



127
282
THS



3 1293 10491 8846

THESIS



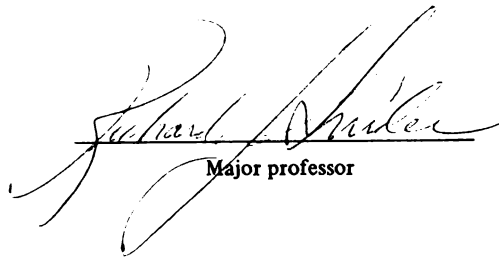
This is to certify that the
thesis entitled

SIDE EFFECTS OF NO-TILL METHODS AND
HERBICIDE PARAQUAT UPON COLLEMBOLAN
POPULATIONS
presented by

Jusup Subagja

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Zoology


Major professor

Date Feb 12, 1981



OVERDUE FINES:

25¢ per day per item

RETURNING LIBRARY MATERIALS:

Place in book return to remove
charge from circulation record

W 08-35-042 CB

STANDARD 10.5 (1967)

May 10, 1993
124

320

SIDE EFFECTS OF NO-TILL METHODS AND HERBICIDE PARAQUAT
UPON COLLEMBOLAN POPULATIONS

By
Jusup Subagja

A DISSERTATION

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

DOCTOR OF PHILOSOPHY

Department of Zoology

1981



ABSTRACT

SIDE EFFECTS OF NO-TILL METHODS AND HERBICIDE PARAQUAT UPON COLLEMBOLAN POPULATIONS

By

Jusup Subagja

Collembolan populations were studied in grassland, No-till corn without herbicide, and No-till corn with paraquat plots during the period of May through December 1979. No-till corn reduced the numbers of the hemiedaphic species temporarily, and they recovered by the end of the study. Euedaphic species, *Tullbergia granulata* and *Onychiurus armatus*, were not affected by the practice, but tended to have more individuals in deeper soil layer than in grassland. Paraquat application significantly reduced the number of *Lepidocyrtus pallidus* immediately, and then diminished after four months. However, reduction in numbers of *Brachystomella parvula* and *Tullbergia granulata* were significant for only two months, and they were able to recover.

A two-dimensional ordination of the collembolan communities of the three habitats showed that the three communities were affected by No-till corn and paraquat application. Among the habitats studied, grassland was the most favorable habitat followed by No-till corn without herbicide, while No-till with paraquat was the least.

Jusup Subagja

The degree of aggregation of Collembola changed to various degrees depending on the species and the changes of habitat. In No-till corn without herbicide, hemiedaphic and more active species decreased their aggregations, while euedaphic and slow moving species were more aggregated. Paraquat application increased the degree of aggregation of all Collembola.



ACKNOWLEDGMENTS

I wish to express my deepest appreciation to Dr. Richard J. Snider for serving as my major professor during my study at Michigan State University. His attitude, understanding and indispensable help have maintained my enthusiasm during my graduate study.

A special note of thanks and appreciation are due to members of my guidance committee: Dr. T. Wayne Porter, Dr. Ralph A. Pax and Dr. Lynn S. Robertson for their participation in my graduate program and critical evaluation of the manuscript.

I would also thank Dr. Kenneth A. Christiansen of Grinnell College, Iowa, for identification of certain Collembola, Dr. Darryl D. Warncke for his advice in the measurements of soil pH and moisture, Mr. Dallas Hyde, Soil Farm Supervisor, for the preparation of field study.

I also express gratitude to Gadjah Mada University, my home country university, for providing me opportunity to study in the United States, the MUCIA - Indonesian Higher Agricultural Education Project, and Indonesian Government for financial support and assistance.

Finally, a special gratitude goes to my family: my late father, Soedomo Dwidjasatmoko, who passed away during my stay in the United States, and my mother, Soemarmi, for their constant love and encouragement; my wife, Nanni, for her unfailing love, relentless



confidence and encouragement, and my son Alfano, who is my greatest joy, have been my source of strength and purpose. They have made the greatest sacrifices, and I dedicate this dissertation to them.

TABLE OF CONTENTS

	Page
LIST OF TABLES	vi
LIST OF FIGURES	viii
INTRODUCTION	1
MATERIALS AND METHODS	5
Condition of the Field	5
Sampling	7
Extraction Method	8
RESULTS	9
Climatological Data	9
Soil pH	9
Soil Temperature	9
Soil Moisture Content	14
Extraction Efficiency	14
Fluctuations of Collembolan Populations	17
Species Account	17
Age Structure	23
Vertical Distribution	28
DISCUSSION	31
Soil	31
Extraction	31
Effects of No-till	32
Effects of Paraquat	33
COMMUNITY STRUCTURE	37
Results and Discussion	39
AGGREGATION	45
Sampling	45
Mathematical Manipulation	46
Results and Discussion	47



	Page
SUMMARY	50
POSSIBLE IMPROVEMENTS FOR FURTHER STUDY	52
REFERENCES	53
APPENDICES	
I Mean Number of Collembola Collected per Core	57
II Size Structures of Collembola in the Three Habitats . .	65



LIST OF TABLES

TABLE		Page
1	Soil pH on Each Sample Date	11
2	Soil Temperature ($^{\circ}\text{C}$) on Each Sample Date	12
3	Soil Moisture Content (%) on Each Sample Date	13
4	Extraction Efficiency of Tullgren Funnels Determined by Simple Flotation Method	15
5	List of Collembola Species Identified During the Study . .	16
6	Body Length Classes for <i>Hypogastrura manubrialis</i> , <i>Brachystomella parvula</i> , and <i>Tullbergia granulata</i>	24
7	Body Length Classes for <i>Onychiurus armatus</i>	25
8	Body Length Classes for <i>Isotoma notabilis</i>	26
9	Body Length Classes for <i>Lepidocyrtus pallidus</i>	27
10	Body Length Classes for <i>Pseudosinella violenta</i>	28
11	Prominence Values of Collembola Species Collected During the Study	38
12	Coefficient Dissimilarities of Plots Sampled	40
13	$s^2 = a m^b$ for Seven Species of Collembola Derived From 12 Samplings During the Study Period	48
14	Mean Number of Total Collembola Collected per Core Transformed Data: $\text{Log}(x + 1)$	57
15	<i>Hypogastrura manubrialis</i> , Means Number of Animals per Core Transformed Data: $\text{Log}(x + 1)$	58
16	<i>Brachystomella parvula</i> , Mean Number of Animals per Core Transformed Data: $\text{Log}(x + 1)$	59
17	<i>Onychiurus armatus</i> , Mean Number of Animals per Core Transformed Data: $\text{Log}(x + 1)$	60

TABLE		Page
18	<i>Tullbergia granulata</i> , Mean Number of Animals per Core Transformed Data: $\text{Log}(x + 1)$	61
19	<i>Isotoma notabilis</i> , Mean Number of Animals per Core Transformed Data: $\text{Log}(x + 1)$	62
20	<i>Lepidocyrtus pallidus</i> , Mean Number of Animals per Core Transformed Data: $\text{Log}(x + 1)$	63
21	<i>Pseudosinella violenta</i> , Mean Number of Animals per Core Transformed Data: $\text{Log}(x + 1)$	64
22	<i>Hypogastrura manubrialis</i> , Percent of Animals in each Size Class on Every Sampling Dates	72
23	<i>Brachystomella parvula</i> , Percent of Animals in each Size Class on Every Sampling Dates	73
24	<i>Onychiurus armatus</i> , Percent of Animals in each Size Class on Every Sampling Dates	74
25	<i>Tullbergia granulata</i> , Percent of Animals in each Size Class on Every Sampling Dates	75
26	<i>Isotoma notabilis</i> , Percent of Animals in each Size Class on Every Sampling Dates	76
27	<i>Lepidocyrtus pallidus</i> , Percent of Animals in each Size Class on Every Sampling Dates	77
28	<i>Pseudosinella violenta</i> , Percent of Animals in each Size Class on Every Sampling Dates	78



LIST OF FIGURES

FIGURE	Page
1 Map of Field Study	6
2 Average of Weekly Air Temperature (above) and Weekly Total Rainfall (below) During the Study Period	10
3 Seasonal Fluctuation of Collembola Populations	18
4 Vertical Distribution of Collembola During the Study Period	29
5 Distribution of Plots Within Ordination	41
6 Size Structures of <i>Hypogastrura manubrialis</i>	65
7 Size Structures of <i>Brachystomella parvula</i>	66
8 Size Structures of <i>Onychiurus armatus</i>	67
9 Size Structures of <i>Tullbergia granulata</i>	68
10 Size Structures of <i>Isotoma notabilis</i>	69
11 Size Structures of <i>Lepidocyrtus pallidus</i>	70
12 Size Structures of <i>Pseudosinella violenta</i>	71



INTRODUCTION

Grassland soils usually support a diverse soil fauna. The use of certain soils for crop and livestock production affects soil fauna in different ways and to various degrees. Although some animals are benefited, some are deleteriously effected by agricultural practices (Sheals, 1956; Aleinikova & Utrobina, 1975; Edwards & Lofty, 1975). Among the arthropods of soil, order Collembola has the greatest number of soil species besides Acarina. They play an important role in the breakdown of organic matter, and are among the most important producers of humus (Schaller, 1968).

Studies on the arthropods in agricultural soils have been conducted for more than two decades. Early reports stated that soil fauna populations temporarily decreased because of tillage (Tischler, 1955). Apparently agricultural crops affect soil arthropod populations (Aleinikova & Utrobina, 1975). Literature reviews of cultivation effects upon soil arthropod populations have been reported by Christiansen (1964), Butcher et al. (1971), and Ghilarov (1975).

Many studies have been primarily concerned with the effects of tillage upon soil arthropod populations. This was, however, understood that the destruction of soil structure affects soil faunae (Ghilarov, 1975). Tillage is necessary in agricultural lands for several reasons: weed control, management of crop residues, aeration of soil, preparation of good seed bed, shaping and leveling of the field,



loosening compacted soil, incorporation of fertilizer and lime, erosion control, aid in promoting normal root development, and warming of soil in the spring (Robertson et al., 1977).

In recent years, No-till methods of crop production were introduced. These methods basically involve planting a crop on land with unplowed soil. A fluted coulter is used to make a narrow slit in the soil. Seeds are then placed in the slit and covered (Nelson et al., 1977). Compared to conventional tillage, No-till methods have certain advantages: reduce fuel use, reduction of wind and water erosion problems, and increase soil water retention (Baeumer & Bakermans, 1973; Nelson et al., 1977). No-till methods have been recommended for sandy or organic soils with wind erosion problems, and for mineral soils with water erosion problems. The latter includes soils with a slope that are naturally low in organic matter, and soils with a coarse textured surface (Cook & Robertson, 1979). No-till farming has virtually minimum disturbance of ground cover and soil structure, which in turn benefits the soil animals. However, these advantages are counterbalanced by the use of chemicals to control weed, diseases, and animal pests.

Changes in soil fauna can be expected when No-till methods are applied, but suitable information is still scant. Early studies indicated that No-till soil contained more animals than soil tilled conventionally (Baeumer & Bakermans, 1973). In more recent reports the number of Collembola in No-till winter wheat plots was higher than in plowed plots. Acarina populations were also higher in No-till plots (Edwards, 1975).



Since the introduction of No-till farming, research on soil arthropods has been directed at the effects of herbicides upon the animals. This situation can be understood since the use of chemicals in agricultural practices could effect non target animals (Edwards, 1969; Edwards & Thompson, 1973).

Studies on the effects of herbicides upon soil arthropods, especially Collembola, showed different results. In the field, effects are highly variable and depend on a large number of factors, such as soil properties, persistence of herbicide residues in soil, and method of herbicide application. From among several herbicides tested, only those of the triazine group gave consistent results, and appeared to decrease the number of Collembola, at least temporarily (Fox, 1964; Edwards, 1970; Popovici et al., 1977). Contradictory results were found with paraquat. Curry (1970) reported a decrease of Collembola populations, while Edwards (1975) found higher number of Collembola in paraquat treated plots. Extensive review of the subject has been reported by Edwards & Thompson (1973).

Laboratory experiments are helpful in understanding the direct effects of herbicides. Eijsackers (1975; 1978 a, b) has extensively studied the effects of 2,4,5-T on *Onychiurus quadriocellatus* Gisin. Continuous feeding on paraquat and atrazine by *Folsomia candida* (Willem) and *Tullbergia granulata* Mills were studied by Subagja and Snider (in press). They reported effects on reproduction, instar duration and mobility of the Collembola. Indeed, such effects can be documented in the laboratory, but their magnitude in the field are still poorly understood.

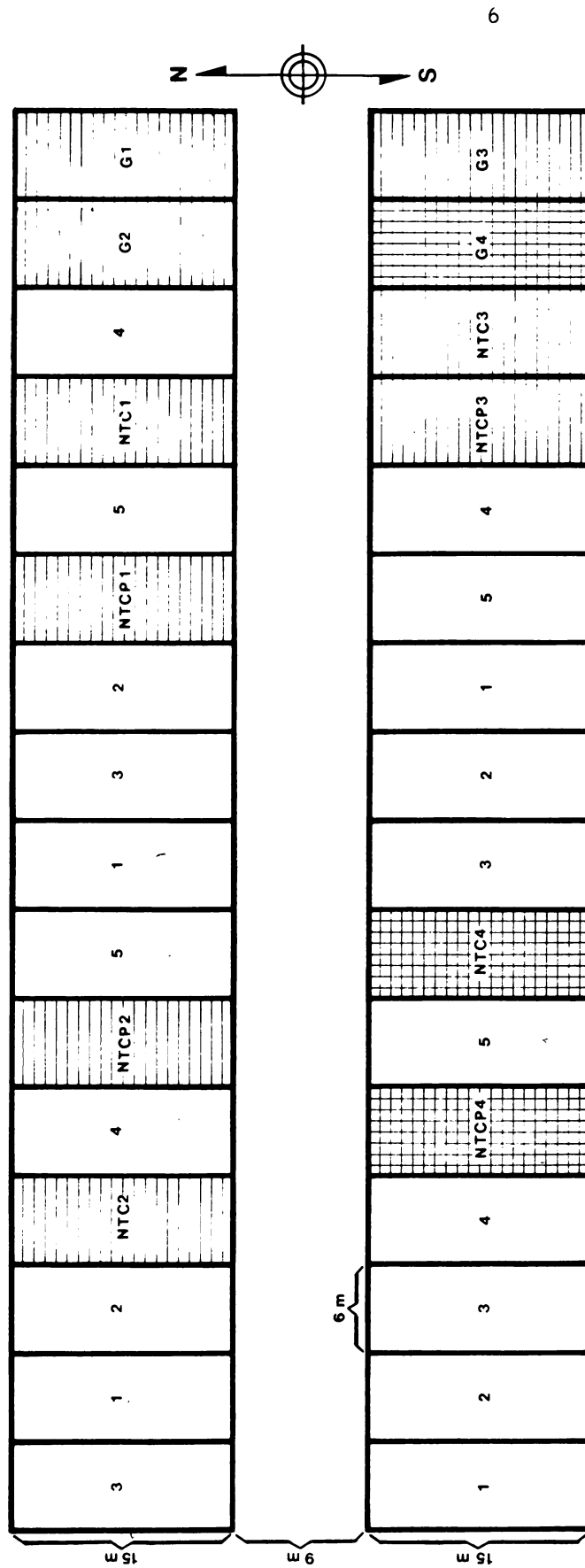
This study is intended to provide information on population fluctuation, vertical distribution, community structure and aggregation or horizontal distribution of Collembola populations in grassland, No-till corn without herbicide, and No-till corn with paraquat. Previous field studies dealt primarily with the comparison of the numbers of animals between herbicide treated plots and untreated plots. In having No-till treatments without herbicide, and with paraquat, the possible effects of No-till may be distinguished from the effects of paraquat.

MATERIALS AND METHODS

Condition of the Field.

