obtained, and this data analysis produced results nearly identical with treatment I.

When compared with controls, overall significant decreases ($P \leq .05$) occurred from Collembola populations in treated plots. Individual analysis showed these decreases continued through the first four sample dates. No significant differences among treatments were observed on any sample date. Population levels of Collembola in control plots increased steadily from June 9, reaching a maximum August 3. This was followed by a steady decrease, reaching a minimum September 23. Treated plots fluctuated little, within a few data points, over the entire growing season, increasing slightly from October to November (Figure 5).

Brachystomella parvula, a hemiedaphic species, (Figure 6), showed overall significant decreases in treated plots compared with controls, and exhibited the same general patterns as total Collembola.

Figure 5. Mean population levels of Collembola.

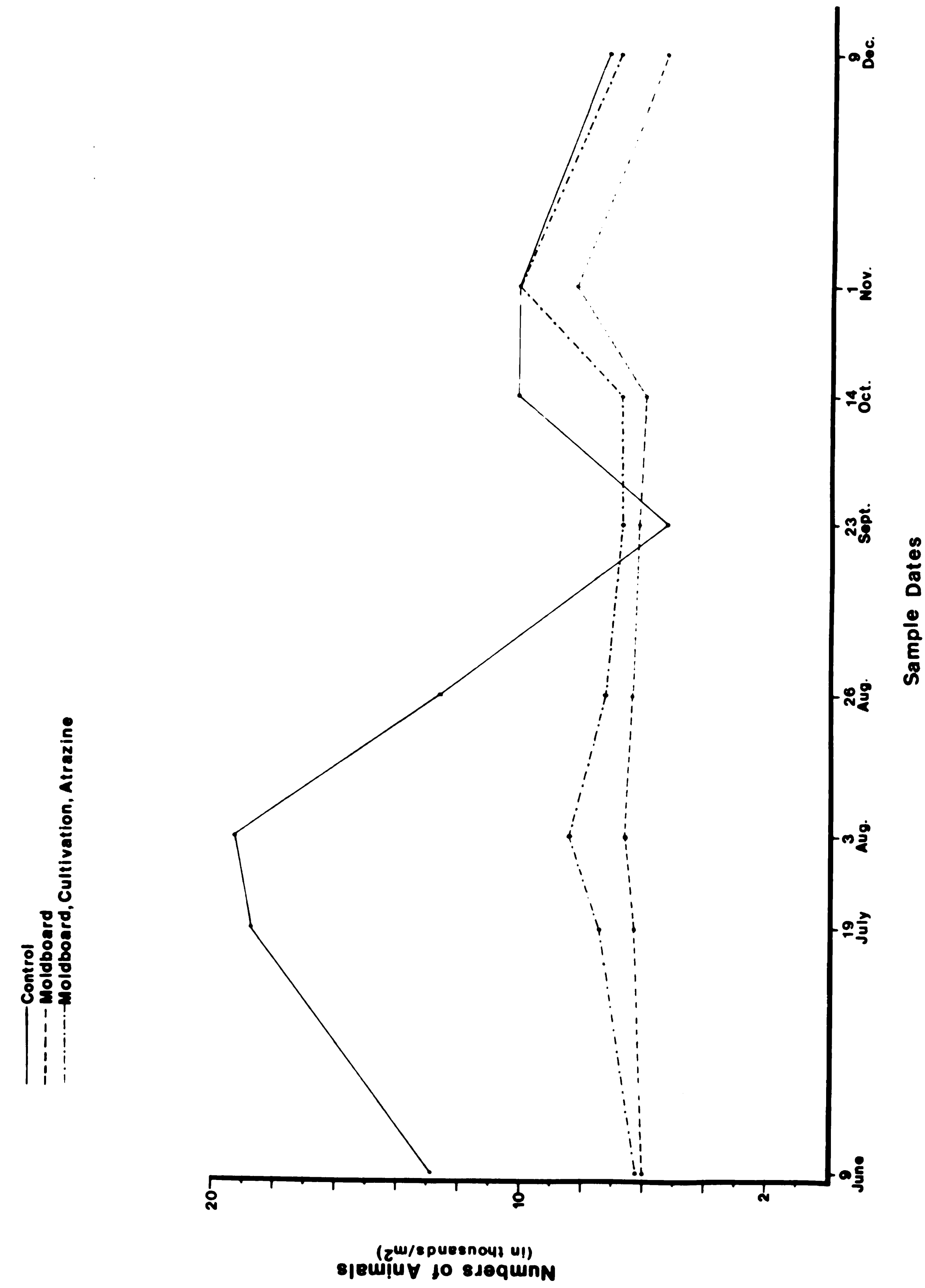
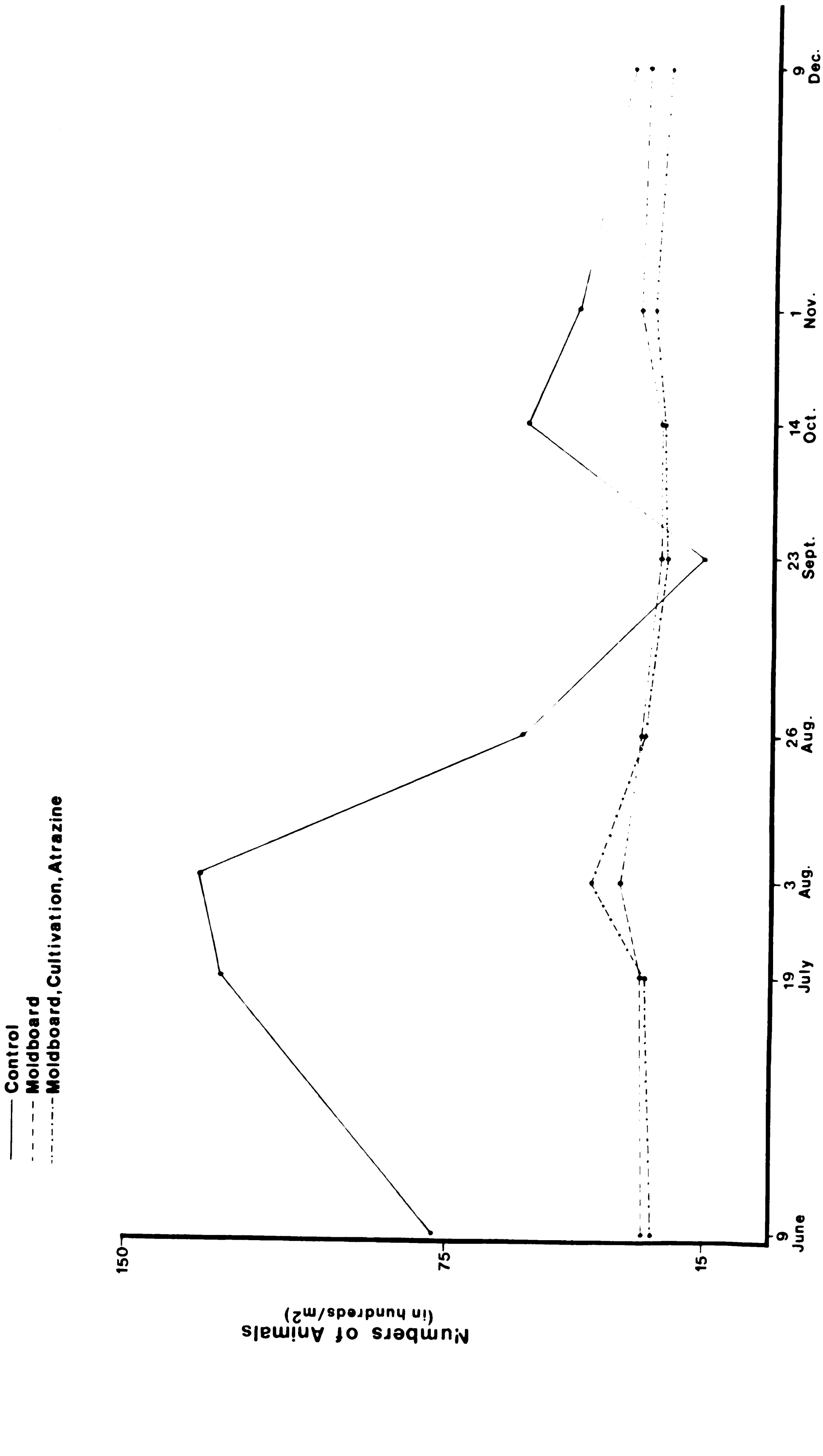

Control
Moldboard
Moldboard, Cultivation, Atrazine
Numbers of Animals
(in thousands/m2)
20
10
2
9 June
19 July
3 Aug.
26 Aug.
23 Sept.
14 Oct.
1 Nov.
9 Dec.
Sample Dates

Figure 6. Mean Population Levels of Brachystomella parvula.


Control
Moldboard
Moldboard, Cultivation, Atrazine
150
75
15
Numbers of Animals
(in hundreds/m2)
9 June
19 July
3 Aug.
26 Aug.
23 Sept.
14 Oct.
1 Nov.
9 Dec.
Sample Dates

Individual sample date significance ($P \leq .05$) ended after three sample dates. Maximum and minimum levels were reached on the same sample dates as total Collembola.