The study area was formerly a grassland community for at least seven years, and no herbicides had been applied. The area was located off Jolly and College roads on the north end of section "C" of the Department of Crop and Soil Science Research Farm at Michigan State University, East Lansing. The field was prepared for conventional tillage and No-till corn studies, by dividing it into plots of 6 by 15 meters. There were four replicates, and each of the plots in each replicate was treated differently (Figure 1). The soil of the area is classed as a Celina loam, and a member of the 2.5a soil management group.

The field was mowed for the last time in late September 1978. The plots were initiated in May 1979. Corn was planted on May 15. In No-till plots, a narrow slit was made in the soil by using a fluted coulter. Seeds were then placed into the slit. On May 18, herbicides were applied to plots indicated in Figure 1. For No-till corn with paraquat plots the concentration was one pint per acre (116.9 cc/m^2). Irrigation by sprinklers for the whole field was as follows: June 26, 8.2 cc; June 28, July 10 and 18, 16.4 cc; July 27, 24.6 cc. The herbicide paraquat destroyed the grasses temporarily. This treatment allowed the corn to grow better than in No-till without herbicide. Two weeks later grasses began to grow rapidly, and by late July the grasses were as tall as those on the grassland and



- 1: Mold-board corn, no herbicide
 2: Mold-board corn, cultivate, no herbicide
 3: Mold-board corn, cultivate, Atrazine
 4: No-till corn with Atrazine
 5: No-till corn with Atrazine and Paraquat
- NTCPi: No-till with corn Paraquat Plot i
 (i = 1, 2, 3, 4).
- NTCi: No-till corn No Herbicide Plot i
 (i = 1, 2, 3, 4).
- Gi: Grassland Plot i
 (i = 1, 2, 3, 4).
- Plot 4 for Aggregation Study.

FIGURE 1.--Map of Field Study.

No-till without herbicide plots. The stand of grasses was chiefly composed of bromes (*Bromus inermis*) and switch grasses (*Panicum virgatum*). A few red clovers (*Trifolium pratense*) and dandelions (*Taraxacum officinale*) were found among the grasses. Corn in No-till plots grew poorly because of competition with grasses.

Sampling.

This study was conducted on grassland, No-till corn without herbicide, and No-till corn with paraquat plots. The other plots were being studied by other investigators. Because of the limited number of Tillgren funnels available for animal extraction, the samples were taken from three replicates. This provided a total of 9 plots which consisted of three plots of grassland, three of No-till corn without herbicide, and three of No-till corn with paraquat.

Each plot was sampled by using a metal core device with diameter of 5 cm, to a depth of 10 cm. The device had a tapered interior to relieve compression of the soil core. Five random soil cores were taken from each plot. Each soil core was divided into two subsamples, this provided subsamples of 0-5 cm and 5-10 cm layers of soil profile. One replicate remained which consisted of one plot of grassland, one of No-till corn without herbicide, and one of No-till corn with paraquat. This was sampled for aggregation studies. Figure 1 shows a map of the field study, and plots which were sampled.

Subsamples were put into plastic bags and sealed, then placed in an ice chest to prevent temperature mortality before extraction. Sampling began on May 6, 1979, and was conducted twice a month thereafter, except for September, November and December, when only one



sampling was taken. On every sample date, soil samples were taken according to the method outlined by Shickluna (1975) for pH measurement. Soil moisture content was also measured. Soil temperatures at depths of 5 cm were measured by using a Yellow Spring Institute Telethermometer. A Beckmann pH meter was used to measure soil pH. Soil samples were brought to the laboratory, weighed, and dried in an oven at 100°C for 48 hours. The oven-dried soils were then reweighed to determine the percent moisture content.

Extraction Method.

Tullgren funnels were used to extract the animals. To provide heat, each funnel had a 25-watt light bulb connected to a rheostat. A vial with a solution of 1% glycerin in 95% alcohol was placed beneath the funnel. Soil cores were kept in the funnels for 72 hours. The heat from the light bulb forced the animals to move downward and fall into the vial.

The efficiency of Tullgren funnel extraction was determined by a simple brine method of flotation (Edwards & Fletcher, 1971). After being extracted by the funnels, 10 subsamples of each sample taken on August 22, September 19, November 11 were subjected to the flotation method. A total of 30 subsamples were used for the determination of extraction efficiency. The number of animals found by flotation represent the animals which were not collected by funnel extraction.

Animals collected were identified in the laboratory. Collembola were separated and identified to species. Other animals were kept in the laboratory for further study in the future.



RESULTS

Climatological Data.

Data on maximum and minimum air temperature and rainfall were obtained from the National Weather Service, South Farm Station. The station is closest to the field study. Air temperature refers to the average of weekly temperatures expressed in degrees C (Figure 2). The figures show the difference between maximum and minimum temperatures during the study were relatively constant. Beginning in September 1979, temperatures decreased rapidly.

Rainfall data is presented as weekly total and expressed in centimeters. September 1979 was recorded as the driest month during the study period. This was confirmed by the soil moisture content measured on September 19 and October 1 (Table 3).

Soil pH.

Soil pH measured on each sample date are presented in Table 1. Two way analysis of variance revealed that the difference between sample dates was significant ($p \leq .05$). The difference between plots within each sample date was not significant.

Soil Temperature.

Soil temperature was measured at a depth of 5 cm, and was taken at 10 a.m. on each sample date. Soil temperatures are presented in Table 2. The highest soil temperature measured during the study

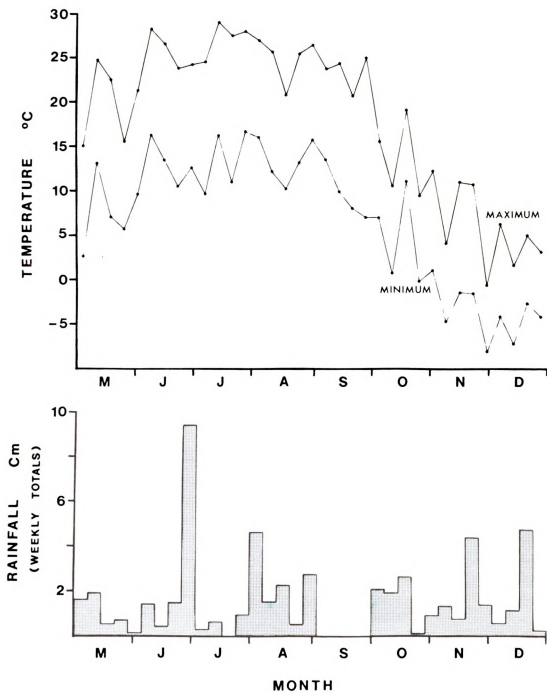


FIGURE 2.--Average of Weekly Air Temperature (above) and Weekly Total Rainfall (below) During the Study Period.

TABLE 1.--Soil pH on Each Sample Date.

Sample Date	G	NTC	NTCP
May 6	6.56 $\pm$.32	6.60 $\pm$.10	6.40 $\pm$.17
May 20	6.80 $\pm$.10	7.72 $\pm$.03	6.75 $\pm$.05
Jun 3	6.90 $\pm$.05	6.85 $\pm$.07	6.78 $\pm$.10
Jun 17	6.88 $\pm$.08	6.85 $\pm$.09	6.75 $\pm$.10
Jul 4	6.65 $\pm$.03	6.70 $\pm$.04	6.55 $\pm$.10
Jul 22	6.50 $\pm$.15	6.47 $\pm$.24	6.45 $\pm$.22
Aug 7	6.87 $\pm$.18	6.88 $\pm$.19	6.73 $\pm$.21
Aug 22	6.67 $\pm$.06	6.67 $\pm$.12	6.45 $\pm$.18
Sep 19	6.60 $\pm$.16	6.58 $\pm$.25	6.45 $\pm$.30
Oct 1	6.73 $\pm$.08	6.60 $\pm$.18	6.50 $\pm$.24
Oct 20	6.95 $\pm$.05	6.92 $\pm$.03	6.95 $\pm$.08
Nov 11	6.85 $\pm$.01	6.85 $\pm$.05	6.88 $\pm$.03
Dec 15	6.45 $\pm$.10	6.52 $\pm$.08	6.55 $\pm$.05

NOTES: G: Grassland
 NTC: No-till Corn No Herbicide
 NTCP: No-till Corn with Paraquat
 $\pm$: standard deviation

TABLE 2.--Soil Temperature ($^{\circ}\text{C}$) on Each Sample Date.

Sample Date	G	NTC	NTCP
May 6	11.17 $\pm$.18	11.17 $\pm$.18	11.17 $\pm$.17
May 20	15.17 $\pm$.15	15.00 $\pm$.18	15.33 $\pm$.20
Jun 3	18.17 $\pm$.10	18.33 $\pm$.05	18.50 $\pm$.10
Jun 17	22.17 $\pm$.10	22.17 $\pm$.10	22.50 $\pm$.15
Jul 4	18.00 $\pm$.05	18.15 $\pm$.07	18.30 $\pm$.05
Jul 22	18.17 $\pm$.12	18.50 $\pm$.15	18.50 $\pm$.10
Aug 7	20.17 $\pm$.10	20.00 $\pm$.10	20.20 $\pm$.12
Aug 22	17.00 $\pm$.08	16.85 $\pm$.05	16.75 $\pm$.08
Sep 19	13.50 $\pm$.05	13.50 $\pm$.10	13.67 $\pm$.05
Oct 1	13.50 $\pm$.07	13.33 $\pm$.05	13.67 $\pm$.08
Oct 20	16.33 $\pm$.01	16.17 $\pm$.05	16.33 $\pm$.04
Nov 11	4.40 $\pm$.01	4.23 $\pm$.01	4.16 $\pm$.03
Dec 15	.93 $\pm$.01	.93 $\pm$.01	.87 $\pm$.01

NOTES: G: Grassland
 NTC: No-till Corn No Herbicide
 NTCP: No-till Corn With Paraquat
 $\pm$: Standard deviation

TABLE 3.--Soil Moisture Content (%) on Each Sample Date.

Sample Date	G	NTC	NTCP
May 6	19.65 $\pm$.20	19.68 $\pm$.16	19.75 $\pm$.15
May 20	13.97 $\pm$.15	13.99 $\pm$.14	14.06 $\pm$.17
Jun 3	13.67 $\pm$.22	13.66 $\pm$.25	13.27 $\pm$.15
Jun 17	10.37 $\pm$.19	10.52 $\pm$.23	10.18 $\pm$.25
Jul 4	20.54 $\pm$.20	20.60 $\pm$.20	20.80 $\pm$.25
Jul 22	15.49 $\pm$.15	15.81 $\pm$.12	15.36 $\pm$.15
Aug 7	19.38 $\pm$.10	19.37 $\pm$.12	19.40 $\pm$.10
Aug 22	19.98 $\pm$.20	20.02 $\pm$.18	20.01 $\pm$.22
Sep 19	8.88 $\pm$.10	8.71 $\pm$.10	8.58 $\pm$.09
Oct 1	8.15 $\pm$.10	8.13 $\pm$.08	8.14 $\pm$.08
Oct 20	19.83 $\pm$.15	19.48 $\pm$.15	19.72 $\pm$.18
Nov 11	19.92 $\pm$.18	19.93 $\pm$.19	20.00 $\pm$.18
Dec 15	19.37 $\pm$.20	19.28 $\pm$.22	19.57 $\pm$.25

NOTES: G: Grassland
 NTC: No-till Corn No Herbicide
 NTCP: No-till Corn With Paraquat
±: Standard deviation



was taken on June 17 - above 22°C. In the fall, soil temperature decreased; began in September with 13.5°C and ended on December 15 with the temperature below 1°C. These figures were paralleled with the recorded air temperature as shown in Figure 2.

Soil temperatures were significantly different between sample dates (two way analysis of variance, $p \leq .05$). However, soil temperatures between plots on each sample date did not differ significantly.

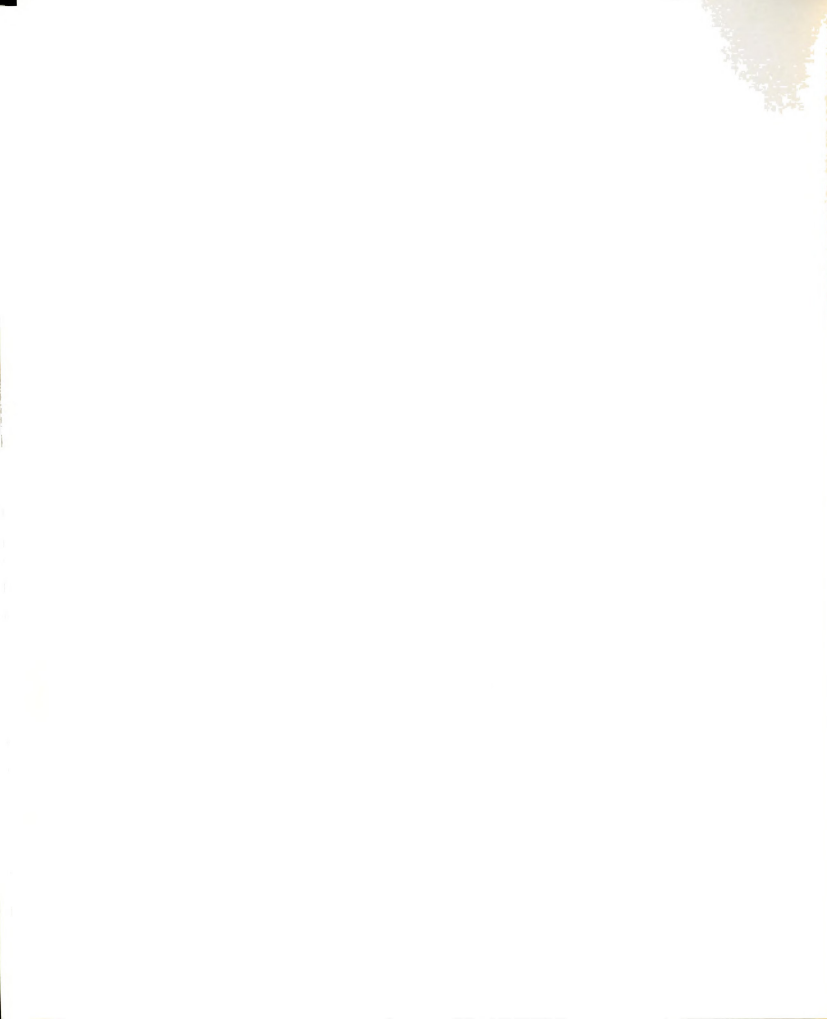
Soil Moisture Content.

Soil moisture content expressed in percent of dry weight is shown in Table 3. The data show a trend parallel with the rainfall data in Figure 2. As mentioned before, on September 19 and October 1, the soil was the driest because there had been no rainfall for a month (Figure 2). In addition, the rainfall in late August was insufficient, and irrigation had been stopped since the end of July.

Two way analysis of variance revealed that the difference between sample dates was significant ($p \leq .05$), as expected. And again, there was no significant difference in soil moisture between plots on each sample date.

Extraction Efficiency.

To produce an accurate measure for the efficiency of funnel extraction is not an easy task to accomplish. This is because of the great variety of reactions that can be expected among a group of animals. The dynamic nature of the process, and the difficulty of obtaining a reliable estimate of the actual number of animals present will influence the results. Furthermore, factors such as behavior,



size, and age will greatly affect the efficiency. Slow moving species, as well as the juveniles and small size species, will be poorly extracted. Organic matter, mineral content, and pore space of a soil are also considered to be factors that influence the efficiency (Haarlov, 1962; Murphy, 1962).

Estimates of extraction efficiency in this study are presented in Table 4. Distinction between the adult and immature forms of the Collembola were not made in this study. A total of 20 species of Collembola were identified during the study, and listed in Table 5. Only common species were given the estimate of extraction efficiency--others were not sufficient in numbers.