Population levels of Tullbergia granulata, an euedaphic species (Figure 7), did not exhibit overall significant differences between treatments and control. Analysis of the first two sample dates exhibited no significant differences among treatments, or between treatments and control. On the remaining six dates, significant differences ($P \leq .05$) existed among treatments, with treatment III populations higher than treatment I. Significant differences ($P \leq .05$) between treatment III and control appeared on sample dates September 23, October 14, and November 1, with treatment III populations higher than control. A significant difference ($P \leq .05$) was displayed on November 1 between treatment I and control, control populations lower.

Population levels of T. granulata in control plots fluctuated little throughout the eight sample dates, with no definite maximum or minimum. Both treated plots had a maximum on November 1, and exhibited no apparent minimum.

Overall, Acarina populations decreased significantly in treated plots ($P \leq .05$). Individual analysis (Figure 8) showed significant differences ($P \leq .05$) between treatment I and controls, control populations higher, on each sample date except August 26. Decreases in treatment III populations were significant ($P \leq .05$) on all sample dates except August 26 and December 9.

Acarina populations in control plots increased steadily from June 9, and reached a maximum August 3. This was followed by a steady

Figure 7. Mean Population Levels of *Tullbergia granulata*.

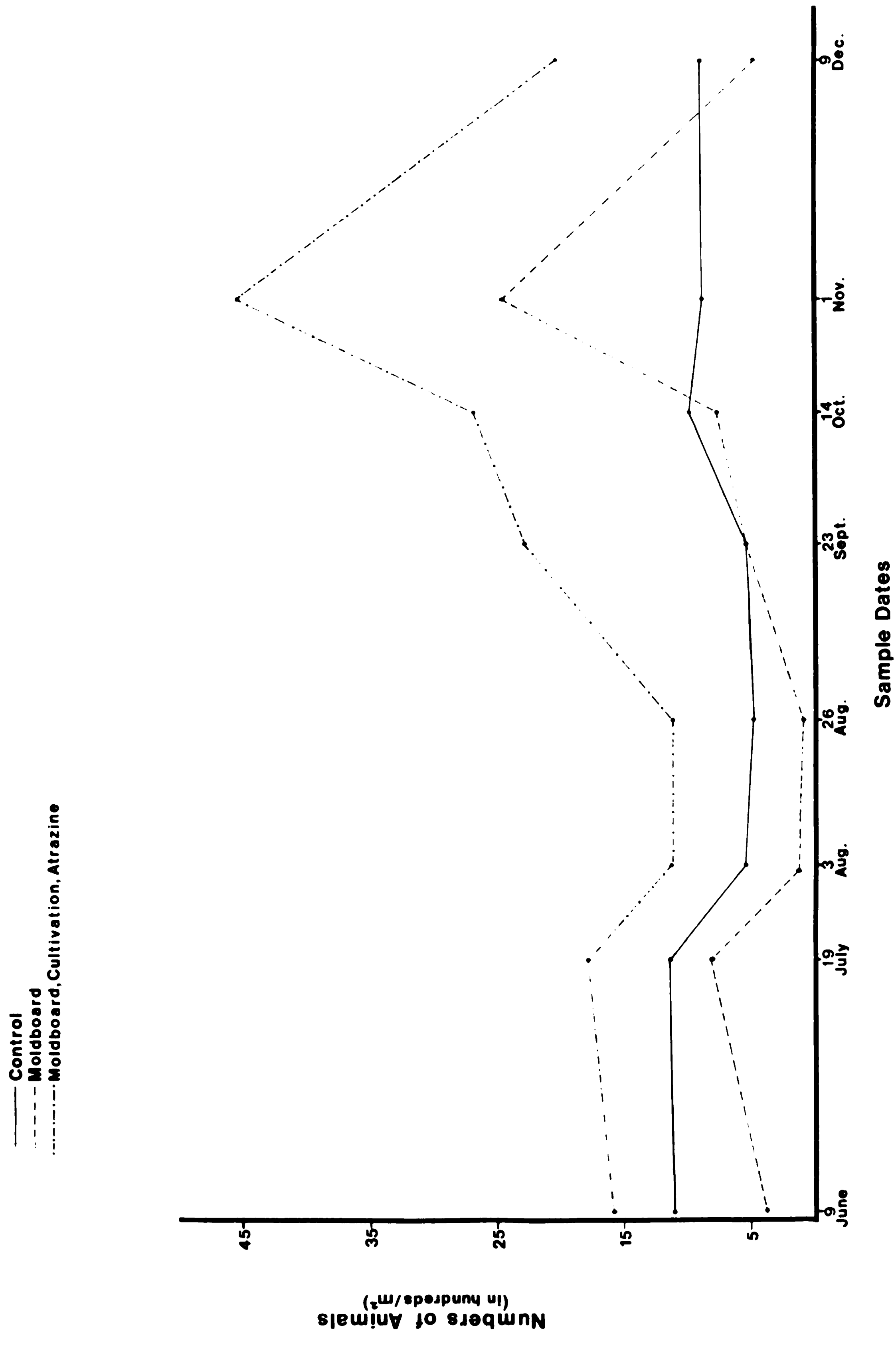
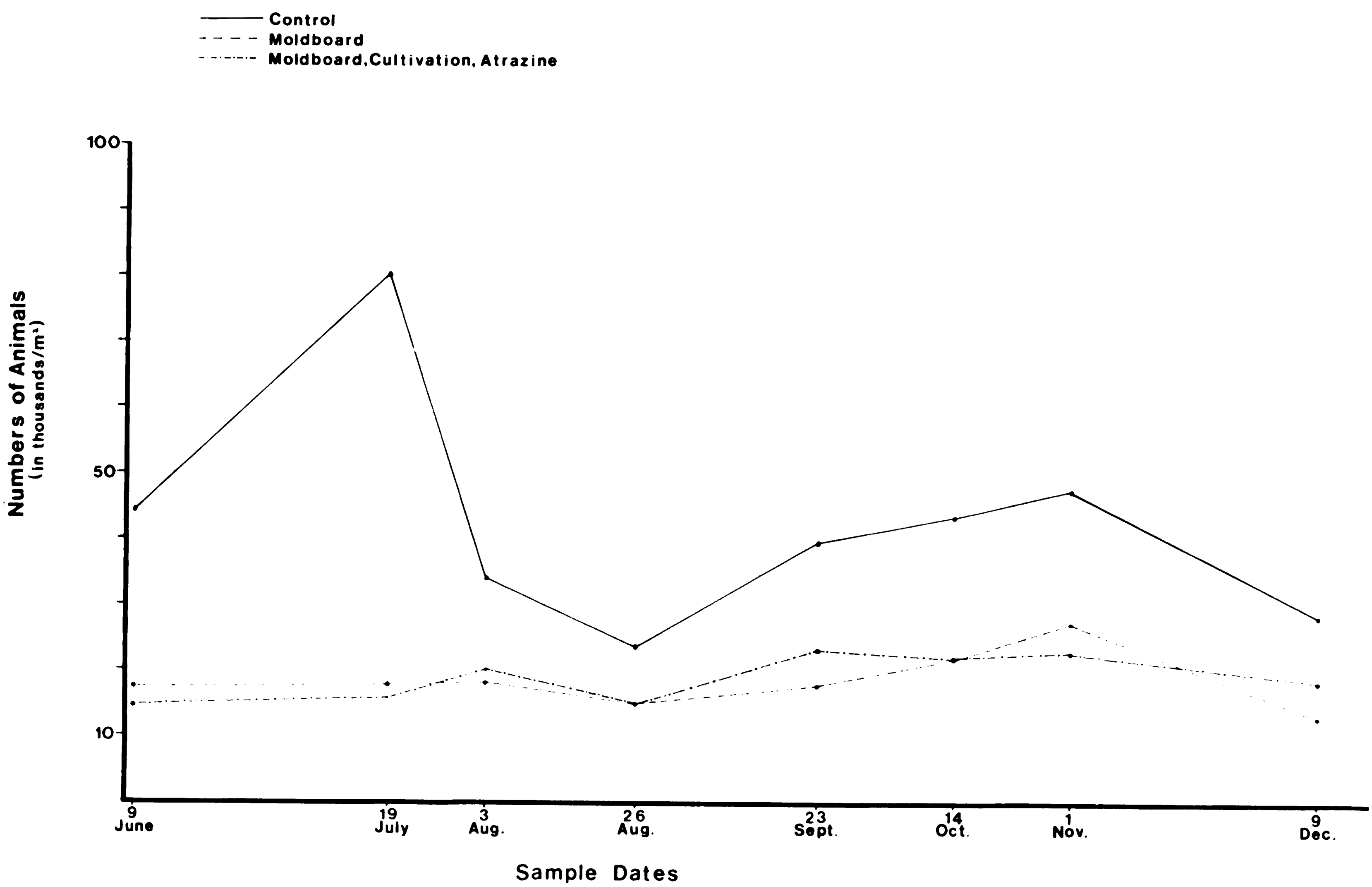

Control
Moldboard
Moldboard, Cultivation, Atrazine
Numbers of Animals
(in hundreds/m²)
45
35
25
15
5
9 June
19 July
3 Aug.
26 Aug.
23 Sept.
14 Oct.
1 Nov.
9 Dec.
Sample Dates

Figure 8. Mean Population Levels of Acarina.



Control
Moldboard
Moldboard, Cultivation, Atrazine
100
50
10
Numbers of Animals
(in thousands/m²)
9 June
19 July
3 Aug.
26 Aug.
23 Sept.
14 Oct.
1 Nov.
9 Dec.
Sample Dates

decrease, reaching a minimum August 26. Treatment levels fluctuated little over the entire growing season.

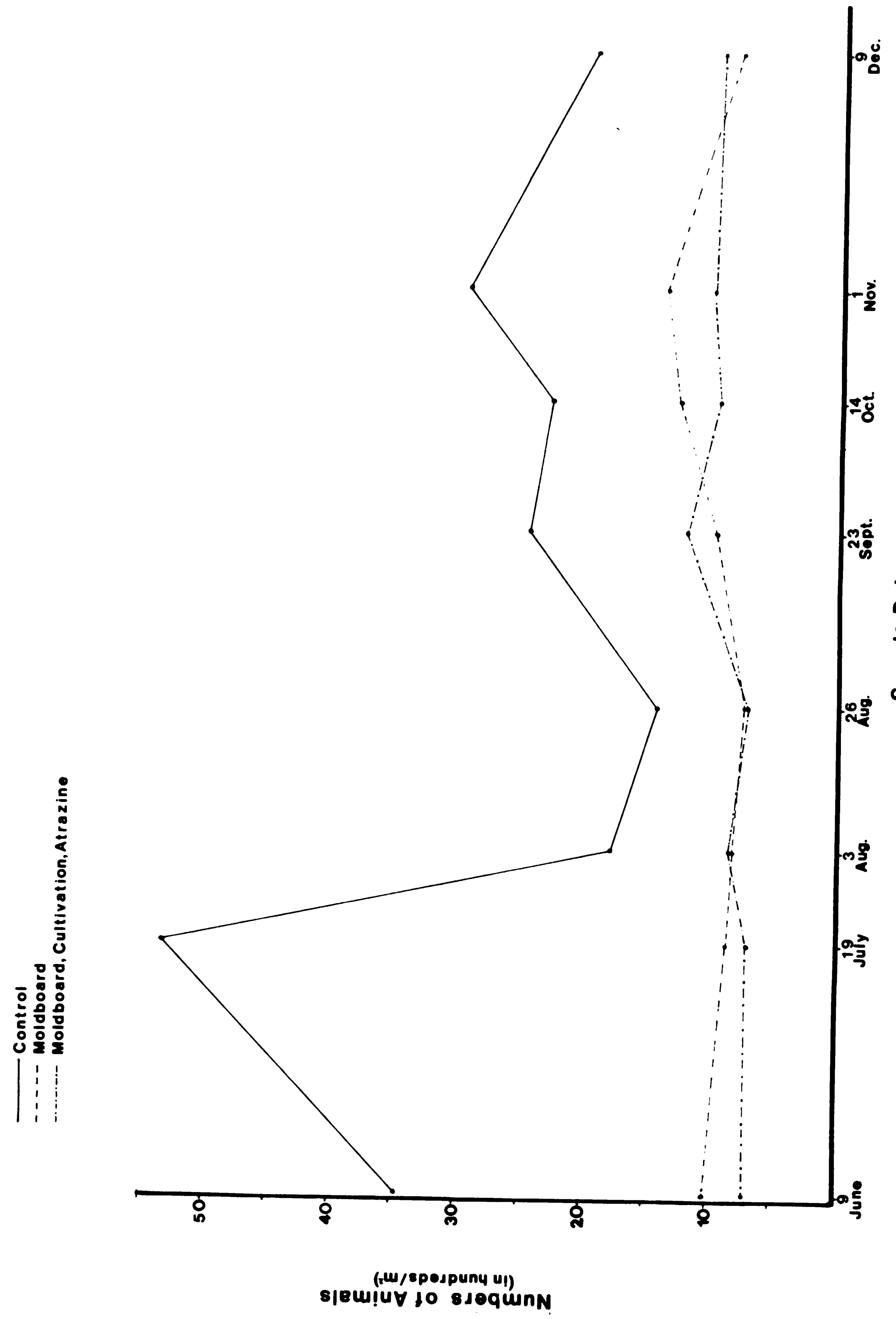
The sub-order Prostigmata and Bakerdania sp. (Figures 9, 10) exhibited significant decreases ($P \leq .05$) in treated plots compared with controls. Individual significant differences, maximum and minimum of controls, and treatment population levels, displayed the same pattern as total Acarina, with the exception of Bakerdania sp. on August 3. No significant differences between the control and treatments occurred on this date.

Mesostigmatid mites (Figure 11) decreased significantly in treated plots ($P \leq .05$), however, individual significant differences occurred only on July 19 and August 3. Reaching a maximum July 19, control populations decreased steadily through the remainder of the growing season, while treatment levels fluctuated little.

Individual significant differences ($P \leq .05$) occurred in populations of Rhodacarellus sp. between treatment I and controls on October 14, and between treatment III and controls July 19 and August 3, control levels higher for both. Rhodacarellus sp. did not display overall differences between treatments and controls. Treatment I populations were significantly higher than treatment III on July 19, and exhibited population peaks July 19 and September 23. Treatment III reached a maximum October 14.

Compared with controls, overall decreases of Cryptostigmata populations in treated plots were significant ($P \leq .05$). Individual analysis of samples (Figure 13) showed decreases in treatment I which occurred on July 19, September 23, and October 14. Decreases in populations from treatment III were significant ($P \leq .05$) on July 19

Figure 9. Mean Population Levels of Prostigmata.



Control
Moldboard
Moldboard, Cultivation, Atrazine
Numbers of Animals
(in hundreds/m²)
50
40
30
20
10
9 June
19 July
3 Aug.
26 Aug.
23 Sept.
14 Oct.
1 Nov.
9 Dec.
Sample Dates

Figure 10. Mean Population Levels of Bakerdania sp.

Control
Moldboard
Moldboard, Cultivation, Atrazine
Numbers of Animals
(in thousands/m²)
30
27
24
21
18
15
12
9
6
3
9 June
19 July
3 Aug.
26 Aug.
23 Sept.
14 Oct.
1 Nov.
9 Dec.
Sample Dates

Figure 11. Mean Population Levels of Mesostigmata.