TABLE 4.--Extraction Efficiency of Tullgren Funnels
Determined by Simple Flotation Method.

Species	Efficiency (%)
<i>Hypogastrura manubrialis</i>	87
<i>Brachystomella parvula</i>	90
<i>Onychiurus armatus</i>	88
<i>Tullbergia granulata</i>	78
<i>Isotoma notabilis</i>	87
<i>Lepidocyrtus pallidus</i>	89
<i>Pseudosinella violenta</i>	92
All Collembola	88

TABLE 5.--List of Collembola Species Identified
During the Study.

Hypogastruridae:

Hypogastrura manubrialis Tullberg
Brachystomella parvula (Schaffer)

Onychiuridae:

Onychiurus armatus (Tullberg)
Tullbergia granulata Mills

Isotomidae:

Folsomia candida (Willem)
Isotoma notabilis Schaffer
Isotoma viridis Bourlet

Entomobryiidae:

Entomobrya multifasciata (Tullberg)
Lepidocyrtus pallidus (Reuter)
Lepidocyrtus violaceus Uzel
Pseudosinella violenta (Folsom)
Pseudosinella sexoculata Schott
Orchesella villosa (Geoffroy)

Sminthuridae:

Neelus minutus Folsom
Arrhopalites caecus (Tullberg)
Sphaeridia pumilis (Krausbauer)
Sminthurinus elegans (Fitch)
Sminthurinus henshawi Folsom
Deuterosminthurus russata (Maynard)

None of the Collembola collected during the study were extracted with 100% efficiency. *Tullbergia granulata* was the lowest with 78% efficiency, while the highest was *Pseudosinella violenta* with a 92% efficiency. Other species had practically the same efficiencies, ranging between 87 to 90%. The average efficiency of extraction for all Collembola collected was 88%. These results suggest that the extraction method used in this study was sufficient.

Fluctuations of Collembolan Populations.

Examination of the data showed that most soil cores contained low numbers of Collembola, although a few contained very large numbers. These figures suggest that the data were highly skewed, and for statistical analysis the data was transformed to $\text{Log}(X + 1)$, as suggested by Green (1979). The transformation was found to be adequate since it gave homogeneous variances. Analysis of variance for a three-stage nested model was applied to the transformed data for each sample date, then followed by Tukey's Honestly Significant Difference (Gill, 1978).

The transformed data were also used in the graphs (Figure 3). The ordinates of the graphs were scaled as $\text{Log}(X + 1)$.

Species Account.

Total Collembola: Population fluctuation of all Collembola is shown in Figure 3. In grassland, Collembola increased in numbers and reached a peak in late summer, then decreased during fall, tended to increase again by the end of fall. In No-till corn without herbicide plots, the pattern was practically the same as in grassland, but reached a peak early in the middle of summer. The numbers of Collembola



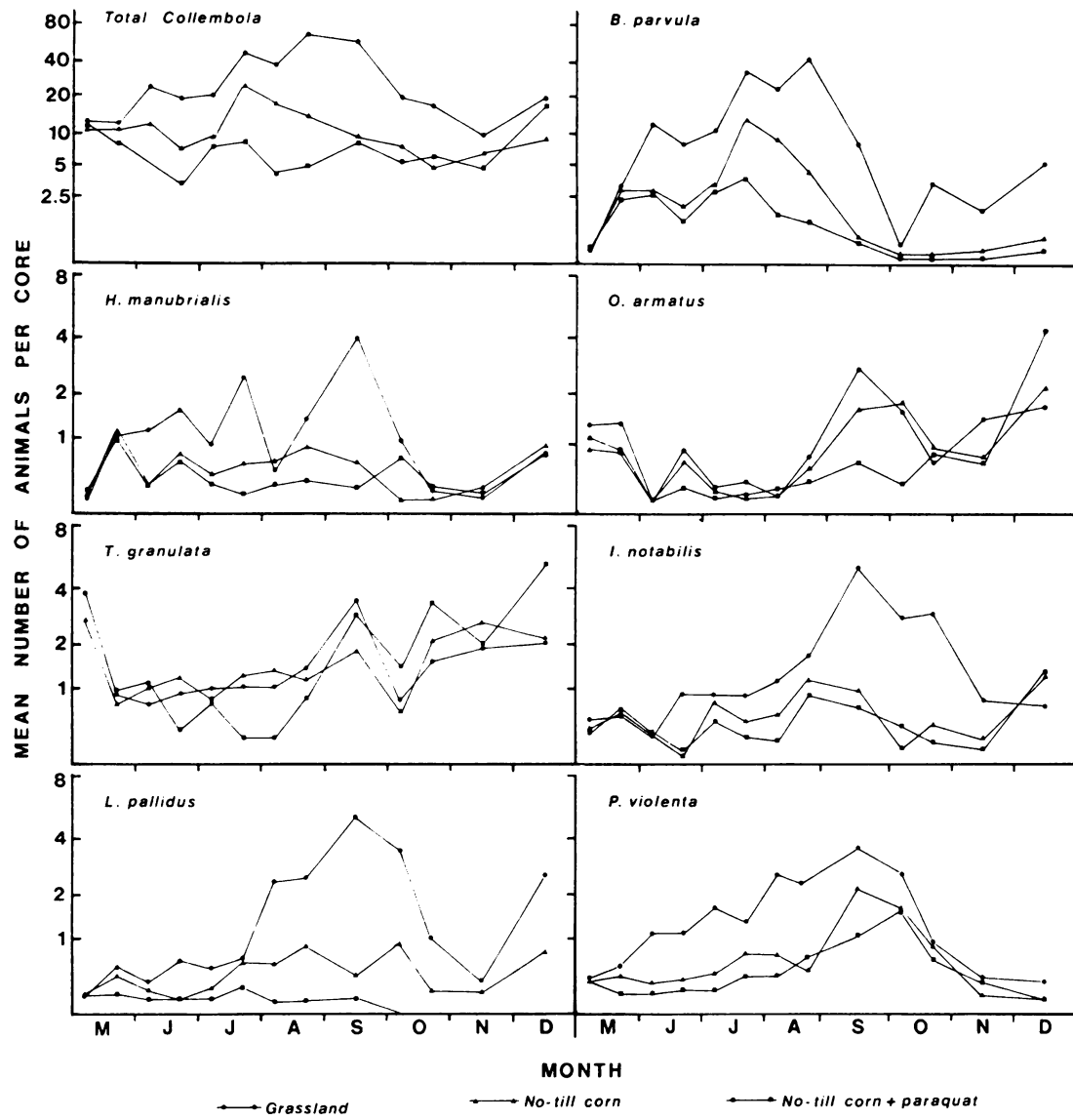


FIGURE 3.--Seasonal Fluctuation of Collembola Populations

in No-till corn with paraquat, however, showed a very different pattern. They did not have a definite peak in the summer, while they increased by the end of the study.

The numbers of Collembola in No-till corn plots were continuously lower than in grassland plots during the study. Statistical analysis showed that the significant difference between No-till corn and grassland occurred from June 17 to October 20, while significant difference between No-till corn with and without paraquat were found from June 17 to September 19 (Appendix I). Apparently the effect of paraquat began to diminish, and the numbers of Collembola increased. On the last sampling (December 15), the numbers of Collembola in all plots were practically the same.

Examination at the species level revealed that seven common species provided considerable material for comparison, because of their adequate numbers. These species are:

Hypogastrura manubrialis: Numbers of *H. manubrialis* in grassland fluctuated in the summer with peaks in June, July, and the highest in September. The numbers decreased in the fall. Numbers in No-till corn plots were lower than in grassland, and they did not have an obvious peak (Figure 3). Differences between the numbers in grassland and No-till corn plots were significant ($p \leq .05$) from June 3 through September 19. However, the numbers in No-till corn with paraquat and without herbicide did not differ significantly during the study period (Appendix I).

Brachystomella parvula: In grassland, the number of this species was very low at the first sampling. They increased tremendously



thereafter, and was the dominant species. In No-till corn plots, their dominance was replaced by other species, began in September. *B. parvula* had a peak in late summer and tended to increase in late fall.

The fluctuation patterns of this species were similar in the three habitats. However during the study period, the numbers in No-till corn plots were continuously lower, and the differences were significant ($p \leq .05$). Although paraquat was applied on May 18, the differences in numbers of this species in No-till corn with paraquat and without herbicide were significant from July 4 through August 22 ($p \leq .05$) (Appendix I). These results suggest that paraquat did not directly affect the numbers of the species, and the effect was only temporary.

Onychiurus armatus: The numbers of *O. armatus* in grassland and No-till corn without herbicide fluctuated in similar ways. This species had high numbers in spring, decreased their numbers in summer, and increased again in fall (Figure 3). During the study period, this species reached a peak in September. In No-till corn with paraquat plots, *O. armatus* never reached a peak in September. The number remained low as in summer, but tended to increase in late fall, with the highest number on the last sample date.

Statistical analysis revealed that differences between grassland and No-till corn without herbicide were not significant. After paraquat application the numbers of *O. armatus* in No-till corn with paraquat plots were continuously lower than in No-till without herbicide, however, these differences were not significant (Appendix I).

Tullbergia granulata: In grassland plots, this species was the dominant species at first sampling; and continued thereafter, to be second. In No-till Corn plots, *T. granulata* began to take over the dominancy in September and continue to the end of the study. As in *O. armatus*, the number of *T. granulata* was high in spring, low in summer, and showed an increase in fall. The fluctuation patterns of the species in the three habitats were similar (Figure 3).

Apparently No-till corn cultivation did not affect this euedaphic species. The number of *T. granulata* in grassland and No-till corn without herbicide were practically equal on every sample date. Statistical analysis confirmed that the differences were not significant (Appendix I). In No-till with paraquat through August 22 were lower than in the other two habitats. Significant differences ($p \leq .05$) were observed from June 17 through August 7 (Appendix I). In the fall, the number of this species in No-till corn with paraquat increased and exceeded the number in grassland and No-till without herbicide.

Isotoma notabilis: In grassland, this species increased in number during the summer and reached a peak in September; the number decreased toward the end of the study. Numbers in No-till corn without herbicide and with paraquat were lower, but tended to increase by the end of the study (Figure 3).

From June 17 through November 11, the number of this species in No-till corn without herbicide and with paraquat were significantly lower than those of grassland ($p \leq .05$). However, there was no significant difference between No-till corn without herbicide and



No-till corn with paraquat, although on each sample date the number of these animals in No-till corn with paraquat plots were lower. On the last sample date (December 15), the number of *I. notabilis* in No-till corn without herbicide and with paraquat were higher than in grassland, but this did not differ significantly (Appendix I).

Lepidocyrtus pallidus: No-till corn cultivation appeared to suppress the population of *L. pallidus*. In grassland, this species reached a peak in September, but there was no definite peak in the treated plots. Furthermore, this species was not found in paraquat treated plots in the fall (Figure 3).

The number of *L. pallidus* in No-till corn without herbicide and with paraquat was lower than in grassland, and these differences were significant ($p \leq .05$). When the differences of the number of the species in No-till corn without herbicide and with paraquat were analyzed, only on June 3 and August 7 were significant ($p \leq .05$); the rest of them did not differ significantly (Appendix I). However, this species diminished in paraquat treated plots.

Pseudosinella violenta: As in *I. notabilis*, the number of *P. violenta* was low in spring, and gradually increased in the summer to reach a peak in September, then decreased toward the end of the study. The patterns of population fluctuation of this species in the three habitats were similar although the number in No-till corn plots were lower (Figure 3).

Numbers in No-till corn plots were significantly lower than in grassland ($p \leq .05$) in summer, but not in fall. There was no significant difference between No-till corn without herbicide and with paraquat during the study period (Appendix I). This suggests

that application of paraquat did not affect the population of *P. violenta*.

Age Structure.

Metamorphosis does not occur in Collembola. The individual grows by a series of moults which continue throughout life, and it is difficult, if not impossible, to distinguish each stadium morphologically. Therefore, for the study of age structure, the individuals were measured, then grouped into body length classes. Although the increase in size is not necessarily even nor the time between moults or instar duration is equal, we may, nevertheless, obtain figures proportional to ages. This method was successfully applied to population studies of Collembola by Takeda (1973) and Petersen (1980).

For taking measurements, the specimen were put on a glass slide with 1% glycerin in alcohol and covered with a cover slip; then they were measured by using an ocular micrometer. Body length of each individual was measured from the front end of the head to the end of abdomen. After completing the measurements, the specimen were put back into vials with 1% glycerin in alcohol for storage.

Hypogastrura manubrialis: Body length classes for this species are defined as indicated in Table 6. Figure 5 (Appendix II) shows that size structures of *H. manubrialis* in the three habitats did not differ. On July 22, the newly hatched individuals were not found in paraquat treated plots, however, they were found in the other habitats.

Brachystomella parvula: Classification of body length for this species is indicated in Table 6. Size structures of *B. parvula* on each sample date are shown in Figure 6 (Appendix II). In grassland

TABLE 6.--Body Length Classes for *Hypogastrura manubrialis*,
Brachystomella parvula, and *Tullbergia granulata*.

Class	Body Length (mm)
1	less than .25
2	.25 - .35
3	.35 - .45
4	.45 - .55
5	.55 - .65
6	.65 - .75
7	over .75

and No-till corn without herbicide, size structures were similar, except that large size individuals (Class 7) were not found immediately after No-till corn planting. Newly hatched individuals were collected on every sample date, except in October. In No-till corn with paraquat plots, however, newly hatched individuals were found only on July 22, August 7, and September 19.

Onychiurus armatus: Body length of this species is grouped as follows in Table 7. Figure 7 (Appendix II) shows the size structures of *O. armatus* in the three habitats on every sample date. During the study period, size structures in the three habitats were similar. No apparent effect of No-till corn planting and paraquat application was observed. Newly hatched individuals were collected on almost every sample date.

TABLE 7.--Body Length Classes for *Onychiurus armatus*.

Class	Body Length (mm)
1	less than .40
2	.40 - .50
3	.50 - .60
4	.60 - .70
5	.70 - .80
6	.80 - .90
7	.90 - 1.00
8	1.00 - 1.10
9	over 1.10

Tullbergia granulata: Classification of body length for *T. granulata* is indicated in Table 6. Size structures on every sample date in the three habitats are presented in Figure 8 (Appendix II).

In grassland and No-till corn without herbicide plots, newly hatched individuals were collected in June and August, but were not found in the fall. Size structures of this species in the two habitats were similar. In paraquat treated habitat, however, newly hatched individuals were found only in the fall.

Isotoma notabilia: Body length of this species are grouped as follows (Table 8):



TABLE 8.--Body Length Classes for *Isotoma notabilis*.

Class	Body Length (mm)
1	less than .35
2	.35 - .45
3	.45 - .55
4	.55 - .65
5	.65 - .75
6	.75 - .85
7	over .85

Size structures in the three habitats on each sample date for this species are shown in Figure 9 (Appendix II). In No-till corn without herbicide and with paraquat plots, individuals of over .85 mm in body length (Class 7) were found only on the last sample date, however, they were found more frequently in grassland. In the three habitats, newly hatched individuals were found on the same sample date.

Lepidocyrtus pallidus: Classification of body length for this species is found in Table 9. Size structures of this species in the three habitats are presented in Figure 10 (Appendix II). After No-till corn planting, large size individuals (Classes 7 and 8) were not found in No-till corn with paraquat plots. In No-till corn without herbicide plots, no individuals in Class 8 were found after the planting, while individuals in Class 7 were found only on October 1 and December 15. In grassland and No-till corn without herbicide, newly hatched

individuals were found on every sample date. However in No-till corn with paraquat plots, they were found only on July 22.