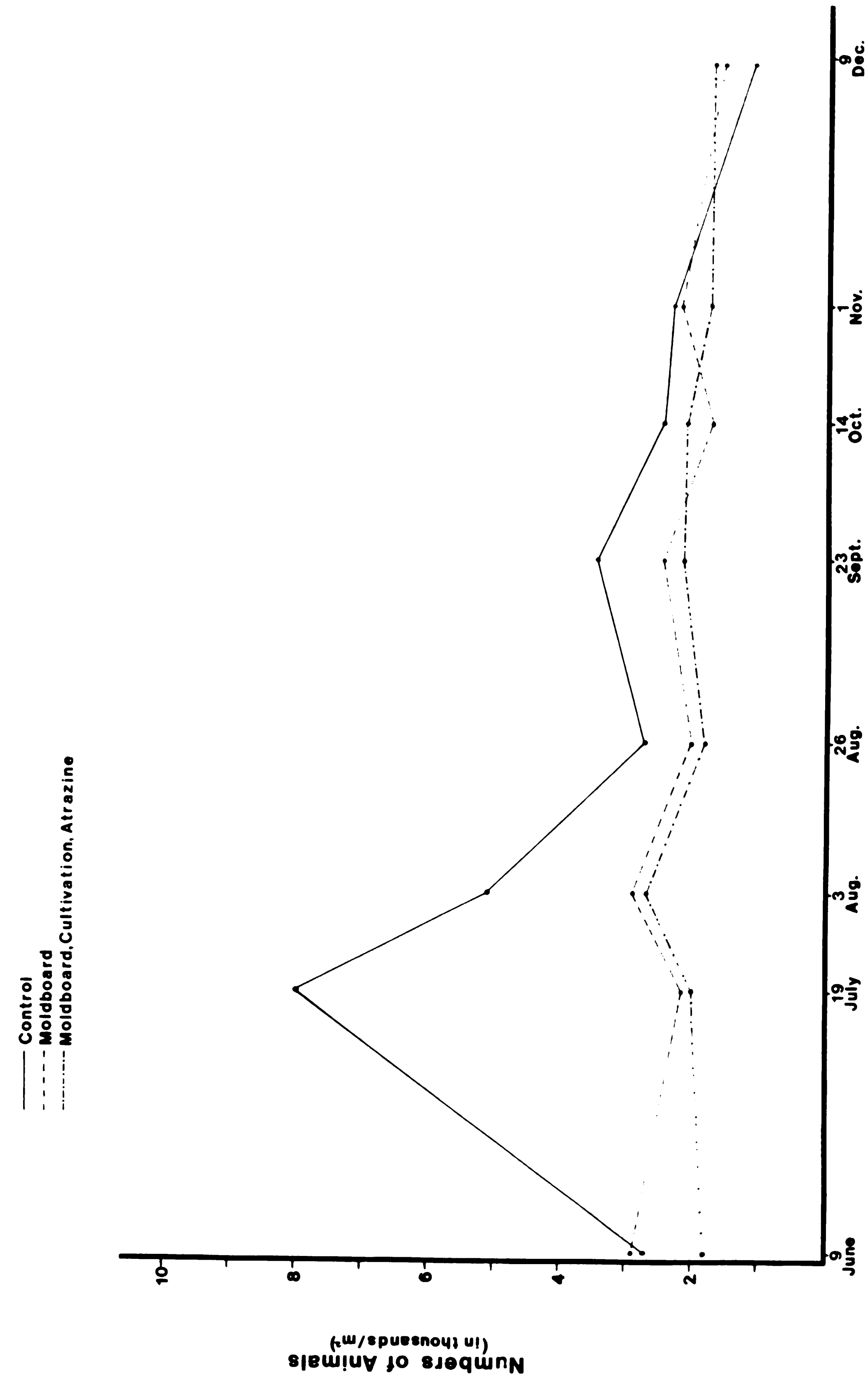
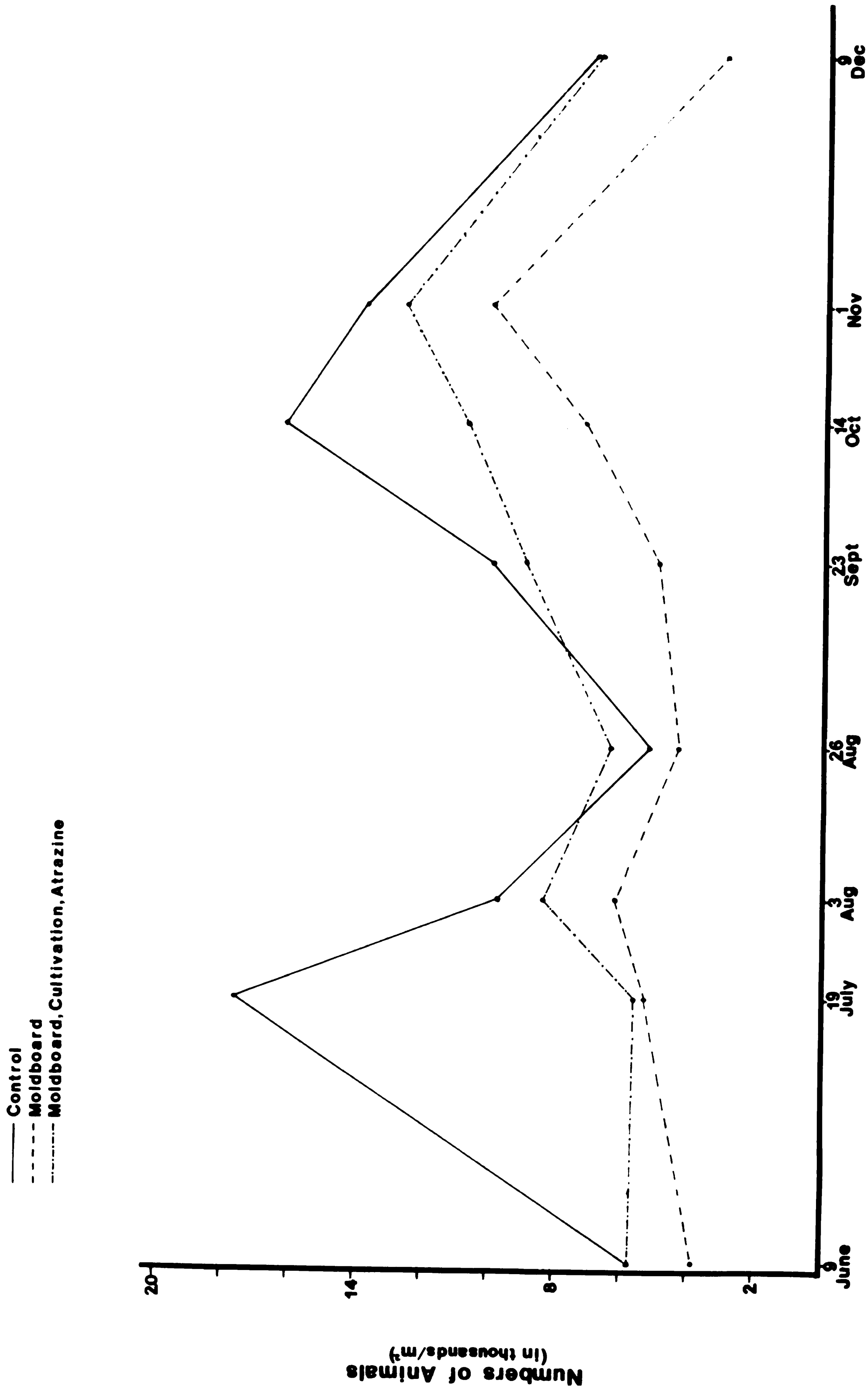

Control
Moldboard
Moldboard, Cultivation, Atrazine
Numbers of Animals
(in thousands/m²)
10
8
6
4
2
9 June
19 July
3 Aug.
26 Aug.
23 Sept.
14 Oct.
1 Nov.
9 Dec.
Sample Dates

Figure 12. Mean Population Levels of Rhodacarellus sp.


Control
Moldboard
Moldboard, Cultivation, Atrazine
Numbers of Animals
(in hundreds/m²)
30
20
10
9 June
19 July
3 Aug
26 Aug
23 Sept
14 Oct
1 Nov
9 Dec
Sample Dates

Figure 13. Mean population levels of Cryptostigmata.

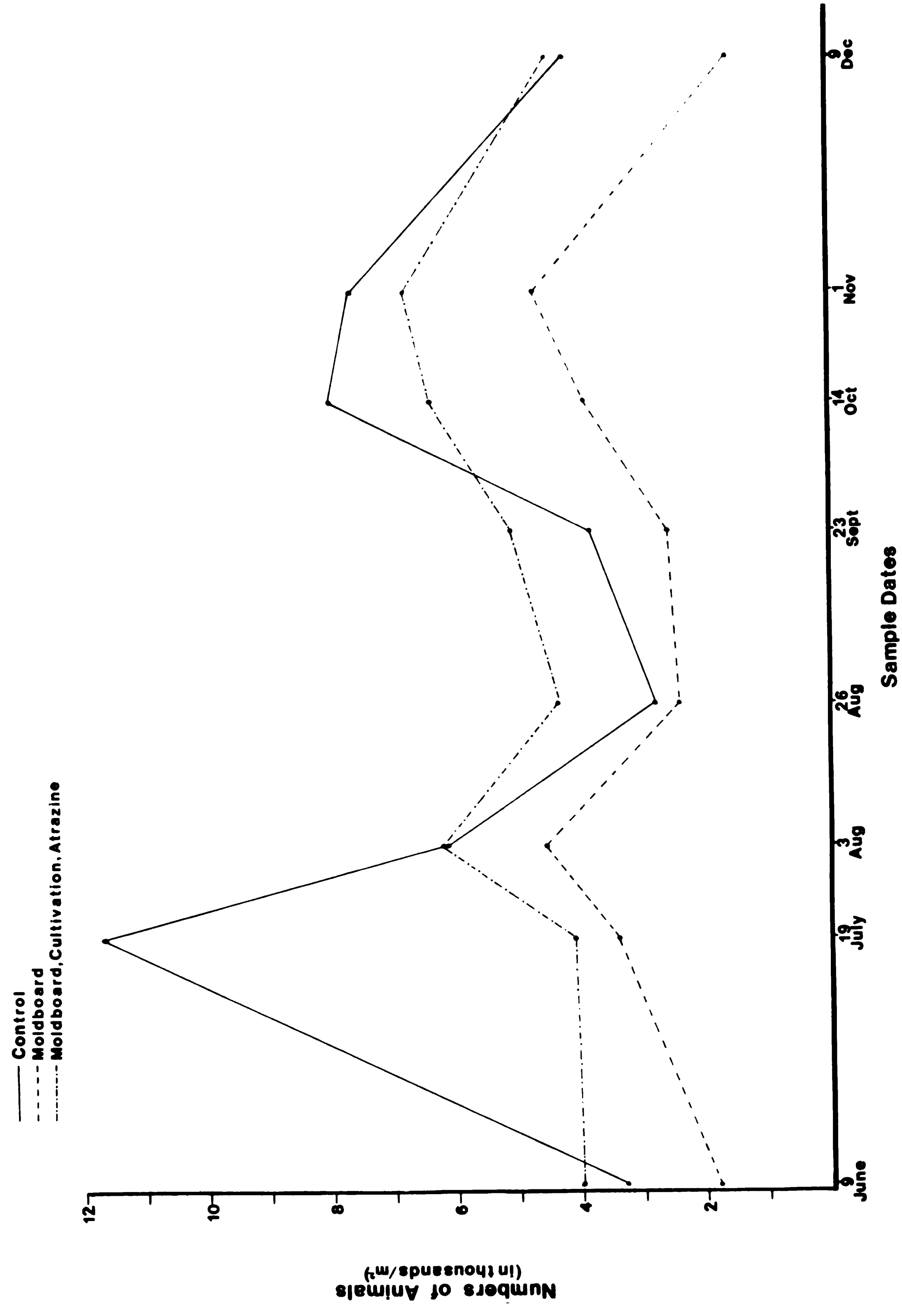

Control
Moldboard
Moldboard, Cultivation, Atrazine
Numbers of Animals
(in thousands/m²)
20
14
8
2
9 June
19 July
3 Aug
26 Aug
23 Sept
14 Oct
1 Nov
9 Dec
Sample Dates

and October 14. Significant differences among treatments occurred on September 23, with treatment III populations higher.