TABLE 9.--Body Length Classes for *Lepidocyrtus pallidus*

Class	Body Length (mm)
1	less than .45
2	.45 - .55
3	.55 - .65
4	.65 - .75
5	.75 - .85
6	.85 - .95
7	.95 - 1.05
8	over 1.05

Pseudosinella violenta: Body length of this species is classified in Table 10. Size structures of this species in the three habitats are presented in Figure 11 (Appendix II). In No-till corn plots, large size individuals (Classes 8 and 9) were not found immediately after No-till corn planting until August. In grassland plots, these individuals were found during that time. In both grassland and No-till corn without herbicide, newly hatched individuals were found on the same sample dates during the period of June through October. In paraquat treated plots, however, they were found only on July 22, September 19 and October 1.

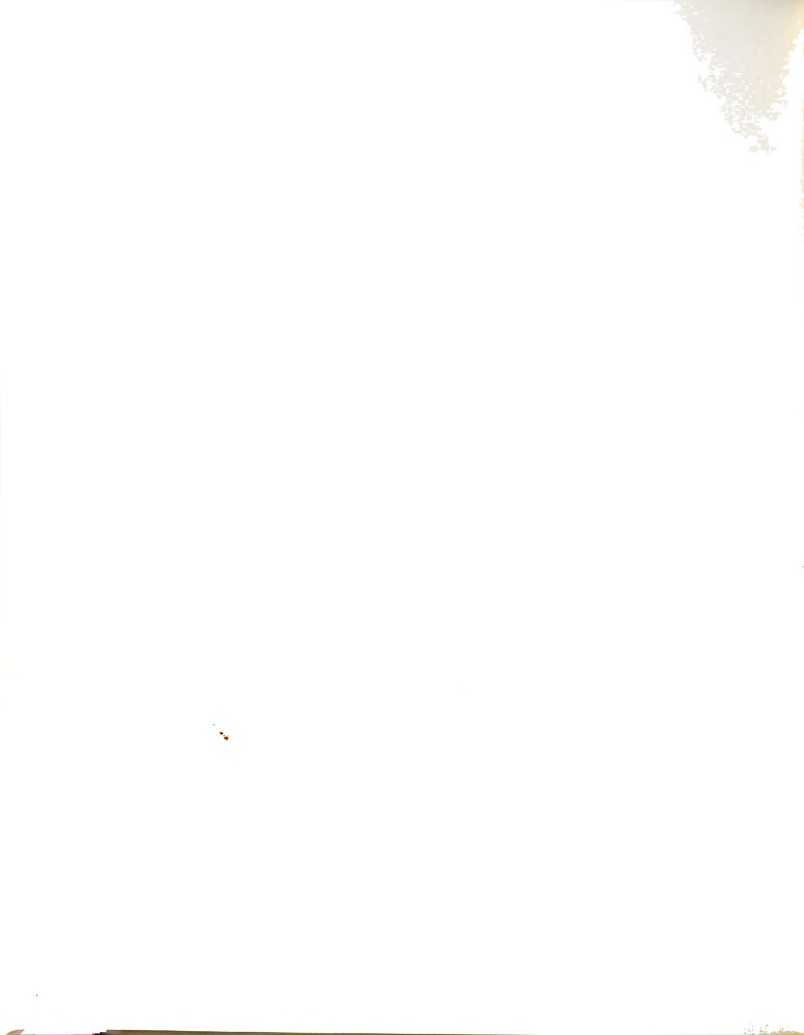


TABLE 10.--Body Length Classes for *Pseudosinella violenta*.

Class	Body Length (mm)
1	less than .45
2	.45 - .55
3	.55 - .65
4	.65 - .75
5	.75 - .85
6	.85 - .95
7	.95 - 1.05
8	1.05 - 1.15
9	over 1.15

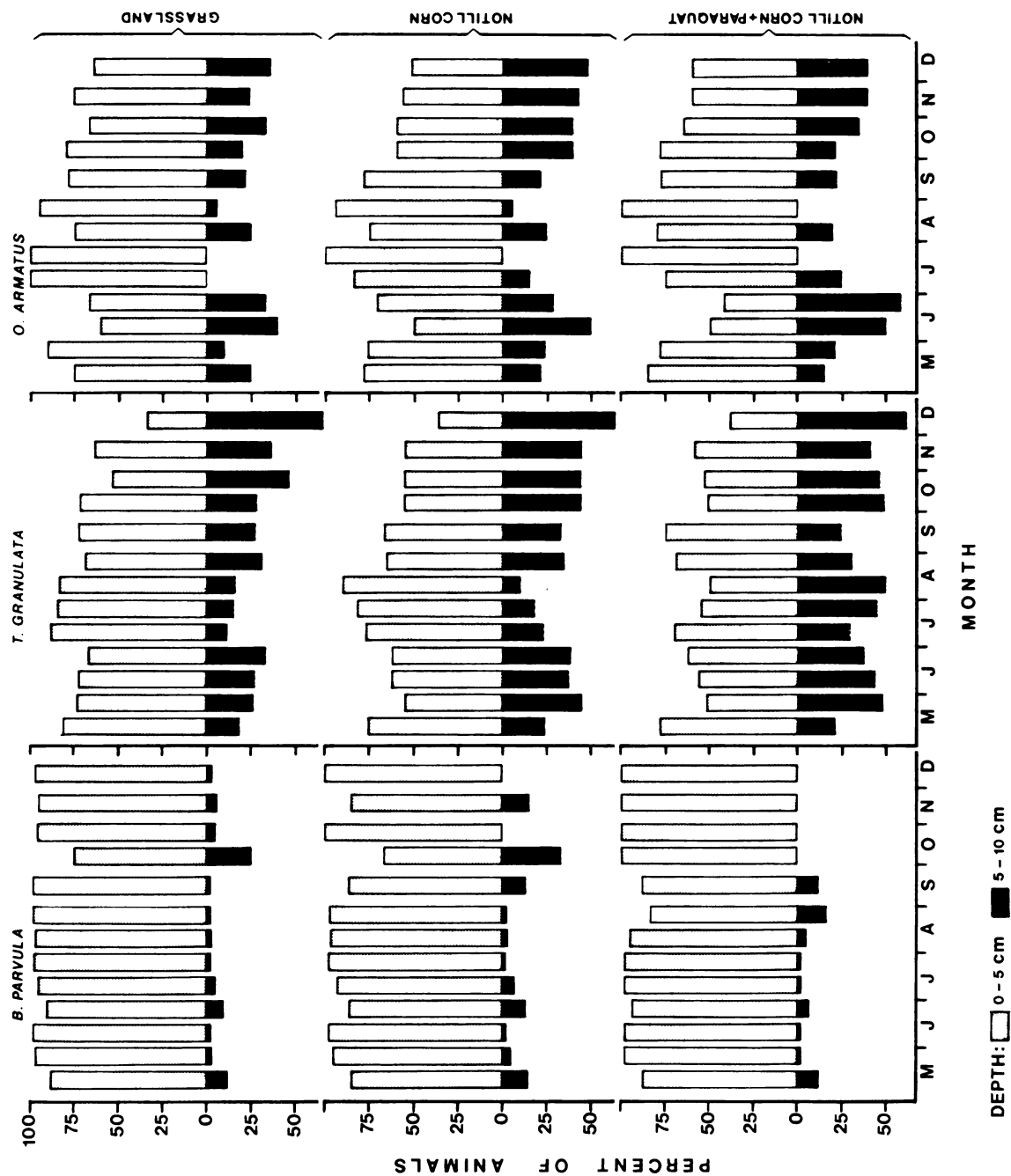
Vertical Distribution.

Of the seven common species already mentioned, only three species were found in soil down to a depth of 10 cm. The species were: *B. parvula*, *T. granulata*, and *O. armatus*. Most species were found down to a depth of 5 cm. *H. manubrialis* and *I. notabilis* were also found in subsamples of 5-10 cm layer, but the numbers were very low. Therefore the two species were not included in the following discussion. The percentage occurring in 0-5 cm and 5-10 cm layers of soil profile of the sampled populations were presented in Figure 4.

Brachystomella parvula: Vertical distributions of this species in the three habitats were similar. Apparently No-till corn cultivation and application of paraquat did not change their vertical distribution.



FIGURE 4.--Vertical Distribution of Collembola During the Study Period.



Tullbergia granulata: Immediately after No-till corn planting and paraquat application, more individuals were found at the 5-10 cm depth. This may have been caused by mortality in 0-5 cm layer rather than an actual downward migration. At the end of the study, vertical distributions of *T. granulata* in the three habitats were similar.

Onychiurus armatus: As in *T. granulata*, *O. armatus* showed the same pattern of vertical distribution. However shortly after paraquat application, more individuals were found in deeper layer than in grassland and No-till corn without herbicide.



DISCUSSION

Soil.

Although it is almost impossible to find a completely homogeneous soil in nature, examination of soil pH, temperature and moisture content of the three habitats showed that they were similar throughout the study period. There was no significant difference observed on each sample date.

Soil pH, temperature, and moisture are considered to be most important environmental factors influencing Collembolan populations in soil (Christiansen, 1964; Butcher et al., 1971). Examination of field data in this study has allowed for an assumption of homogeneous soil conditions.

Extraction.

Low extraction efficiency of *T. granulata* was not unexpected, since the species was small and slow moving. The animals were poorly extracted by the dynamic method of Tullgren funnels used in this study. Haarlov (1962) found that small and sluggish species were subject to the greatest loss in extraction. Later Tamura (1972) reported that only 16% of all Collembola were extracted by use of funnels compared to hand sorting. Earlier, Kempson et al. (1963) obtained 90% efficiency for Collembola extracted from litter samples by funnels. The latter agrees with the present study with 88% efficiency. This may have been caused by careful handling and minimum destruction of



the soil cores when the samples were brought from the field to the laboratory for extraction. The differences in extraction efficiencies can be attributed to time of extraction process, soil texture, and the volume of soil sample (Murphy, 1962; Edwards & Fletcher, 1971). In general, the efficiency of the extraction method used in this study was comparable to other studies. Furthermore, Tullgren funnel extraction is one of standard methods for collecting soil arthropods (Edwards & Fletcher, 1971).

Effects of No-till.

Analysis of the data on population abundance revealed that No-till cultivation decreased Collembolan populations, at least temporarily. Of the seven common species studied, only *T. granulata* and *O. armatus* did not show any significant difference compared to grassland on a given sample date. Other species showed a decrease in numbers immediately after No-till corn planting. In their study on soil microarthropods in No-till and conventionally tilled fields, Edwards (1975) and Loring et al. (in press), reported lower numbers of Collembola populations in No-till plots. Edwards (1975) suggested that soil compaction as the results of planting equipment could disrupt the Collembola populations. In previous studies, however, herbicides were applied, thus No-till cultivation and herbicides might be attributed to the reduction in numbers.

The two species which were not affected, *O. armatus* and *T. granulata*, are euedaphic species (Christiansen, 1964). They live in deeper layers of soil, and it was shown in the present study, that many individuals of these species were found to a depth of 10 cm



(Figure 4). Other species, *H. manubrialis*, *B. parvula*, *I. notabilis*, *L. pallidus* and *P. violenta* are considered to be hemiedaphic species (Christiansen, 1964), and live in the upper layer of soil. These hemiedaphic species were found to be effected by No-till cultivation. Probably soil compaction occurred only in the uppermost layer of soil, and caused reduction of Collembola populations which mainly occupied the upper layer. Compaction of soil also causes reduction of pore space available for inhabitation of soil arthropods. Haarlov (1960) found a direct relationship between the volume of soil pore space and the soil arthropods collected. Data on body length structures show that large size individuals of those hemiedaphic species were not found for a periods of time after No-till planting, while in grassland they were found. Large size individuals of the euedaphic species were still found after No-till corn cultivation.

Significantly lower numbers occurred temporarily, and this was while populations of the same species in grassland were increasing. Apparently, time of No-till cultivation was an important factor. At the time of No-till cultivation, most individuals were at the large size class and assumed to be reproductive individuals. Reduction of reproductive individuals was detrimental to the populations and consequently reduced population growth.

Effects of Paraquat.

Examination of the figures on total collembolan populations indicated that the number was decreased temporarily by application of paraquat. The effect could be detected about one month after application, and lasted for about two months. However, when the seven selected



species were analyzed, only three species had significantly decreased in numbers. Those species were *B. parvula*, *L. pallidus* and *T. granulata*. Edwards and Stafford (1979) reported that the number of soil inhabiting Collembola (Onychiuridae and Poduridae) was lower in No-till with paraquat than in conventional tillage cultivation, although the numbers of surface forms such as Isotomidae, Entomobryiidae and Sminthuridae were higher. Their result were average for over five years. No doubt tillage in conventional cultivation deleteriously reduced euedaphic Collembola populations (Ghilarov, 1975). Earlier, Curry (1970) reported the decrease of collembolan populations after paraquat application; and *Tullbergia krausbaueri* (Borner) was significantly lower after one month of application. All species were numerically lower compared to grassland. Curry's study agrees with the present study.

Recent studies by Loring et al. (in press) also found lower numbers of *T. granulata* in No-till corn due to herbicides application, and suggested that the effect on collembolan populations might be due to the feeding habit of the animals. Paraquat molecules may remain unchanged in soil for long periods of time. They are bonded tightly to clay and organic matter, and become biologically inactive (Williams, 1970; Klingman & Ashton, 1975). Collembola normally ingest much organic and mineral matter (Sharma & Kevan, 1963; McMillan, 1975). In the laboratory, paraquat was shown to lessen fecundity, prolong instar duration and delay the hatching time of eggs of *T. granulata* and *F. candida* (Subagja & Snider, in press). However, those results were obtained by continuous feeding of paraquat after hatching. Such



situations can hardly be found in nature. Eijsackers (1975; 1978 b) suggested that Collembola, in nature, might be able to avoid feeding on contaminated food.

From the data on age structure which based on body length classes, there was evidence to support the possibility of disturbance in reproduction as previously reported in laboratory studies (Eijsackers, 1978 a; Subagja & Snider, in press). Newly hatched individuals of *B. parvula* were not found for about two months after the application of paraquat, although they were found in plots without paraquat. During that time, the number of *B. parvula* was significantly lower than in plots without paraquat. The same situation was observed for *T. granulata*. Newly hatched individuals were found later, and then the number increased tremendously to exceed the number in grassland on the last sample date. Severe effects were shown for *L. pallidus*. This species was greatly reduced, and after four months there were no individuals found. Obviously this species is very vulnerable to the disturbance of habitat. They were also greatly reduced by No-till cultivation. It seemed that time of herbicide application could play an important role in affecting the collembolan populations. During the application, the numbers of animals were still low and most of them were mature and are assumed to be reproductive. Disturbance of the population and reproduction can still be detected some time after the application. Furthermore, reproduction is one of the important parameters of population dynamics. Any detriment to this parameter will consequently affect the population.

Data on vertical distribution suggest that euedaphic species such as *T. granulata* and *O. armatus* tend to be more numerous in deeper



soil after treatment application. This may be a result of elimination of some individuals in the uppermost layer of soil profile, while individuals in deeper layers still survived. However, separation by 5 cm for vertical distribution analysis gave little useful information. This could have been better shown if the soil layers were separated by 2.5 cm apart. Therefore, data from the present study give only trends in vertical distribution.



COMMUNITY STRUCTURE

All the living organisms found within any given habitat are collectively known as an ecological community. This study dealt mainly with the collembolan community.

Examination of the species composition of the three habitats showed that they were very similar. No change in species composition occurred during the study, despite the No-till cultivation and paraquat application. Twenty species identified during the study, and represented four families of Collembola (Table 2). They also represented various ecological life forms as outlined by Christiansen (1964).

In order to compare the three collembolan communities, prominence values (PV) of each species in each plot was calculated as follows (Beals, 1960):

$$PV = d \sqrt{f}$$

where,

$$d = \text{density} = \frac{\text{total individuals collected}}{\text{total cores taken}}$$

$$f = \text{frequency} = \frac{\text{total cores in which the individuals were found}}{\text{total cores taken}}$$

Prominence values of all species at every plot sampled are presented in Table 11.