Population levels of controls peaked twice over the growing season, with maxima occurring July 19 and October 15, and a minimum September 26. Treatment levels fluctuated over several data points, but never enough to display a distinct maximum or minimum.

Opiella sp. (Figure 14) displayed no significant differences between treatment I and controls on September 23, or between treatment III and controls on October 14. Population peaks in control plots were similar to total Cryptostigmata. Maxima of treatment populations occurred August 3 and November 1, with a minimum September 26. Except for the above two dates, *Opiella* sp. displayed the same overall, and individual significant differences as total Cryptostigmata.

Figure 14. Mean Population Levels of *Opiella* sp.



Control
Moldboard
Moldboard, Cultivation, Atrazine
Numbers of Animals
(in thousands/m²)
12
10
8
6
4
2
9 June
19 July
3 Aug
26 Aug
23 Sept
14 Oct
1 Nov
9 Dec
Sample Dates

DISCUSSION AND CONCLUSIONS

In this study, population levels of Acarina and Collembola from grassland controls increased in June, with maxima occurring in July for Acarina and in August for Collembola. However, trends in natural population levels of these soil animals show a great deal of variation with respect to seasonal fluctuations. Thompson (1924), Ford (1937, 1938), and Dowdy (1965) found Acarina and Collembola populations peaked during winter months, November through February. Dhillon (1962) reported peaks in June, with minimum levels in December. Edwards and Thompson (1975) found population maxima during Spring and Fall. Shaddy and Butcher (1977) reported no distinct population peaks.

Tullbergia granulata also exhibited variations with respect to its seasonal fluctuations. In this study, *T. granulata* populations fluctuated little, and did not exhibit any distinct maximum or minimum levels. Usher (1970) found *T. granulata* peaked September through October, while Shaddy and Butcher (1977) reported peaks in July.

Numerous ecological factors, such as variations in soil type, climatic conditions, moisture regimes, and the frequency and quantity of samples taken, may be involved in these discrepancies.

Conventional tillage, utilizing the moldboard plow, significantly reduced populations of Acarina and Collembola immediately following its use. These results are in agreement with studies by Tischler (1955), Sheals (1956) and Edwards and Lofty (1969, 1975). However, Edwards and Lofty (1969) reported Prostigmata were least affected by tillage and Cryptostigmata were affected most. In this study, contrary data showed an opposite effect. For example, Prostigmata were significantly reduced over the entire growing season following tillage. Initially Cryptostigmata showed no response to tillage, and exhibited significant reductions on only three of eight sample dates.

After seven months, no recovery to levels comparable to controls were observed for total Acarina or Prostigmata. Cryptostigmata began to recover after five months, while Mesostigmata recovered after just three months. Levels of Rhodacarellus sp. (Mesostigmata) increased initially following tillage, and displayed the same pattern as control populations over the first five sample dates. This increase in Rhodacarellus sp., and quick recovery of Mesostigmata, in general may be attributed to the predatory behavior of Mesostigmata. Being active predators, they range freely through soil. Frequently they are not associated with the soil to the degree of other euedaphic mites (Usher, 1971).

Populations of Collembola, with the exception of Tullbergia granulata, began to recover after four months. T. granulata populations were not effected detrimentally by tillage. Their levels remained nearly equal to control levels, and even increased to levels significantly higher than controls after five months.

The effects of Atrazine on populations of Acarina and Collembola in this study are difficult to assess. The majority of taxa analyzed showed no differences between cultivated plots with and without Atrazine. Tillage, being so great a destructive force on soil animals, has masked any apparent herbicidal effects. Between cultivated plots with and without Atrazine, a few taxa exhibited significant differences. Cryptostigmata, Opiella sp. and Rhodacarellus sp. all had one sample date where these differences occurred. However, differences were probably the result of high natural variation that occurs in soil animal populations owing to their non-random, aggregated distribution (Hughes, 1962; Nef, 1962; and Berthet and Gerard, 1965).

Only Tullbergia granulata displayed consistently distinct differences between cultivated plots with and without Atrazine, thus exposing possible herbicide effects. After the first two dates sampled, populations of T. granulata increased significantly higher than control or treatment I levels. This is indicative of possible stimulation of T. granulata populations caused by Atrazine usage, and is in direct contrast to studies by Subaja and Snider (1981, in press). They reported longer instar duration and decreased egg production for Atrazine fed T. granulata. These results also contradict studies by Fox (1964), Edwards and Thompson (1973). They found Atrazine decreased Collembola populations. Reasons for these discrepancies are not readily apparent, but demonstrate the need for further investigations into possible herbicidal side-effects on soil fauna.

Before concluding this study, an important consideration should be made. Although some taxa exhibited levels equivalent to controls in December, the final date sampled, the assumption should not be made that total recovery of Acarina and Collembola populations has occurred. In subsequent months, control populations may increase steadily, while treated plots continue to remain at low levels. Only continuous sampling through subsequent months can reveal long-term effects of these treatments.

RECOMMENDATIONS FOR FUTURE STUDY

Based on the results of this study, the following recommendations are proposed for the future:

1) Evaluate effects of herbicide applications on grass plots without tillage.
2) Examine changes in vertical distribution of soil fauna following tillage.
3) Environmental parameters such as soil moisture, organic matter content and pH should be measured.
4) Continue to monitor soil fauna throughout the entire year.
5) Monitor soil fauna in treated plots in successive year.

APPENDIX

APPENDIX A: Inventory of Arthropods from Control Plots.

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Order Collembola	105	334	683	383	106	313	283	167	2369
Hypogasturidae									
Brachystomella parvula	70	245	506	195	28	205	163	88	1500
Hypogastura manubrialis	3	4	18	3	4	3	0	2	37
Onychiuridae									
Tullbergia granulata	7	14	4	1	3	22	16	16	83
Onychiuris encarpatus	3	12	11	32	18	4	12	13	105
Isotomidae									
Isotoma notabolus	6	18	52	16	17	20	26	12	167
Isotoma viridis	0	0	1	6	0	0	1	2	10
Sminthuridae									
Sminthuris elegans	5	5	12	29	0	18	2	1	72
Sphaeridia pumulis	2	12	26	10	0	8	0	0	58
Deuterosminthuris russata	2	0	2	0	0	0	0	0	4
Arhopalites caecus	0	0	1	1	1	0	0	0	3
Neelidae									
Neelus sp.	0	0	0	0	1	0	1	0	2

APPENDIX A: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Entomobryidae									
Pseudocinella violenta	2	16	28	32	12	3	6	13	112
Pseudocinella sexoculata	0	1	2	4	0	0	1	0	8
Lepidocyrtus pallidus	5	7	26	51	17	28	47	20	201
Lepidocyrtus paradoxus	0	0	1	3	2	1	0	0	7
Entomobrya multifasciata	0	0	0	0	0	1	0	1	2
Orchesella villosa	0	0	3	0	1	0	1	0	5
Order Acarina									
Prostigmata (=Trombidiformes)									
Bakerdania sp. (Pygmephoridae)	127	533	110	50	240	221	335	237	1853
Tarsonemus sp. (Tarsonemidae)	6	70	79	85	181	130	78	32	661
Scutacarus sp. (Scutacaridae)	73	139	38	12	74	47	237	46	666
*Eupodidae	38	106	77	19	56	52	56	48	452
Rhagidia sp. (Rhagidiidae)	2	25	10	4	1	2	3	2	49
Triophtydeus sp. (Tydeidae)	9	13	20	3	11	6	6	9	77

*Eupodes sp. and Cocceupodes sp. together

APPENDIX A: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Eustigmaeus sp. (Stigmaeidae)	1	0	1	0	3	26	0	0	31
Nanorchestes sp. (Nanorchestidae)	0	3	1	0	1	0	1	1	7
Speleorchestes sp. (")	1	1	0	0	0	1	1	0	4
Spinibdella sp. (Bdellidae)	2	0	0	2	2	1	0	0	7
Belaustium sp. (Erythraeidae)	1	1	2	0	0	0	0	0	4
Eriophyidae	0	0	0	0	1	1	0	0	2
Bryobia sp. (Tetranychidae)	0	0	0	0	0	1	0	0	1
Astigmata (= Acaridei)									
Schwieba sp. (Acaridae)	0	2	4	0	0	6	10	2	24
Tyrophagus sp. (Acaridae)	1	7	10	5	24	14	44	3	108
Cryptostigmata (= Sarcoptiformes)									
Oppiella sp. (Oppiidae)	10	187	153	17	54	229	199	59	908
Oppia sp. (Oppiidae)	3	9	0	1	3	11	4	0	31
Scheloribates sp. (Oribatulidae)	0	5	16	17	56	91	81	19	285
Epilohmannia sp. (Epilohmanniidae)	0	7	2	1	1	3	12	1	27
Brachychtonius sp. (Brachychtoniidae)	0	3	1	0	1	0	1	0	6