All Collembola collected were subjected to a two-dimensional community ordination as outlined by Beals (1960). This analysis method provides a comparison of each community utilizing geometric



TABLE 11.--Prominence Values of Collembola Species Collected During the Study.

Species	Grassland			No-till Corn No Herbicide			No-till Corn With Paraquat					
	Plot 1	Plot 2	Total	Plot 1	Plot 2	Total	Plot 1	Plot 2	Total			
<i>H. manubrialis</i>	.6480	1.9005	4.1735	.5643	.7139	.2824	1.5606	.5755	.3743	.2270	1.1768	
<i>B. parvula</i>	15.4508	11.6235	15.1227	42.1970	5.4807	4.3854	2.3799	12.2460	.5895	2.8322	4.9337	
<i>O. armatus</i>	1.0340	.8851	2.0428	3.9619	2.0323	1.0144	1.0241	4.0708	.7870	.7395	.5771	2.1036
<i>T. granulata</i>	1.6787	3.1646	2.5772	7.4205	1.2229	2.0492	2.8733	6.1454	1.4939	3.7641	2.2013	7.4593
<i>F. candida</i>	-	-	-	-	-	.0019	-	.0019	-	-	-	.0019
<i>I. notabilis</i>	1.4790	1.5553	3.6287	6.6630	.4020	.8312	.4484	1.6816	.1161	1.3901	.2246	1.7308
<i>I. viridis</i>	.6904	.0327	.1329	.8560	.1317	.0132	.0019	.1468	.0099	.0213	.0213	.0525
<i>E. multifasciata</i>	.0019	.0132	.0555	.0706	-	.0019	-	.0019	-	.0019	.0019	.0038
<i>L. pallidus</i>	3.1898	1.5347	1.7868	6.5113	.4670	.4453	2.105	1.1228	.0432	.0327	.1076	.1835
<i>L. violaceus</i>	.0280	.0353	.0099	.0732	.0213	.0099	.0353	.0665	.0280	-	.0432	.0712
<i>L. paradoxus</i>	.0949	.0486	.0189	.1624	.0467	.0198	.0099	.0764	-	.0019	.0019	.0038
<i>P. violenta</i>	2.8319	1.2119	1.7267	5.7705	.4955	.4720	.3498	1.3173	.6731	.2833	.2886	1.2450
<i>P. sexoculata</i>	.0651	.0019	.0054	.0724	.0191	.0054	.0191	.0436	-	-	.0486	.0486
<i>O. villosa</i>	.0081	.0019	.0054	.0154	-	.0019	.0054	.0073	-	-	-	-
<i>N. minutus</i>	.0191	.0081	.0280	.0552	.0054	.0054	.0191	.0299	.0432	.0432	.0505	.1369
<i>A. caecus</i>	.0054	.0108	.0054	.0216	.0019	.0299	.0099	.0417	.0054	.0019	.0019	.0092
<i>S. pumilis</i>	.1514	.1652	.1514	.4680	.1848	.0784	.0784	.3416	.0809	.0561	.0505	.1875
<i>S. elegans</i>	.8837	1.1238	1.2751	3.2751	.8583	.8112	.6772	2.3467	.6072	.4122	.3076	1.3270
<i>S. henschawi</i>	.0280	.0054	.1101	.1435	.0555	.0191	.0054	.0800	.0019	-	.0054	.0073
<i>D. russata</i>	.0256	.0327	.0648	.1231	.0454	.0515	.0114	.1083	.0640	.0909	.0229	.1778
Totals	28.3138	23.3552	30.3727	82.0417	12.0348	10.9609	8.4414	31.4371	6.1198	10.0456	4.6939	20.8593



principles. The method is based on a coefficient of dissimilarity between two plots by the use of prominence values already calculated. The method has been applied successfully for the study of collembolan communities in agroecosystems by Clemen and Pedigo (1970).

The coefficient dissimilarity (CD) was calculated as follows:

$$CD = 1.00 - \frac{2w}{a+b}$$

where,

a = sum of PV's for all species at one plot

b = sum of PV's for all species at another plot

w = sum of the smallest PV's of species that the plots have in
common

A matrix of coefficient of dissimilarities was constructed and it is presented in Table 12. The result of two-dimensional ordination of the three collembolan communities are shown in Figure 5.

Results and Discussion.

Species with the highest sum of prominence values indicates greater success in term of density and/or spatial distribution of the species within a particular habitat. In this study, *B. parvula* absolutely dominated the collembolan populations in grassland, and still dominated in No-till corn without herbicide. However, *T. granulata* was the dominant species in No-till corn with paraquat, although the dominance was not as absolute as with *B. parvula* in grassland. Other prominent species in this study were: *H. manubrialis*, *O. armatus*, *I. notabilis*, *L. pallidus*, *P. violenta*, and *S. elegans*.



TABLE 12.--Coefficient Dissimilarities of Plots Sampled.

	Grassland			No-till Corn No Herbicide			No-till Corn With Paraquat		
	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3	Plot 1	Plot 2	Plot 3
Grassland:									
Plot 1		.2160	.1561	.4569	.4667	.6063	.6482	.5896	.7501
Plot 2	.2160		.1655	.3913	.3720	.4798	.5893	.4400	.6722
Plot 3	.1561	.1655		.4365	.4710	.5825	.6665	.5635	.7379
No-till Corn No Herbicide:									
Plot 1	.4569	.3913	.4365		.1724	.3432	.3839	.4175	.5676
Plot 2	.4667	.3720	.4710	.1724		.3111	.3152	.2682	.4363
Plot 3	.6063	.4798	.5825	.3452	.3111		.2562	.1839	.3008
No-till Corn with Paraquat:									
Plot 1	.6482	.5893	.6665	.3839	.3152	.2562		.3546	.3113
Plot 2	.5896	.4400	.5635	.4175	.2682	.1839	.3546		.3881
Plot 3	.7501	.6722	.7379	.5676	.4363	.3008	.3113	.3881	
Totals	3.8899	3.3261	3.7795	3.1713	2.8129	3.0658	3.5252	3.2054	4.1643



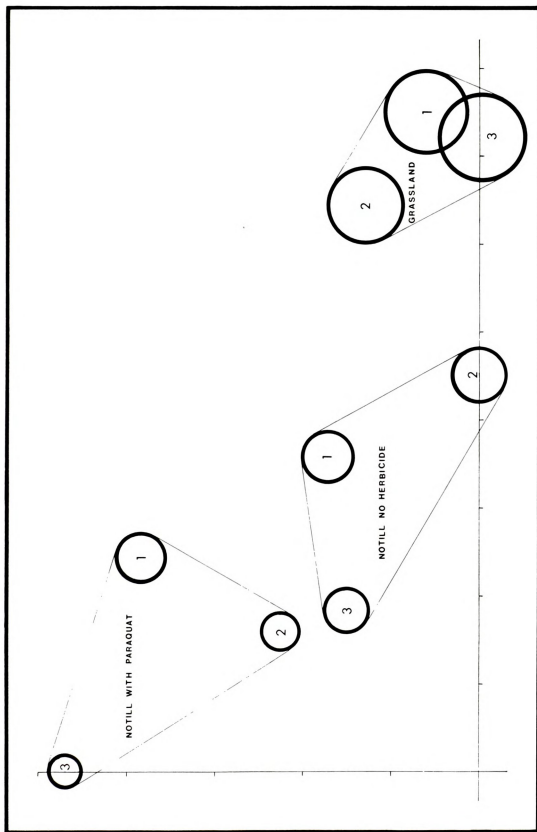


FIGURE 5.—Distribution of Plots Within Ordination



Almost all species decreased their prominence values due to No-till cultivation and application of paraquat. There were three species that appeared as species tolerant to alteration of grassland habitat to No-till corn with and without paraquat. They had practically similar prominence values in the three habitats. They were: *D. russata*, *T. granulata* and *L. cyaneus*. One should note that *N. minutus* appeared to increase its numbers in paraquat treated plots.

A habitat with the highest sum of prominence values indicates more favorable condition for collembolan populations. In this study, grassland was the most favorable among the three habitats studied, with the highest sum of prominence values. The disruption of collembolan communities by No-till cultivation was clearly shown in this study. Compared to grassland, the sum of prominence values of No-till corn without herbicide was only about 1/3 of grassland, while sum of prominence values of No-till corn with paraquat was only 1/4 of grassland.

A two-dimensional community ordination (Figure 5) shows clearly the effects of No-till cultivation and application of paraquat upon the collembolan community. The area of the circle for each plot is directly proportional to the sum of prominence values for the plot. The greater dissimilarity between plots, the further separated they are within ordination.

When plots of the same habitat were connected to each other, as shown in Figure 5, three clusters of three habitats were formed. No-till corn with paraquat was among the least in sum of prominence

values, and the most dissimilar to the other plots. The three habitats were separated and did not overlap. This means that although the species composition of the three habitats were similar, they formed very different communities.

Considering the plots within the same habitat, the ordination shows that grassland plots were quite homogeneous. They were close to each other, and furthermore, plot 1 and 3 were overlapped. On the other hand, plots of No-till corn with and without paraquat were widely separated, indicating that the two habitats were more heterogeneous. Apparently, No-till corn cultivation as well as application of paraquat resulted in various kinds of microhabitats available for collembolan populations. This was dependant on soil conditions and other environmental factors associated with them. This situation did not occur in the grassland habitat since the habitat was not disrupted by agricultural practices.

The two-dimensional ordination of the three collembolan communities (Figure 5) also shows that the collembolan community was altered by the changes of grassland habitat into No-till corn with and without paraquat. This analysis also found that euedaphic species such as *N. minutus*, *O. armatus*, and *T. granulata* were not seriously affected by those agricultural practices, although there was a temporary decrease in number of *Tullbergia granulata* when paraquat was applied. They were able to recover in the fall.

No-till cultivation did not alter species composition, but changes in their abundance were observed. Most of the species of *Collembola* collected in this study were edaphic, migration from nearby habitats was limited, especially for a short time. Curry (1970)



reported that reduction of numbers because of paraquat application did not seriously reduced in the diversity of Collembola.

Considering the fact that depletion of collembolan population was only temporary, and there were no changes in species composition, continuous No-till cultivation with paraquat may not deleteriously affect collembolan communities. Collembola may be able to adapt to the microhabitat available to them. Reduction of some species will be counterbalanced by the increase of others. Furthermore, the possibility of resistance to the herbicide may occur. Aleinikova and Utrobina (1975) suggested that the use of soil for farm crops has resulted in various kinds of soil animal communities, depending on the crops and methods applied, and on the soil properties. However, long term study is needed in order to provide a better understanding of the effects of No-till cultivation as well as the application of paraquat.



AGGREGATION

Horizontal distribution of Collembola in soil is not random, but aggregated (Poole, 1961; Hale, 1966; Joose, 1970). Aggregation of Collembola is possible as the result of a suitable microhabitat or food source, and also of the reproductive process where individuals lay eggs in clusters combined by slow dispersion of the individuals (Hale, 1966). However, in euedaphic species, aggregations are not related to egg cluster (Poole, 1961). Apparently, moisture condition of habitat and species activity influence the horizontal distribution of Collembola (Joose, 1970). Recently, Shaddy and Butcher (1977) reported different degrees of aggregations of soil microarthropods in cultivated and uncultivated fields. Besides, aggregation of animals could be the result of attraction of one to another (Odum, 1971).

Sampling.

Three plots, 6 by 15 m, grassland, No-till corn without herbicide, and No-till corn with paraquat were sampled for this study. The location and description of the field were given in previous chapters.

A metal core soil sampler of 5 cm diameter was used to sample the plots to a depth of 5 cm. Fifteen samples were taken from each plot at every sample date. The samplings were taken on May 23, June 10 and 20, July 7 and 22, August 11 and 24, September 21, October 3 and 17, and December 10, 1979. Collembola were extracted by the use of Tullgren funnels as already mentioned.



Mathematical Manipulation.

When a population has individuals randomly distributed, the population has the variance (s^2) with each population density equal to the mean (m). Ratio of variance (s^2) to mean (m) is less than unity when the individuals have a regular distribution. However, when the individuals have clumped distribution or are aggregated, the variance is greater than the mean. Generally in aggregated distribution, when population density increases the ratio of variance to mean increases.

Using Taylor's Power Law, aggregation can be measured in the expression:

$$s^2 = a m^b$$

where, s^2 is variance, m is the mean, and a and b are population's parameters. For more convenience, the expression may be demonstrated as a regression equation in logarithms as follows:

$$\log s^2 = \log a + b \log m$$

When using this equation, it is clear that $\log a$ is the intercept, and b is the regression coefficient (Taylor, 1961; 1964). Different sampling methods, and perhaps also population growth rate change a , while b ranges widely in different species, but is specific for a certain species in a given habitat.

For aggregation study, b is the most important, and known as index of aggregation as a measure of the degree of aggregation of a certain species in a given habitat. It describes an intrinsic property of the species concerned with a continuous graduation from near regular distribution ($b \rightarrow 0$), through random distribution ($b = 1$) to highly aggregated ($b \rightarrow \infty$) (Taylor, 1961; Taylor et al., 1978).



Taylor's Power Law was successfully applied for the study of collembolan aggregation in different habitats by Joose (1970).

Results and Discussion.

Index of aggregations of selected species are presented in Table 13. The data were obtained by equation of Taylor's Power Law derived from 12 samplings during this study. From the data it can be concluded that there was a marked aggregation in all species selected.

T. granulata was found to be more aggregated in No-till with and without paraquat. This also happened with *B. parvula*. This can be understood since the slow moving species have less ability to move to find other more suitable locations when their habitat is disturbed. Furthermore, euedaphic species that live deep in the soil, such as *T. granulata*, do not have much choice for their habitat preferences. On the other hand, the more active and hemiedaphic species, could easily move to explore other suitable loci when they were disturbed. This was obvious in *O. armatus*, *H. manubrialis*, *L. pallidus*, *I. notabilis*, and *P. violenta* that they were less aggregated in No-till plots.

For most active hemiedaphic species such as *L. pallidus*, *P. violenta* and *I. notabilis*, the addition of corn in their habitat seemed to provide more habitat preferences. They had very low degrees of aggregations in No-till corn without herbicide, and apparently were able to explore wider habitat preferences. But in No-till corn with paraquat, they were strongly aggregated, although less than in grassland. Probably the application of paraquat reduced their habitat alternatives.



TABLE 13.--^a $s^2 = a^2$ for Seven Species of Collembola Derived From 12 Samplings During the Study Period.

Collembola	Grassland	NTC*	NTCP**
<i>T. granulata</i>	$s^2 = 3.800$ m 1.670	$s^2 = 2.771$ m 1.719	$s^2 = 2.081$ m 1.801
<i>O. azmatus</i>	$s^2 = 3.447$ m 1.781	$s^2 = 4.993$ m 1.780	$s^2 = 3.066$ m 1.506
Onychiuridae	$s^2 = 3.706$ m 1.572	$s^2 = 1.829$ m 2.016	$s^2 = 1.749$ m 1.877
<i>B. parvula</i>	$s^2 = 2.762$ m 1.524	$s^2 = 2.420$ m 1.588	$s^2 = 3.176$ m 1.564
<i>H. manubrialis</i>	$s^2 = 2.350$ m 1.614	$s^2 = 2.896$ m 1.384	$s^2 = 2.867$ m 1.354
Hypogastruridae	$s^2 = 4.123$ m 1.369	$s^2 = 2.218$ m 1.686	$s^2 = 2.956$ m 1.629
<i>L. pallidus</i>	$s^2 = 1.703$ m 2.001	$s^2 = 2.386$ m 1.453	$s^2 = 3.388$ m 1.540
<i>P. violenta</i>	$s^2 = 1.609$ m 1.952	$s^2 = 2.287$ m 1.488	$s^2 = 3.347$ m 1.801
Entomobryidae	$s^2 = 0.690$ m 2.248	$s^2 = 1.673$ m 1.699	$s^2 = 3.050$ m 1.813
<i>I. notabilis</i>	$s^2 = 3.777$ m 1.763	$s^2 = 2.218$ m 1.442	$s^2 = 4.162$ m 1.720
All Collembola (seven species)	$s^2 = 2.602$ m 1.542	$s^2 = 0.256$ m 1.451	$s^2 = 3.761$ m 1.306

*NTC: No-till Corn No Herbicide.

**NTCP: No-till Corn With Paraquat.



The degrees of aggregations for the seven species in all the three habitats were lower than that of each single species. This indicates that in each habitat, all species did not aggregate in the same loci, and also indicated that the species balanced each other in utilizing their habitat.

However, when species belonging to the same family were examined, the results were different. *T. granulata* and *O. armatus* (Onychiuridae) tended to aggregate in the same loci in No-till corn plots, although they appeared to aggregate in different loci in grassland. The same results were obtained for Hypogastruridae (*B. parvula* and *H. manubrialis*). These situations may lead to greater competition between species, and furthermore, if this actually occurs, it may be deleterious.

Obviously *L. pallidus* and *P. violenta* (Entomobryiidae) are closely related. They were found to aggregate in the same locations, whether they were in grassland, No-till corn without herbicide, or No-till corn with paraquat. This was expected, since the two species are usually collected in the same habitat in Michigan (Snider, 1967).

As Eijsackers (1975, 1978 b) suggested, in nature Collembola may be able to avoid herbicide, and severe effects could be avoided. The ability to react and overcome the disturbance in their habitats lead to various changes in their degrees of aggregations as shown in this study. The increase of the degree of aggregation in less active species may be beneficial to them, although this may lead to an increase in intraspecific competition. Odum (1971) stated, that this is often more than counterbalanced by increased survival of the group. This is because the surface area exposed to unfavorable environment (such as herbicide) is less in proportion to the mass.



SUMMARY

Collembolan populations were studied in grassland, No-till corn without herbicide, and No-till corn with paraquat plots during the period of May through December 1979. Seven species were selected for the study, they were *Hypogastrura manubrialis*, *Brachystomella parvula*, *Onychiurus armatus*, *Tullbergia granulata*, *Isotoma notabilis*, *Lepidocyrtus pallidus*, and *Pseudosinella violenta*.

Apparently No-till cultivation reduced the numbers of hemiedaphic species temporarily, and they recovered by the end of this study. Only euedaphic species, *T. granulata* and *O. armatus*, were not effected by the practice, however they tended to have more individuals in deeper soil layers in No-till than in grassland plots. This reduction of the numbers of hemiedaphic species may have been caused by soil compaction when the vehicle placed seeds into the soil .

Three species of Collembola were affected by paraquat application. *L. pallidus* was significantly reduced in numbers immediately, and the species was not found after four months. Reduction of the numbers of *B. parvula* and *T. granulata* were significant only for two months, and they recovered. *T. granulata* increased rapidly after the recovery period, and by the end of the study their numbers were higher than in grassland plots. The decrease of the numbers of the three species apparently was due to disturbance in their reproduction. Newly hatched individuals in paraquat treated plots were not found immediately



after herbicide application. Vertical distribution also indicated that *T. granulata* and *O. armatus* had more individuals in deeper soil layers after paraquat application. Time of No-till planting and herbicide application could play important factor in reduction of the number of collembolan populations.

The collembolan community of the three habitats were subjected to two-dimensional ordination community analysis. Although the species composition of the collembolan community was not altered, the community was affected by No-till corn cultivation and application of paraquat. Among the three habitats, grassland was the most favorable habitat, and No-till with paraquat was the least.

All seven species of *Collembola* showed a marked aggregation in all habitats, but they did not aggregate in the same loci. Corn in No-till plots appeared to offer more microhabitat alternatives for hemiedaphic and more active species such as *L. pallidus*, *P. violenta*, *I. notabilis* and *H. manubrialis*, since they decreased the degree of aggregations. On the other hand, the euedaphic and slow moving species such as *T. granulata*, *O. armatus* and *B. parvula* were more aggregated in the treated plots. Application of paraquat increased the degree of aggregations of all seven species. Although this may increase competition among them, the survival of the group seemed to be increased as the favorability of the environment decreased.

POSSIBLE IMPROVEMENTS FOR FURTHER STUDY

Alternation of grassland habitat into No-till cultivation changes the biotic communities as shown in the present study. However, the use of lands for continuous No-till cultivation may cause stability in the community. A long term study should be conducted in order to conclude advance understanding of collembolan populations in No-till ecosystems.

In the present investigation, no attempt was made to do separate observation on the surface litter. This investigation observed that by the end of the study, surface litter on the field became obvious and could be significant factor. Collembolan communities of the surface litter could be the most important in humus production. Monitoring of the community should be conducted by sampling of the surface litter separately to observe a possible significant effects on the community. Furthermore, vertical distribution could be better studied by separation of soil cores into 2.5 cm apart or less.

Special effort should be made to analyze herbicide residues in the soil. Soil compaction should also be measured, since changes in soil compaction greatly influence the collembolan populations.



REFERENCES

- Aleinikova, M. M. & N. M. Utrobina. 1975. Changes in the structure of animal populations in soil under the influence of farm crops. In: Progress in Soil Zoology. J. Vanek (ed.). Academia: Publishing House of the Czechoslovak Acad. of Sci. Prague. pp. 429-435.
- Baeumer, K. & W. A. P. Bakermans. 1973. Zero-tillage. Advances in Agronomy 25:77-121.
- Beals, E. 1960. Forest bird communities in the Apostle Islands of Wisconsin. Wilson Bull. 72(2):157-181.
- Butcher, J. W., R. M. Snider & R. J. Snider. 1971. Bioecology of edaphic Collembola and Acarina. Ann. Rev. Ent. 16:249-288.
- Christiansen, K. 1964. Bionomics of Collembola. Ann. Rev. Ent. 9:147-178.
- Christiansen, K & P. Bellinger. 1980. The Collembola of North America. North of the Rio Grande. A taxonomic analysis. Grinnel College, Iowa.
- Clemen, R. B. & L. P. Pedigo. 1970. Collembola populations from selected arable fields. Proc. North Central Branch - E.S.A. 26(2):115-119.
- Cook, W. J. & L. S. Robertson. 1979. Conservation Tillage. Coop. Ext. Ser. M.S.U. Ext. Bull. E-1354, Nov. 1979.
- Curry, J. P. 1970. The effects of different methods of new sward establishment and the effects of the herbicides paraquat and dalapon on the soil fauna. Pedobiologia 10(5):329-361.
- Edwards, C. A. 1969. Soil pollutants and soil animals. Sci. Amer. 220:88-99.
- _____. 1970. Effects of herbicides on the soil fauna. Proc. 10th. Brit. Weed Control Conf. pp. 1052-1062.
- _____. 1975. Effects of direct drilling on the soil fauna. Outlook on Agriculture 8:243-244.



- Edwards, C. A. & K. E. Fletcher. 1971. A comparison of extraction methods for terrestrial arthropods. In: Methods of Study in Quantitative Soil Ecology: population, production and energy flow. J. Phillipson (ed.). Blackwell Sci. Publ. Oxford, Edinburgh. pp. 150-185.
- Edwards, C. A. & A. R. Thompson. 1973. Pesticides and the soil fauna. Residue Rev. 45:1-79.
- Edwards, C. A. & J. R. Lofly. 1975. The influence of cultivations on soil animal populations. In: Progress in Soil Zoology. J. Vanek (ed.). Academia: Publishing House of the Czechoslovak Acad. of Sci. Prague. pp. 399-407.
- Edwards, C. A. & C. J. Stafford. 1979. Interaction between herbicides and the soil fauna. Ann. Appl. Biol. 91:132-137.
- Eijsackers, H. 1975. Effects of herbicide 2,4,5-T on *Onychiurus quadriocellatus* Gisin (Coll.). In: Progress in Soil Zoology. J. Vanek (ed.). Academia: Publishing House of the Czechoslovak Acad. of Sci. Prague. pp. 481-488.
- _____. 1978 a. Side effects of the herbicide 2,4,5-T on reproduction, food consumption, and moulting of springtail *Onychiurus quadriocellatus* Gisin (Collembola). Z. ang. Ent. 85:341-360.
- _____. 1978b. Side effects of the herbicide 2,4,5-T affecting mobility and mortality of springtail *Onychiurus quadriocellatus* Gisin (Collembola). Z. ang. Ent. 86:349-372.
- Fox, C. J. B. 1964. The effects of five herbicides on the numbers of certain invertebrate animals in grassland soil. Can. J. Plant Sci. 44:405-409.
- Ghilarov, M. S. 1975. General trends of changes in soil animal populations of arable land. In: Progress in Soil Zoology. J. Vanek (ed.). Academia: Publishing House of the Czechoslovak Acad. of Sci. Prague. pp. 31-39.
- Gill, J. L. 1978. Design and Analysis of Experiments in the Animal and Medical Sciences. The Iowa State Univ. Press. Volumes 1, 2, 3.
- Green, R. H. 1979. Sampling Design and Statistical Methods for Environmental Biologists. John Wiley & Sons. 257 pp.
- Haarlov, N. 1960. Microarthropods from Danish soils: ecology and phenology. Oikos. Suppl. 3:1-165.
- _____. 1962. A quantitative comparison of hand-sorting and extraction with a Tullgren funnel. In: Progress in Soil Zoology. P. W. Murphy (ed.). Butterworths, London. pp. 156-168.



- Hale, W. G. 1966. A population study of moorland Collembola. *Pedobiologia* 6:65-99.
- Joosse, E. N. G. 1970. The formation and biological significance of aggregation in the distribution of Collembola. *Neth. J. Zool.* 20(3):299-314.
- Kempson, D., M. Lloyd & R. Ghelardi. 1963. A new extractor for woodland litter. *Pedobiologia* 3:1-21.
- Klingman, G. C. & F. M. Ashton. 1975. *Weed Science: Principles and Practices.* John Wiley & Sons.
- Loring, S. J., R. J. Snider & L. S. Robertson. (in press). Comparative effects of three tillage methods on soil microarthropod populations. *Pedobiologia*.
- McMillan, J. H. 1975. Interspecific and seasonal analysis of the gut contents of three Collembola (Family Onychiuridae). *Rev. Ecol. Biol. Sol.* 12:449-457.
- Murphy, P. W. 1962. Extraction methods for soil animals. In: *Progress in Soil Zoology.* P. W. Murphy (ed.). Butterworths, London. pp. 75-155.
- Nelson, L. V., L. S. Robertson, M. H. Erdman, R. G. White & D. Quisenberry. 1976. Guide Lines. No-till Corn. Coop. Ext. Ser. M.S.U. Ext. Bull. E-904, March 1976.
- Odum, E. P. 1971. *Fundamentals of Ecology.* 3rd ed. W. B. Saunders Co. 547 pp.
- Petersen, H. 1980. Population dynamics and metabolic characterization of Collembola species in a beech forest ecosystem. In: *Soil Biology as Related to Land Use practices.* Proc. VIIth Int. Coll. Soil Zool. pp. 806-827.
- Poole, T. B. 1961. An ecological study of the Collembola in a coniferous forest soil. *Pedobiologia* 1:113-137.
- Popovici, I., G. Stan, D. Stefan, R. Tomescu, A. Duncan, A. Tarta & F. Dan. 1977. The influence of atrazine on soil fauna. *Pedobiologia* 17:209-215.
- Robertson, L. S., A. E. Erickson & C. M. Hansen. 1977. Tillage systems for Michigan soils and crops. Coop. Ext. Ser. M.S.U. Ext. Bull. E-1041, Jan. 1977.
- Schaller, F. 1968. *Soil Animals.* The University of Michigan Press. Ann Arbor. 144 pp.



- Shaddy, J. H. & J. W. Butcher. 1977. The distribution of some soil arthropods in a manipulated ecosystems. Great Lakes Ent. 10: 131-144.
- Sharma, G. D. & D. K. McE. Kevan. 1963. Observations on *Isotoma notabilis* (Collembola: Isotomidae) in Eastern Canada. Pedobiologia 3:34-47.
- Sheals, J. G. 1956. Soil population studies. I. The effect of cultivation and treatment with insecticides. Bull. Ent. Res. 47:803-822.
- Shickluna, J. C. 1975. Sampling Soils. Coop. Ext. Ser. M.S.U. Ext. Bull. E-498, July 1975.
- Snider, R. J. 1967. An annotated list of the Collembola (spring-tails) of Michigan. Mich. Ent. 1:179-234.
- Southwood, T. R. E. 1978. Ecological Methods. 2nd ed. Halstead Press, New York. 524 pp.
- Subagja, J. & R. J. Snider. (in press). The side effects of herbicides atrazine and paraquat upon *Folsomia candida* (Willem) and *Tullbergia granulata* Mills (Collembola). Pedobiologia.
- Takeda, H. 1973. A preliminary study on collembolan in pine forest. Res. Pop. Ecol. 15(1):76-89.
- Tamura, H. 1976. Biases in extracting Collembola through Tullgren funnel. Rev. Ecol. Biol. Sol. 13:21-34.
- Taylor, L. R. 1961. Aggregation, variance and the mean. Nature 189: 732-735.
- _____. 1965. A natural law for the spatial disposition of insects. Proc. XIIth. Int. Congr. Ent. pp. 396-397.
- Taylor, L. R., I. P. Woiwod & J. N. Perry. 1978. The density-dependence of spatial behaviour and the variety of randomness. J. Anim. Ecol. 47:383-406.
- Tischler, W. 1955. Effects of agricultural practice on soil fauna. In: Soil Zoology. D. Kevan (ed.). Butterworths, London. pp. 215-230.
- Wallwork, J. A. 1976. The Distribution and Diversity of Soil Fauna. Academic Press. London. 355 pp.
- Williams, J. H. 1970. Herbicides--Their fate and persistence in soils, NAAS Quart. Rev. 87:119-131.



APPENDICES



APPENDIX I

MEAN NUMBER OF COLLEMBOLA COLLECTED PER CORE



APPENDIX I

MEAN NUMBER OF COLLEMBOLA COLLECTED PER CORE

TABLE 14.--Mean Number of Total Collembola Collected per Core Transformed Data: $\text{Log}(x + 1)$

Sampling Dates	Grassland Plots	No-till No Herbicide Plots	No-till With Paraquat Plots
May 6	1.1193	1.0574	1.0980
May 20	1.1071	1.0639	.9513
Jun 3	1.3995	1.1294	1.0060
Jun 17	1.2901	.9065	.6358
Jul 4	1.3343	1.0095	.9131
Jul 22	1.6685	1.4289	.9511
Aug 7	1.5806	1.2673	.7033
Aug 22	1.8071	1.1694	.7934
Sep 19	1.7651	1.0441	.9450
Oct 1	1.3083	.9274	.7987
Oct 20	1.2354	.7573	.8373
Nov 11	1.0113	.8652	.6960
Dec 15	1.3118	.9588	1.2426

NOTE: Means underscored by the same line do not differ significantly ($p \leq .05$).