APPENDIX A: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Tectocepheus sp. (Tectocepheidae)	1	1	1	1	6	8	1	2	21
Euphthiracarus sp. (Euphthiracaridae)	0	0	0	0	0	5	9	0	14
Palaeacarus sp. (Palaeacaridae)	0	0	0	0	1	0	0	0	1
Immatures	3	61	62	10	103	55	65	19	378
Mesostigmata									
Rhodacarellus sp. (Rhodacaridae)	11	43	57	16	30	34	27	7	225
Asca sp. (Ascidae)	7	53	63	34	64	49	64	17	351
Cheiroseius sp. (Ascidae)	0	0	2	0	0	0	0	0	2
Gamaselloides sp. (Ascidae)	0	0	2	0	0	2	0	0	4
Arctoseius sp. (Ascidae)	0	3	2	1	0	0	0	0	6
Amblyseius sp. (Phtoseiidae)	0	6	7	11	6	10	3	0	43
Phytoseius sp. (Phytoseiidae)	2	3	2	3	1	0	12	2	25
Hypoaspis sp. (Laelapidae)	0	7	7	3	9	2	2	6	36
Androlaelaps sp. (Laelapidae)	0	8	5	5	1	2	0	0	21
Parasitus sp. (Parasitidae)	0	22	7	6	6	3	0	0	44
Pergamasus sp. (Parasitidae)	0	0	0	0	0	1	3	0	4
Alliphis sp. (Eviphididae)	0	0	0	0	0	0	0	0	0
Uropoda sp. (Uropodidae)	0	0	0	0	0	0	0	0	0
Immatures	4	1	33	10	3	3	0	0	54

APPENDIX A: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Miscellaneous									
Diplopoda	2	1	3	2	4	4	3	2	21
Coleoptera	2	14	11	11	6	4	5	2	55
Ants	6	0	11	13	5	2	3	0	40
Homoptera	1	6	9	3	4	4	1	2	30
Hymenoptera	2	6	0	2	3	0	0	0	13
Thysanoptera	11	49	23	16	25	13	12	14	164
Diplura	5	9	12	71	5	4	18	4	128
Psocoptera	1	0	0	0	0	0	0	0	1
Symphyla	1	38	50	22	6	13	43	3	176
Coleoptera larvae	1	0	14	14	7	8	16	6	66
Diptera	0	2	4	0	0	1	3	1	11
Diptera larvae	1	0	6	1	0	1	6	4	19
Pauropoda	0	1	1	0	0	3	2	4	11
Protura	0	1	0	0	0	0	0	0	1
Chilopoda	0	0	0	1	0	1	1	0	3
Isopoda	0	1	0	2	1	2	3	0	9
Araneae	0	1	1	2	7	0	1	1	13

APPENDIX B: Inventory of Arthropods from Moldboard Plots.

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
ORDER COLLEMBOLA	65	82	76	90	72	70	140	47	642
Hypogasturidae									
Brachystomella parvula	14	18	27	21	2	6	20	17	125
Hypogastura manubrialis	0	0	0	0	0	0	0	0	0
Onychiuridae									
Tullbergia granulata	15	31	7	5	21	31	86	19	216
Onychiuris encarpatus	4	9	16	23	23	4	20	6	104
Isotomidae									
Isotoma notabolus	3	9	11	4	5	8	9	1	50
Isotoma viridis	0	0	1	0	0	0	0	0	1
Sminthuridae									
Sminthuris elegans	13	2	3	8	0	1	0	0	27
Sphaeridia pumulis	2	3	0	1	0	0	0	0	6
Deuterosminthuris russata	4	0	3	11	0	0	0	0	18
Arhopalites caecus	0	0	0	0	0	0	0	0	0
Neelidae									
Neelus sp.	0	3	0	0	0	1	1	0	5

APPENDIX B: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec 9	Total
Entomobryidae									
Pseudocinella violenta	0	3	8	17	21	14	2	0	65
Pseudocinella sexoculata	0	0	0	0	0	0	1	0	1
Lepidocyrtus pallidus	5	1	1	0	0	0	2	1	10
Lepidocyrtus paradoxus	0	0	0	0	0	0	0	0	0
Entomobrya multifasciata	0	0	0	0	0	1	0	0	1
Orchecella villosa	0	1	0	0	0	0	0	0	1
ORDER ACARINA									
Prostigmata									
Bakerdania sp. (Pygmephoridae)	103	71	50	8	51	68	100	33	483
Tarsonemus sp. (Tarsonemidae)	8	0	2	0	54	77	66	16	223
Scutacarus sp. (Scutacaridae)	6	4	8	19	3	39	16	1	96
*Eupodidae	4	23	8	16	15	46	51	12	175
Rhagidia sp. (Rhagidiidae)	4	5	1	1	3	3	3	3	23
Triophtydeus sp. (Tydeidae)	0	1	4	5	5	10	2	4	31

*<u>Eupodes</u> sp. and <u>Cocceupodes</u> sp. together

APPENDIX B: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Eustigmaeus sp. (Stigmaeidae)	1	0	0	1	1	1	0	0	4
Nanorchestes sp. (Nanorchestidae)	0	2	0	0	1	0	0	0	3
Speleorchestes sp. (")	1	0	0	4	0	0	0	0	5
Spinibdella sp. (Bdellidae)	0	0	0	0	0	0	0	0	0
Balaustium sp. (Erythraeidae)	0	0	0	0	0	0	0	0	0
Bryobia sp. (Tetranychidae)	0	0	0	0	0	0	0	0	0
Eriophyidae	0	0	0	0	0	0	0	0	0
Astigmata (= Acaridei)									
Schwieba sp. (Acaridae)	1	12	17	28	7	2	7	0	66
Tyrophagus sp. (Acaridae)	0	0	7	0	0	3	1	1	12
Cryptostigmata (= Sarcoptiformes)									
Opiella sp. (Oppiidae)	24	83	113	51	50	107	121	16	565
Oppia sp. (Oppiidae)	5	0	0	3	6	14	5	0	33
Scheloribates sp. (Oribatulidae)	2	3	5	16	8	29	33	10	106
Epilohmannia sp. (Epilohmanniidae)	14	15	13	15	4	10	24	3	98
Brachychtonius sp. (Brachychtoniidae)	3	2	0	0	1	0	0	1	7

APPENDIX B: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Tectocepheus sp. (Tectocepheidae)	1	0	5	4	7	4	3	0	25
Euphthiracarus sp. (Euphthiracaridae)	0	0	0	0	1	0	0	0	1
Palaeacarus sp. (Palaeacaridae)	0	0	0	0	0	0	0	0	0
Immatures	9	14	3	1	29	34	31	3	134
Mesostigmata									
Rhodacarellus sp. (Rhodacaridae)	34	70	35	11	39	15	12	2	218
Asca sp. (Ascidae)	16	0	3	0	0	4	2	5	30
Cheiroseius sp. (Ascidae)	0	0	0	1	0	1	0	1	3
Gamaselloides sp. (Ascidae)	0	0	2	0	0	2	0	0	4
Arctoseius sp. (Ascidae)	0	2	0	2	0	0	0	0	4
Amblyseius sp. (Phytoseiidae)	4	0	0	3	0	0	3	0	10
Phytoseius sp. (Phytoseiidae)	4	0	0	0	0	1	0	0	5
Hypoaspis sp. (Laelapidae)	0	0	0	0	0	0	0	0	0
Androlaelaps sp. (Laelapidae)	0	0	0	0	0	1	0	0	1
Alliphis sp. (Eviphididae)	1	0	0	0	1	0	0	0	2
Parasitus sp. (Parasitidae)	2	1	0	3	0	0	1	0	7
Pergamasus sp. (Parasitidae)	0	1	2	1	0	0	0	0	4

APPENDIX B: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Uropoda sp. (Uropodidae)	0	2	0	0	0	0	1	2	5
Immatures	2	0	9	2	0	4	2	1	20
MISCELLANEOUS									
Diplopoda	1	1	0	4	1	0	3	0	10
Coleoptera	2	16	7	6	1	7	4	2	45
Ants	3	0	0	96	3	5	3	0	110
Homoptera	1	3	5	4	4	12	2	0	33
Hymenoptera	1	3	0	1	2	1	0	0	8
Thysanoptera	5	4	2	0	6	1	2	3	23
Diplura	0	2	0	5	0	1	0	4	12
Psocoptera	1	0	0	0	0	0	0	0	1
Symphyla	7	7	3	0	5	0	0	0	22
Coleoptera larvae	6	0	3	2	1	2	2	2	18
Diptera	1	3	2	0	0	0	0	2	8
Diptera larvae	0	0	2	0	0	2	3	4	11
Pauropoda	2	0	0	1	1	3	3	1	11
Protura	0	0	0	0	0	0	0	0	0
Chilopoda	0	0	0	0	4	3	1	0	8

APPENDIX B: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Isopoda	0	0	0	2	5	3	0	0	10
Araneae	0	0	0	0	1	0	0	0	1

APPENDIX C: Inventory of Arthropods from Moldboard and Cultivated Plots

	Oct. 14	Nov. 1	Dec. 9	Total
ORDER COLLEMBOLA				
Hypogasturidae				
Brachystomella parvula	13	16	5	34
Hypogastura manubrialis	0	0	0	0
Onychiuridae				
Tullbergia granulata	10	53	15	78
Onychiuris encarpatus	6	19	2	27
Isotomidae				
Isotoma notabolus	6	3	0	9
Isotoma viridis	0	0	0	0
Sminthuridae				
Sminthuris elegans	3	1	0	4
Sphaeridia pumulis	0	0	0	0
Deuterosminthuris russata	0	0	0	0
Arhopalites caecus	0	0	0	0
Neelidae				
Neelus sp.	3	0	0	3
Entomobryidae				
Pseudocinella violenta	3	3	2	8
Pseudocinella sexoculata	3	0	0	3
Lepidocyrtus pallidus	0	0	1	1
Lepidocyrtus paradoxus	2	1	0	3
Entomobrya multifasciata	0	0	0	0
Orchecella villosa	0	0	0	0
ORDER ACARINA				
Prostigmata				
Bakerdania sp. (Pygmephoridae)	42	87	39	169
Tarsonemus sp. (Tarsonemidae)	10	32	38	80
Scutacarus sp. (Scutacaridae)	0	2	17	19

APPENDIX C: (Cont.)

	Oct. 14	Nov. 1	Dec. 9	Total
*Eupodidae	22	32	22	169
Rhagidia sp. (Rhagidiidae)	3	5	0	8
Triophtydeus sp. (Tydeidae)	0	7	1	8
Eustigmaeus sp. (Stigmaeidae)	0	3	0	8
Nanorchestes sp. (Nanorchestidae)	11	12	10	33
Speleorchestes sp. (Nanorchestidae)	1	2	0	3
Spinibdella sp. (Bdellidae)	0	0	0	0
Balaustium sp. (Erythraeidae)	0	0	0	0
Bryobia sp. (Tetranychidae)	0	1	0	1
Eriophyidae	0	0	0	0
Astigmata (= Acaridei)				
Schwieba sp. (Acaridae)	0	3	7	10
Tyrophagus sp. (Acaridae)	0	1	0	1
Cryptostigmata (= Sarcoptiformes)				
Opiella sp. (Oppiidae)	28	42	28	98
Oppia sp. (Oppiidae)	0	3	0	3
Scheloribates sp. (Oribatulidae)	0	13	1	14
Ephilohmannia sp. (Epilohmanniidae)	7	11	5	23
Brachychtonius sp. (Brachychtoniidae)	0	1	1	2
Tectocepheus sp. (Tectocepheidae)	0	7	3	10
Euphthiracarus sp. (Euphthiracaridae)	1	0	0	1
Palaeacarus sp. (Palaeacaridae)	0	0	0	0
Immatures	8	0	2	10
Mesostigmata				
Rhodacarellus sp. (Rhodacaridae)	11	4	4	19
Asca sp. (Ascidae)	1	0	0	1

*Eupodes sp. and Cocceupodes sp. together

APPENDIX C: (Cont.)

	Oct. 14	Nov. 1	Dec. 9	Total
Cheiroseius sp. (Ascidae)	0	0	0	0
Gamaselloides sp. (Ascidae)	0	0	0	0
Arctoseius sp. (Ascidae)	0	0	0	0
Amblyseius sp. (Phytoseiidae)	0	0	0	0
Phytoseius sp. (Phytoseiidae)	1	3	0	4
Hypoaspis sp. (Laelapidae)	0	5	0	5
Androlaelaps sp. (Laelapidae)	0	0	0	0
Alliphis sp. (Eviphididae)	0	0	1	1
Parasitus sp. (Parasitidae)	0	0	0	0
Pergamasus sp. Parasitidae)	0	0	0	0
Uropoda sp. (Uropodidae)	0	0	0	0
Immatures	0	0	0	0
MISCELLANEOUS				
Diplopoda	1	0	0	1
Coleoptera	1	7	1	9
Ants	3	2	1	6
Homoptera	6	0	0	6
Hymenoptera	0	0	0	0
Thysanoptera	1	0	0	1
Diplura	4	0	0	4
Psocoptera	1	0	0	1
Symphyla	1	0	0	1
Coleoptera larvae	0	0	1	1
Diptera	0	0	0	0
Diptera larvae	26	12	0	38
Pauropoda	0	2	0	2
Protura	0	0	0	0
Chilopoda	1	0	0	1
Isopoda	1	0	0	1
Araneae	4	0	0	4

APPENDIX D: Inventory of Arthropods from Moldboard, Cultivated, and Atrazine Treated Plots.

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
ORDER COLLEMBOLA									
Hypogasturidae									
Brachystomella parvula	10	22	63	19	4	4	7	1	130
Hypogastura manubrialis	0	0	0	0	0	0	0	2	2
Onychiuridae									
Tullbergia granulata	1	11	2	6	25	45	80	21	191
Onychiuris encarpatus	1	9	12	7	0	4	30	23	86
Isotomidae									
Isotoma notabolus	0	13	9	3	9	8	6	6	54
Isotoma viridis	0	0	1	2	2	0	0	2	7
Sminthuridae									
Sminthuris elegans	6	2	4	9	0	0	1	0	22
Sphaeridia pumulis	1	0	1	1	0	0	0	0	3
Deuterosminthuris russata	1	0	1	4	0	0	0	0	6
Arhopalites caecus	0	0	1	0	0	2	0	0	3
Neelidae									
Neelus sp.	0	2	0	0	0	2	0	4	8
Nanorchestes sp. (Nanorchestidae)	0	1	1	0	4	3	2	4	15

APPENDIX D: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Speleorchestes sp. (Nanorchestidae)	0	1	1	0	4	3	2	4	15
Spinibdella sp. (Bdellidae)	0	0	0	0	0	0	0	0	0
Balaustium sp. (Erythraeidae)	0	0	0	0	0	0	0	0	0
Bryobia sp. (Tetranychidae)	0	0	0	0	0	0	0	0	0
Eriophyidae	0	0	0	0	0	0	0	0	0
Astigmata (= Acaridei)									
Schwieba sp. (Acaridae)	4	34	11	2	1	35	6	2	95
Tyrophagus sp. (Acaridae)	0	1	2	0	0	0	0	0	3
Cryptostigmata (= Sarcoptiformes)									
Opiella sp. (Oppiidae)	10	23	95	27	48	106	80	39	428
Oppia sp. (Oppiidae)	6	0	0	1	1	5	4	5	22
Scheloribates sp. (Oribatulidae)	3	7	20	14	33	14	20	19	130
Epilohmannia sp. (Epilohmanniidae)	15	9	6	11	6	14	10	8	79
Brachychtonius sp. (Brachychtoniidae)	0	0	1	0	2	0	0	1	4
Tectocepheus sp. (Tectocepheidae)	3	0	3	6	9	9	8	2	40
Euphthiracarus sp. (Euphthiracaridae)	0	0	0	0	0	1	0	0	1
Palaeacarus sp. (Palaeacaridae)	0	0	0	0	0	0	0	0	0
Immatures	0	3	11	2	33	0	47	11	107

APPENDIX D: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Mesostigmata									
Rhodacarellus sp. (Rhodacaridae)	8	20	12	5	15	24	3	6	93
Asca sp. (Ascidae)	4	1	7	2	2	1	1	1	19
Cheiroseius sp. (Ascidae)	0	0	0	1	0	0	0	0	1
Gamaselloides sp. (Ascidae)	0	0	1	0	0	0	0	0	1
Arctoseius sp. (Ascidae)	1	0	2	0	0	2	0	0	5
Amblyseius sp. (Phytoseiidae)	0	9	1	0	1	0	1	3	15
Phytoseius sp. (Phytoseiidae)	0	1	0	1	1	0	0	1	4
Hypoaspis sp. (Laelapidae)	1	0	5	0	2	1	3	2	14
Androlaelaps sp. (Laelapidae)	0	1	0	0	0	1	0	0	2
Alliphis sp. (Eviphididee)	1	1	3	4	1	0	0	0	10
Parasitus sp. (Parasitidae)	0	0	3	0	1	0	2	0	6
Pergamasus sp. (Parasitidae)	0	0	0	0	0	0	0	0	0
Uropoda sp. (Uropodiade)	0	0	0	2	0	0	0	0	2
Immatures	1	1	16	0	1	0	0	0	19
MISCELLANEOUS									
Diplopda	2	3	2	0	0	6	0	0	13
Coleoptera	3	7	5	5	2	4	1	1	28

APPENDIX D: (Cont.)

	June 9	July 19	Aug. 3	Aug. 26	Sept. 23	Oct. 14	Nov. 1	Dec. 9	Total
Ants	11	0	5	43	30	9	2	0	100
Homoptera	0	2	2	1	0	9	0	0	14
Hymenoptera	1	6	0	0	0	0	0	0	7
Thysanoptera	1	7	3	1	0	1	0	1	14
Diplura	2	1	2	1	0	2	2	0	10
Psocoptera	0	0	6	0	1	0	0	0	7
Symphyla	0	1	0	1	2	2	0	0	6
Coleoptera larvae	5	6	2	3	0	0	0	2	18
Diptera	0	1	2	1	0	0	1	1	6
Diptera larvae	2	0	5	0	0	0	1	2	10
Pauropoda	0	0	1	1	0	0	3	0	5
Protura	2	0	0	0	0	0	0	0	2
Chilopoda	0	1	1	2	2	4	3	0	13
Isopoda	0	0	0	0	0	1	0	0	1
Araneae	0	0	0	1	1	1	1	1	4

LIST OF REFERENCES

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Aleinikova, M. M. and N. M. Utrobina. 1975. Changes in the structure of animal populations in soil under the influence of farm crops. Proc. V Coll. Soil Zool. Prague.

Audus, L. J. 1964. The Physiology and Biochemistry of Herbicides. Ed. L. J. Audus. p. 163. N. Y. Academic Press.

Berthet, P. and G. Gerard. 1965. A statistical study of micro-distribution of Oribatei. I. The distribution pattern. Oikos 16: 214-227.

Block, W. C. 1966. Distribution of Soil Acarina on Eroding Blanket Bog. Pedobiologia 6: 27-34.

Buckle, P. 1921. A preliminary survey of the soil fauna on agricultural lands. Ann. Appl. Biol. 8: 135-145.

Burnett, G. F. 1968. The effect of irrigation, cultivation, and some insecticides on the soil Arthropods of an East African dry grassland. J. Appl. Ecol. 5: 141-156.

Burnside, O. C., G. A. Wicks, and C. R. Fenster. 1965. Herbicide longevity in Nebraska soils. Weeds 13: 277.

Butcher, J. W., R. M. Snider, and R. J. Snider. 1971. Bioecology of edaphic Collembola and Acarina. Annual Review of Entomology 16: 249-288.

Christiansen, K., and P. Bellinger. 1979. Collembola of North America. Entomological reprint specialists.

Davis, B. N. K. 1965. Immediate and long term effects of the herbicide MCPA on soil Arthropods. Bull. Ent. Res. 56: 357-366.

Dhillon, B. S., and N. H. E. Gibson. 1962. A study of Acarina and Collembola of agricultural soils. Pedobiologia 1: 189-209.

Dowdy, W. W. 1965. Studies on the ecology of mites and Collembola. Am. Mid. Nat. 74: 196-210.

Edwards, C. A. 1965. Effects of pesticide residues on soil invertebrates and plants. Fifth Symp. Brit. Ecol. Soc. 239-261. Edology and the industrial society. Oxford: Blackwell.

Edwards, C. A., and M. K. Arnold. 1964. Side effects of toxic chemicals in the soil on Arthropods and earthworms. Rep. Rothamsted Exp. St. for 1963. p. 148.

Edwards, C. A., and J. R. Lofty. 1969. The influence of agricultural practice on soil microarthropod populations. In: The Soil Ecosystem. J. G. Sheals (Ed.). The Systematic Assoc. Publication No. 8. London. 237-247.

Edwards, C. A., and A. R. Thompson. 1973. Pesticides and soil. Fauna Residue Review 45: 1-79.

Edwards, C. A., and J. R. Lofty. 1975. The influence of cultivations on soil animal populations. In: Progress in Soil Zoology. J. vanek (Ed.) Academia Prague 399-407.

Engelmann, M. D. 1961. The role of soil arthropods in the energetics of an old field community. Ecol. Monogr. 31: 221-238.

Ford, J. 1937. Fluctuations in natural populations of Collembola and Acarina. J. Animal Ecol. 6: 98-111.

Ford, J. 1938. Fluctuations in natural populations of Collembola and Acarina. Part 2. J. Animal Ecol. 7: 350-369.

Fox, C. J. S. 1964. The effects of five herbicides on the number of certain invertebrate animals in grassland soils. Can. J. Plant Sci. 44: 405-409.

Frantz, H. 1962. Habitat characteristics with particular reference to the soil. In: Progress in Soil Zoology. P. W. Murphy (Ed.). 311-318.

Gill, J. L. 1978. Design and Analysis of Experiments in the Animal and Medical Sciences. Vol. I. Iowa State University Press. Ames, Iowa. 409 pages.

Haarlov, N. 1962. A quantitative comparison of hand sorting and extraction with a Tullgren funnel. In: Progress in Soil Zoology. P. W. Murphy (Ed.). Butterworths, London. 156-157.

Harris, C. I. and G. F. Warren. 1964. Adsorption of herbicides by soil. Weeds 12: 120.

Hughes, R. D. 1962. The study of aggregated populations. In: Progress in Soil Zoology. P. W. Murphy (Ed.). 51-55.

Kaufman, D. D. and P. C. Kearney. 1970. Microbial degradation of s-triazine herbicides. Residue Reviews 32: 235-265.

Kevan, D. McE. 1962. Soil Animals. Philosophical Library. New York. 237 pages.

Krantz, G. W. 1978. A Manual of Acarology. Oregon State University Bookstores, Corvallis, Oregon. 509.

Lebrum, P. 1979. Soil mite community diversity. In: Recent Advances in Acarology, Vol. I. Academic Press 603-613.

McCormick, J. and L. C. Hiltbold. 1966. Microbiological decomposition of Atrazine and Diuron in soils. Weeds 14: 77-82.

Nef, L. 1962. The roles of desication and temperature in the Tullgren funnel method of extraction. In: Progress in Soil Zoology, P. W. Murphy (Ed.). Butterworths, London. 169-173.

Popovici, I., G. Stan, V. Stefan, R. Tomescu, A. Dumea, A. Turta, and F. Dan. 1977. The influence of Atrazine on soil fauna. Pedobiologia 17: 209-215.

Prasse, J. 1975. The effect of herbicide 2,4-D and Simazin on the coenosis of Collembola and Acari in arable soil. In: Progress in Soil Zoology, 469-480.

Rapoport, E. H., and G. Canglioli. 1963. Herbicides and soil fauna. Pedobiologia 2: 235-238.

Robertson, L. S., A. E. Erickson, and C. M. Hanson. 1977a. Tillage systems for Michigan soils and crops. Part I. Deep, Primary, Supplemental and No-till. Michigan State University Cooperative Extension Service. Extension Bulletin E-1041.

Robertson, L. S., A. E. Erickson, and C. M. Hanson. 1977b. Tillage systems for Michigan soils and crops. Part II. Secondary Tillage and Cultivation. Michigan State University Cooperative Extension Service. Extension Bulletin E-1042.

Roeth, F. W., T. L. Levy, and O. C. Burnside. 1969. Degradation of Atrazine in soils. Weeds 17: 202-205.

Satchell, J. E., and J. M. Nelson. 1962. Comparison of the Tullgren funnel and flotation methods of extracting soil Acarina from woodland soil. In: Progress in Soil Zoology. P. W. Murphy (Ed.) Butterworths, London. 212-216.

Shaddy, J. H., and J. W. Butcher. 1977. Distribution of some soil Arthropods in a manipulated ecosystem. Great Lakes Entomologist 10: 131-144.

Sheals, J. G. 1957. Collembola and Acarina of uncultivated soil. J. Animal Ecology 26: 125-134.

Sheals, J. G. 1956. Soil population studies. I. The effects of cultivation and treatment with insecticides. Bull. Ent. Res. 47: 803-822.

Skipper, H. D., and V. V. Volk. 1972. Biological and chemical degradation of Atrazine in three Oregon soils. Weeds 20: 344-346.

Snider, R. J. 1967. An annotated list of the Collembola of Michigan. The Michigan Entomologist 1: 179-234.

Strickland, A. H. 1947. The soil fauna of two contrasted plots of land in Trinidad, British West Indies. J. Animal Ecol. 16: 1-10.

Subaja, J. D., and R. J. Snider. 1981. The side effects of the herbicides Atrazine and Paraquat upon Folsomia candida and Tullbergia granulata. Pedobiologia (in press).

Tamura, H. 1976. Biases in extracting Collembola through Tullgren funnels. Rev. Ecol. Biol. Sci. 13: 21-34.

Thompson, M. 1924. The soil population. An investigation of the soil biology in certain districts of Aberystwyth. Ann. Appl. Biol. 11: 349-374.

Tischler, W. 1955. Effects of agricultural practice on the soil fauna. In: Soil Zoology. D. Kevan (Ed.) Butterworths, London. 215-230.

Upchurch, R. P. 1966. Behavior of herbicides in soil. Residue Revue. Francis A. Gunther (Ed.). Springer-Verlag, New York Inc. 46-86.

Usher, M. B. 1970. Seasonal and vertical distribution of a population of soil Arthropods: Collembola, Pedobiologia 10: 224-236.

Usher, M. B. 1971. Seasonal and vertical distribution of a population of soil Arthropods: Mesostigmata. Pedobiologia 11: 27-39.

Witkamp, J. C., and D. A. Crossley, Jr. 1966. The role of Arthropods and microflora in breakdown of white oak litter. Pedobiologia 6: 293-303.