APPENDIX I

MEAN NUMBER OF COLLEMBOLA COLLECTED PER CORE

TABLE 15.--*Hypogastrura manubrialis*, Means Number of Animals per Core
Transformed Data: $\text{Log}(x + 1)$

Sampling Dates	Grassland Plots	No-till No Herbicide Plots	No-till With Paraquat Plots
May 6	<u>.0636</u>	<u>.0867</u>	<u>.0837</u>
May 20	<u>.3079</u>	<u>.3128</u>	<u>.3056</u>
Jun 3	<u>.3226</u>	<u>.1068</u>	<u>.1068</u>
Jun 17	<u>.4069</u>	<u>.2265</u>	<u>.1899</u>
Jul 4	<u>.2560</u>	<u>.1439</u>	<u>.1003</u>
Jul 22	<u>.5417</u>	<u>.1935</u>	<u>.0719</u>
Aug 7	<u>.1640</u>	<u>.2022</u>	<u>.0920</u>
Aug 22	<u>.3745</u>	<u>.2643</u>	<u>.1283</u>
Sep 19	<u>.6966</u>	<u>.1924</u>	<u>.0920</u>
Oct 1	<u>.3084</u>	<u>.0519</u>	<u>.2189</u>
Oct 20	<u>.0837</u>	<u>.0602</u>	<u>.1068</u>
Nov 11	<u>.0602</u>	<u>.0920</u>	<u>.0867</u>
Dec 15	<u>.2487</u>	<u>.2689</u>	<u>.2320</u>

NOTE: Means underscored by the same line do not differ significantly
(p .05).



APPENDIX I

MEAN NUMBER OF COLLEMBOLA COLLECTED PER CORE

TABLE 16.--*Brachystomella parvula*, Mean Number of Animals per Core
Transformed Data: $\text{Log}(x + 1)$

Sampling Dates	Grassland Plots	No-till No Herbicide Plots	No-till With Paraquat Plots
May 6	<u>.1121</u>	<u>.1238</u>	<u>.1322</u>
May 20	<u>.6038</u>	<u>.5884</u>	<u>.5096</u>
Jun 3	1.1060	<u>.5685</u>	<u>.5318</u>
Jun 17	.9486	<u>.4491</u>	<u>.3388</u>
Jul 4	1.0690	.6199	.5636
Jul 22	1.5298	1.1440	.6610
Aug 7	1.3971	.9844	.3475
Aug 22	1.6362	.7248	.3226
Sep 19	.9432	<u>.2087</u>	<u>.1522</u>
Oct 1	.1522	<u>.0602</u>	<u>.0201</u>
Oct 20	.6351	<u>.0602</u>	<u>.0201</u>
Nov 11	.4262	<u>.1003</u>	<u>.0318</u>
Dec 15	.8048	<u>.2022</u>	<u>.1003</u>

NOTE: Means underscored by the same line do not differ significantly (p .05).



APPENDIX I

MEAN NUMBER OF COLLEMBOLA COLLECTED PER CORE

TABLE 17.--*Onychiurus armatus*, Mean Number of Animals per Core Transformed Data: $\text{Log}(x + 1)$

Sampling Dates	Grassland Plots	No-till No Herbicide Plots	No-till With Paraquat Plots
May 6	<u>.3408</u>	<u>.2541</u>	<u>.3026</u>
May 20	<u>.3559</u>	<u>.2390</u>	<u>.2424</u>
Jun 3	<u>.0519</u>	<u>.0602</u>	<u>.0602</u>
Jun 17	<u>.2590</u>	<u>.1968</u>	<u>.0920</u>
Jul 4	<u>.1003</u>	<u>.0803</u>	<u>.0519</u>
Jul 22	<u>.1204</u>	<u>.0563</u>	<u>.0602</u>
Aug 7	<u>.0719</u>	<u>.0719</u>	<u>.0920</u>
Aug 22	<u>.2223</u>	<u>.1762</u>	<u>.1121</u>
Sep 19	<u>.5749</u>	<u>.4176</u>	<u>.2086</u>
Oct 1	<u>.4101</u>	<u>.4368</u>	<u>.1144</u>
Oct 20	<u>.1905</u>	<u>.2689</u>	<u>.2340</u>
Nov 11	<u>.3822</u>	<u>.2253</u>	<u>.2075</u>
Dec 15	<u>.4339</u>	<u>.4985</u>	<u>.7365</u>

NOTE: Means underscored by the same line do not differ significantly ($p > .05$).



APPENDIX I

MEAN NUMBER OF COLLEMBOLA COLLECTED PER CORE

TABLE 18.--*Tullbergia granulata*, Mean Number of Animals per Core
Transformed Data: $\text{Log}(x + 1)$

Sampling Dates	Grassland Plots	No-till No Herbicide Plots	No-till With Paraquat Plots
May 6	<u>.6838</u>	<u>.5715</u>	<u>.6805</u>
May 20	<u>.2849</u>	<u>.2476</u>	<u>.2887</u>
Jun 3	<u>.2468</u>	<u>.3109</u>	<u>.3222</u>
Jun 17	<u>.2825</u>	<u>.3458</u>	<u>.1322</u>
Jul 4	<u>.3089</u>	<u>.2624</u>	<u>.2424</u>
Jul 22	<u>.3162</u>	<u>.3597</u>	<u>.1003</u>
Aug 7	<u>.3192</u>	<u>.3737</u>	<u>.1003</u>
Aug 22	<u>.3893</u>	<u>.3354</u>	<u>.2631</u>
Sep 19	<u>.6581</u>	<u>.4574</u>	<u>.5980</u>
Oct 1	<u>.2560</u>	<u>.2424</u>	<u>.3941</u>
Oct 20	<u>.4121</u>	<u>.4884</u>	<u>.6400</u>
Nov 11	<u>.4665</u>	<u>.5768</u>	<u>.4759</u>
Dec 15	<u>.4827</u>	<u>.4986</u>	<u>.7911</u>

NOTE: Means underscored by the same line do not differ significantly ($p = .05$)



APPENDIX I

MEAN NUMBER OF COLLEMBOLA COLLECTED PER CORE

TABLE 19.--*Isotoma notabilis*, Mean Number of Animals per Core Transformed Data: $\text{Log}(x + 1)$

Sampling Dates	Grassland Plots	No-till No Herbicide Plots	No-till With Paraquat Plots
May 6	.1723	.1322	.1155
May 20	.1885	.1924	.2075
Jun 3	.1121	.1204	.1238
Jun 17	.2805	.0201	.0519
Jul 4	.2722	.2442	.1601
Jul 22	.2624	.1640	.1003
Aug 7	.3378	.1905	.0920
Aug 22	.4320	.3362	.2662
Sep 19	.7797	.2912	.2223
Oct 1	.5874	.0901	.1356
Oct 20	.5927	.1439	.0867
Nov 11	.2560	.0920	.0401
Dec 15	.2223	.3374	.3591

NOTE: Means underscored by the same line do not differ significantly (p .05).



APPENDIX I

MEAN NUMBER OF COLLEMBOLA COLLECTED PER CORE

TABLE 20.--*Lepidocyrtus pallidus*, Mean Number of Animals per Core
Transformed Data: $\log(x + 1)$

Sampling Dates	Grassland Plots	No-till No Herbicide Plots	No-till With Paraquat Plots
May 6	.0620	.0602	.0719
May 20	.1806	.1439	.0719
Jun 3	.1204	.0920	.0602
Jun 17	.2158	.0602	.0602
Jul 4	.1840	.1003	.0602
Jul 22	.2268	.1988	.1038
Aug 7	.5215	.1958	.0401
Aug 22	.5375	.1269	.0401
Sep 19	.7926	.1587	.0602
Oct 1	.6611	.2844	-
Oct 20	.3082	.0803	-
Nov 11	.1269	.0803	-
Dec 15	.5598	.2476	-

NOTE: Means underscored by the same line do not differ significantly ($p < .05$).



APPENDIX I

MEAN NUMBER OF COLLEMBOLA COLLECTED PER CORE

TABLE 21.--*Pseudosinella violenta*, Mean Number of Animals per Core
Transformed Data: $\text{Log}(x + 1)$

Sampling Dates	Grassland Plots	No-till No Herbicide Plots	No-till With Paraquat Plots
May 6	<u>.1322</u>	<u>.1121</u>	<u>.1155</u>
May 20	<u>.1806</u>	<u>.1322</u>	<u>.0719</u>
Jun 3	<u>.3143</u>	<u>.1121</u>	<u>.0719</u>
Jun 17	<u>.3171</u>	<u>.1204</u>	<u>.0837</u>
Jul 4	<u>.4109</u>	<u>.1534</u>	<u>.0803</u>
Jul 22	<u>.3631</u>	<u>.2233</u>	<u>.1204</u>
Aug 7	<u>.5408</u>	<u>.2223</u>	<u>.1322</u>
Aug 22	<u>.5198</u>	<u>.1640</u>	<u>.2106</u>
Sep 19	<u>.6501</u>	<u>.4945</u>	<u>.3079</u>
Oct 1	<u>.5583</u>	<u>.4147</u>	<u>.4035</u>
Oct 20	<u>.2825</u>	<u>.2522</u>	<u>.2062</u>
Nov 11	<u>.1322</u>	<u>.0719</u>	<u>.1185</u>
Dec 15	<u>.1121</u>	<u>.0401</u>	<u>.0401</u>

NOTE: Means underscored by the same line do not differ significantly ($p < .05$).



APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS



APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

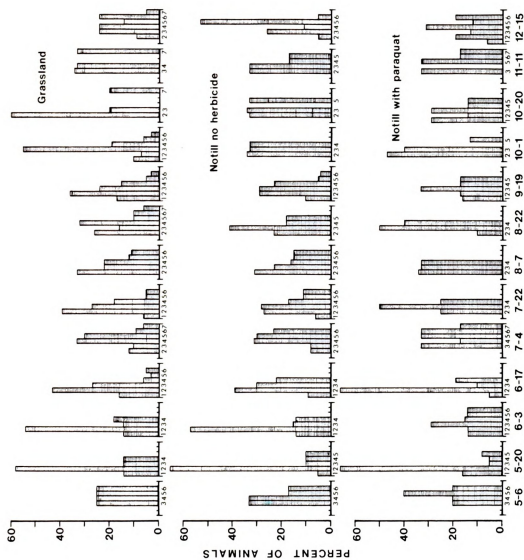
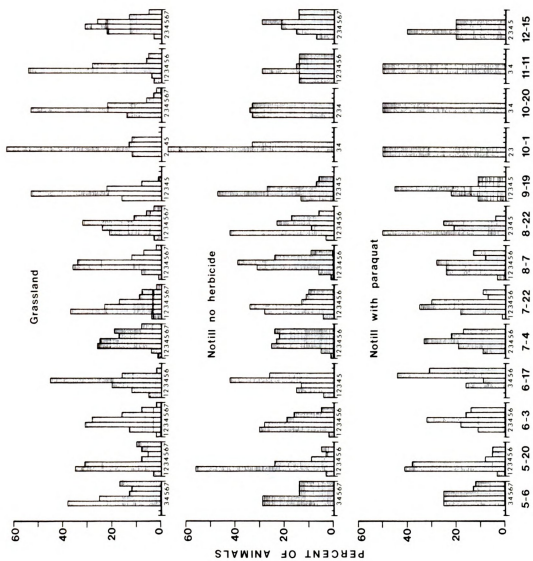


FIGURE 6.--Size Structures of *Hypogastrura manubialis*



SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS





APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

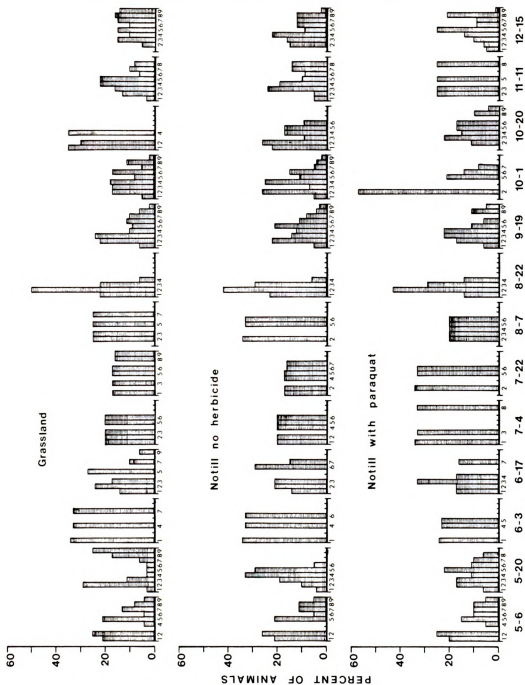


FIGURE 8.-- Size Structures of *Onychiurus armatus*.



APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

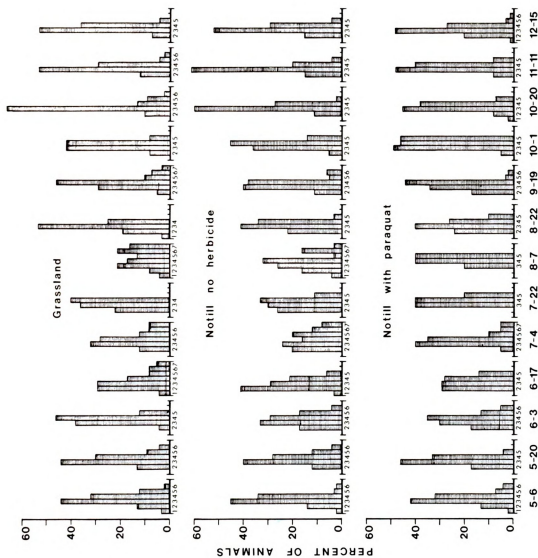
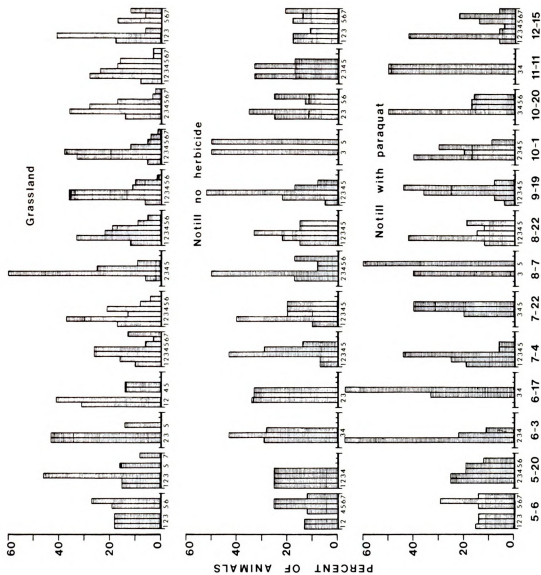


FIGURE 9.—Size Structures of *Tullbergia granulata*



SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

FIGURE 10.-- Size Structures of *Isotoma notabilis*



APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

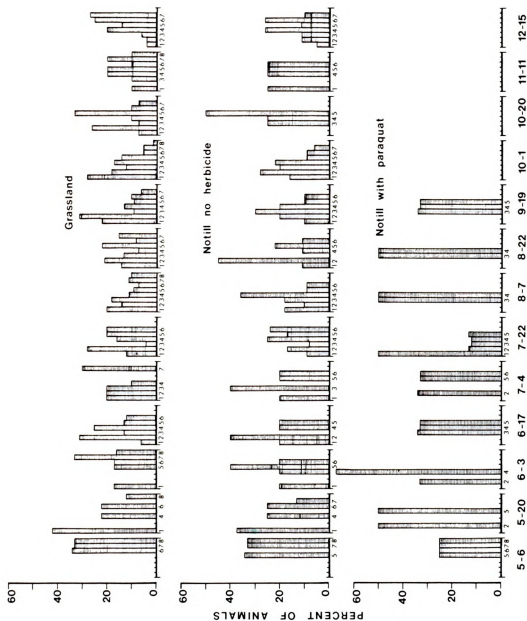


FIGURE 11.--Size Structures of *Lepidocyrtus pallidus*:

APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

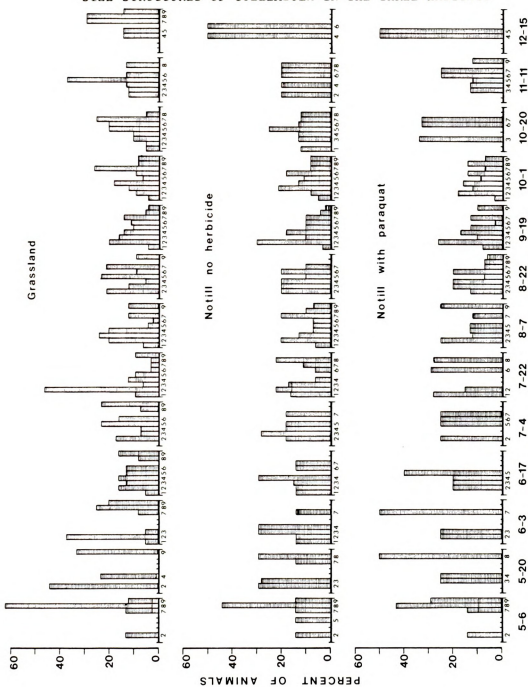
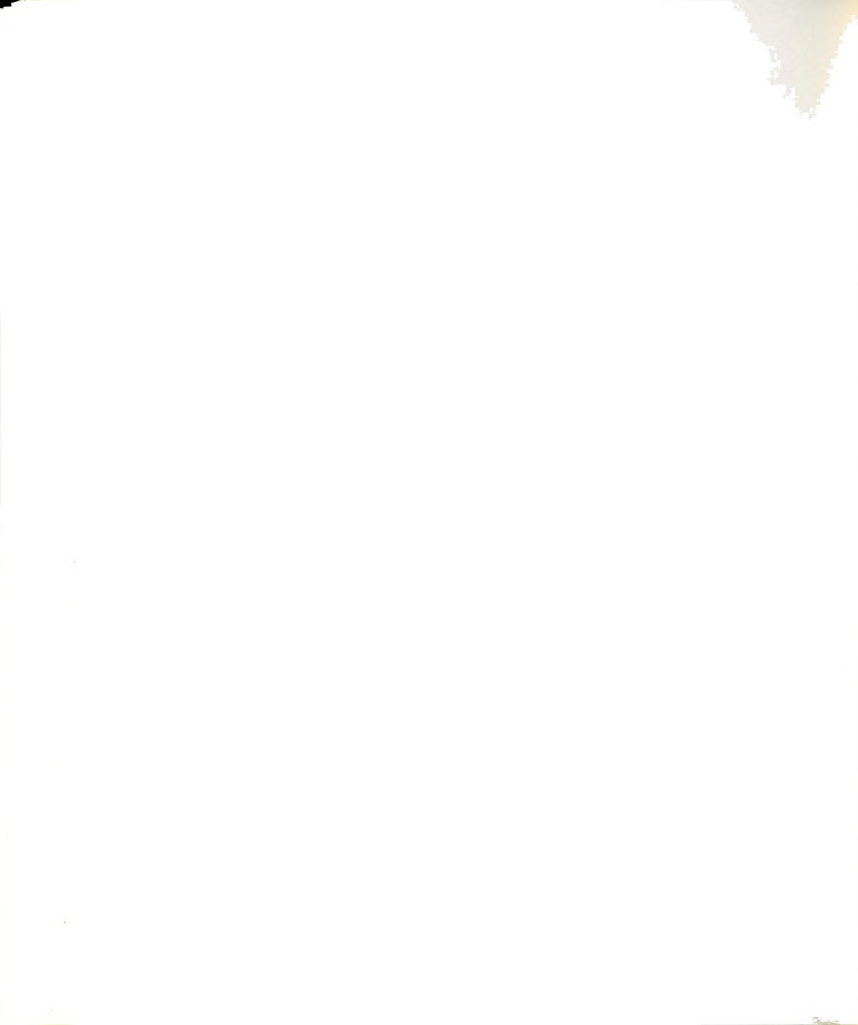


FIGURE 12.—Size Structures of *Pseudosinella violenta*



APPENDIX

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

TABLE 22.--*Hypogastrura manubrialis*, Percent of Animals in each Size Class on Every Sampling Dates

Dates	Grassland							No-till Corn No Herbicide							No-till Corn With Paraquat						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
May 6	-	-	25	25	25	25	-	-	-	33	33	17	17	-	-	-	20	20	40	20	-
May 20	14	58	14	7	7	-	-	5	65	10	10	10	-	-	16	66	5	5	8	-	-
Jun 3	14	54	14	18	-	-	-	14	57	15	14	-	-	-	14	14	29	15	14	14	-
Jun 17	16	43	27	6	3	5	-	9	39	30	22	-	-	-	5	66	10	19	-	-	-
Jul 4	-	12	10	33	30	9	6	-	8	8	31	30	23	-	-	-	33	17	33	33	17
Jul 22	6	39	27	18	5	5	-	6	27	28	17	11	11	-	-	25	50	25	-	-	-
Aug 7	-	33	22	22	12	11	-	-	31	23	16	15	15	-	-	34	33	33	-	-	-
Aug 22	-	26	16	32	10	10	6	-	23	41	18	18	-	-	-	10	50	40	-	-	-
Sep 19	17	36	24	15	5	3	-	10	29	29	23	5	4	-	16	17	33	17	17	-	-
Oct 1	10	7	55	19	6	3	-	-	34	33	33	-	-	-	-	47	40	-	13	-	-
Oct 20	-	60	20	-	-	-	20	-	33	34	-	33	-	-	29	14	29	14	14	-	-
Nov 11	-	-	34	33	-	-	33	-	33	33	17	17	-	-	-	33	-	33	17	17	-
Dec 15	-	9	24	24	14	24	5	-	5	26	11	53	5	-	6	19	13	31	12	19	-

NOTE: Size Class: 1 - less than .25 mm; 2 - .25-.35 mm; 3 - .35-.45 mm; 4 - .45-.55 mm; 5 - .55-.65 mm; 6 - .65-.75 mm; 7 - over .75 mm.

APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

TABLE 23.--*Brachystomella parvula*, Percent of Animals in each Size Class on Every Sampling Dates.

Dates	Grassland							No-till Corn No Herbicide							No-till Corn With Paraquat						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
May 6	-	-	38	25	13	12	17	-	-	29	29	14	14	14	-	-	25	25	25	13	12
May 20	3	35	31	8	5	8	10	3	56	24	9	3	5	-	3	41	38	8	5	5	-
Jun 3	2	13	31	28	16	8	2	2	30	28	19	16	5	-	-	11	18	32	16	14	-
Jun 17	5	12	20	45	16	2	-	4	15	13	42	26	-	-	-	-	16	9	44	31	-
Jul 4	1	4	26	25	17	19	8	1	5	25	23	22	24	-	-	9	19	33	22	17	-
Jul 22	4	37	23	17	9	8	2	4	28	34	13	11	10	-	1	18	35	30	7	9	-
Aug 7	1	8	36	34	12	7	2	1	6	31	39	14	9	-	3	24	24	28	8	13	-
Aug 22	3	21	24	32	11	6	3	3	42	9	23	17	6	-	-	50	21	25	4	-	-
Sep 19	16	53	22	8	1	-	-	13	47	27	7	-	6	-	11	22	45	11	11	-	-
Oct 1	-	12	63	13	12	-	-	-	-	67	33	-	-	-	-	50	50	-	-	-	-
Oct 20	-	14	53	22	6	3	2	-	33	34	33	-	-	-	-	-	50	50	-	-	-
Nov 11	3	4	54	28	6	5	-	14	14	29	15	14	14	-	-	-	50	50	-	-	-
Dec 15	-	3	22	31	26	13	5	-	7	15	21	29	14	14	-	20	40	20	20	-	-

NOTE: Size Class: 1 - less than .25 mm; 2 - .25-.35 mm; 3 - .35-.45 mm; 4 - .45-.55 mm; 5 - .55-.65 mm; 6 - .65-.75 mm; 7 - over .75 mm.



APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

TABLE 24. --*Oxyechirus armatus*, Percent of Animals in each Size Class on Every Sampling Dates.

Dates	Grassland									No-till Corn No Herbicide									No-till Corn With Paraquat								
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
May 6	21	25	-	4	21	4	13	8	4	21	26	-	-	21	5	11	11	5	20	25	-	5	15	10	10	10	5
May 20	3	29	11	3	3	3	6	17	25	4	10	19	33	29	5	-	-	-	6	17	17	11	22	11	10	6	-
Jun 3	34	-	-	33	-	-	33	-	-	34	-	-	33	-	33	-	-	-	34	-	-	33	33	-	-	-	-
Jun 17	14	24	19	-	27	-	10	-	6	14	21	21	-	-	29	15	-	-	17	17	33	17	-	16	-	-	-
Jul 4	20	20	20	-	20	20	-	-	-	20	20	-	20	20	20	-	-	-	34	-	33	-	-	-	33	-	-
Jul 22	17	-	17	-	17	17	-	16	16	17	17	-	17	17	16	16	-	-	34	-	-	33	33	-	-	-	-
Aug 7	-	25	25	-	25	-	-	-	-	-	34	-	-	33	33	-	-	-	-	20	20	20	20	-	-	-	-
Aug 22	22	50	22	6	-	-	-	-	-	23	42	29	6	-	-	-	-	-	14	43	29	14	-	-	-	-	-
Sep 19	6	22	24	10	9	11	10	6	2	5	22	14	12	21	11	8	4	3	6	17	22	22	11	6	-	11	5
Oct 1	5	17	17	18	8	17	5	11	2	5	26	7	25	11	15	5	4	2	-	57	-	-	21	14	8	-	-
Oct 20	35	30	-	35	-	-	-	-	-	22	26	9	17	17	9	-	-	-	-	11	22	15	19	19	-	10	4
Nov 11	3	13	16	22	22	6	10	8	-	5	5	24	19	10	9	14	14	-	-	25	25	-	25	-	-	25	-
Dec 15	-	5	15	10	15	10	15	16	14	-	15	16	22	9	12	12	12	2	5	6	10	14	25	9	9	21	1

NOTE: Size Class: 1 - Less than .40 mm; 2 - .40-.50 mm; 3 - .50-.60 mm; 4 - .60-.70 mm; 5 - .70 - .80 mm; 6 - .80-.90 mm; 7 - .90-1.00 mm; 8 - 1.00-1.10 mm; 9 - over 1.10 mm.

APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

TABLE 25.--*Tullbergia granulata*, Percent of Animals in each Size Class on Every Sampling Dates

Dates	Grassland							No-till Corn No Herbicide							No-till Corn With Paraquat						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
May 6	3	13	44	32	6	2	-	2	14	45	34	3	2	-	2	13	42	32	7	4	-
May 20	-	13	44	30	9	4	-	-	12	40	28	12	4	-	-	17	46	33	4	-	-
Jun 3	3	4	38	46	12	-	-	-	17	33	29	17	4	-	-	17	30	35	13	5	-
Jun 17	4	29	29	17	8	8	5	3	41	29	21	6	-	-	-	29	29	28	14	-	-
Jul 4	-	12	32	28	12	8	8	-	20	24	16	20	12	8	-	5	40	35	10	5	5
Jul 22	-	24	36	40	-	-	-	-	26	30	33	11	-	-	-	-	40	40	20	-	-
Aug 7	4	8	21	17	13	21	16	4	16	26	32	3	16	3	-	-	20	40	40	-	-
Aug 22	3	19	53	25	-	-	-	-	22	41	34	3	-	-	-	-	24	40	26	10	-
Sep 19	-	5	29	46	10	7	3	-	11	40	38	5	6	-	-	17	34	44	3	2	-
Oct 1	-	8	42	42	8	-	-	-	5	36	45	14	-	-	-	5	49	46	-	-	-
Oct 20	-	10	66	13	9	2	-	-	11	60	27	2	-	-	2	8	45	38	7	-	-
Nov 11	-	12	53	29	4	2	-	-	15	61	20	4	-	-	-	8	48	40	4	-	-
Dec 15	-	7	53	36	4	-	-	-	15	52	29	4	-	-	1	20	48	27	3	1	-

NOTE: Size Class: 1 - less than .25 mm; 2 - .25-.35 mm; 3 - .35-.45 mm; 4 - .45-.55 mm; 5 - .55-.65 mm; 6 - .65-.75 mm; 7 - over .75 mm.

APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

TABLE 26.---*Isotoma notabilis*, Percent of Animals in each Size Class on Every Sampling Dates

Dates	Grassland							No-till Corn No Herbicide							No-till Corn With Paraquat						
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
May 6	18	18	18	-	19	27	-	13	13	12	-	25	25	12	15	14	14	-	14	29	14
May 20	15	15	46	-	16	-	8	25	25	25	25	-	-	-	-	25	25	19	19	12	-
Jun 3	-	43	43	-	14	-	-	-	29	43	28	-	-	-	-	67	22	11	-	-	-
Jun 17	31	41	-	14	14	-	-	-	34	33	33	-	-	-	-	-	33	67	-	-	-
Jul 4	10	16	26	26	6	3	13	7	7	43	29	14	-	-	19	25	44	6	6	-	-
Jul 22	17	37	13	21	8	4	-	10	40	10	20	20	10	-	-	-	20	40	40	-	-
Aug 7	-	6	60	25	9	-	-	-	17	50	8	8	17	-	-	-	40	-	60	-	-
Aug 22	12	33	22	19	9	5	-	15	22	33	15	15	-	-	12	42	15	12	19	-	-
Sep 19	6	36	36	11	10	1	-	5	22	52	17	4	-	-	4	8	36	44	8	-	-
Oct 1	5	33	38	12	7	4	1	-	-	50	-	50	-	-	1	40	20	30	9	-	-
Oct 20	-	14	36	28	17	3	2	-	25	37	-	13	25	-	-	-	50	17	17	16	-
Nov 11	8	28	24	17	16	3	3	-	33	17	33	17	-	-	-	-	50	50	-	-	-
Dec 15	18	41	6	-	17	6	12	18	18	11	-	18	14	21	6	42	6	4	14	22	6

NOTE: Size Class: 1 - less than .35 mm; 2 - .35-.45 mm; 3 - .45-.55 mm; 4 - .55-.65 mm; 5 - .65-.75 mm; 6 - .75-.85 mm; 7 - over .85 mm.

APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

TABLE 27.--*Lepidocyrtus pallidus*, Percent of Animals in each Size Class on Every Sampling Dates

Dates	Grassland								No-till Corn No Herbicide								No-till Corn With Paraquat							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
May 6	-	-	-	-	-	34	33	33	-	-	-	-	34	-	33	33	-	-	-	-	25	25	25	25
May 20	44	-	-	22	-	22	-	12	37	-	-	25	-	25	-	13	-	50	-	-	50	-	-	-
Jun 3	17	-	-	-	17	17	33	16	20	-	-	20	40	20	-	-	-	33	-	67	-	-	-	-
Jun 17	6	31	13	25	13	12	-	-	20	40	-	20	20	-	-	-	-	-	34	33	33	-	-	-
Jul 4	20	20	20	10	-	-	30	-	20	-	40	-	20	20	-	-	-	34	-	-	33	33	-	-
Jul 22	12	28	4	16	20	20	-	-	9	17	8	25	17	24	-	-	50	13	12	12	13	-	-	-
Aug 7	20	14	18	11	9	7	11	10	18	10	18	36	9	9	-	-	-	-	50	50	-	-	-	-
Aug 22	14	21	13	7	22	8	15	-	11	45	-	11	22	11	-	-	-	-	50	50	-	-	-	-
Sep 19	22	31	9	13	9	10	6	-	10	20	30	20	10	10	-	-	-	-	34	33	33	-	-	-
Oct 1	28	18	12	17	14	5	5	1	16	28	10	22	9	9	6	-	-	-	-	-	-	-	-	-
Oct 20	7	26	7	10	33	10	7	-	-	-	25	25	50	-	-	-	-	-	-	-	-	-	-	-
Nov 11	10	-	10	20	20	10	20	10	25	-	-	25	25	25	-	-	-	-	-	-	-	-	-	-
Dec 15	4	4	6	20	14	25	27	-	5	11	11	26	11	26	10	-	-	-	-	-	-	-	-	-

NOTE: Size Class: 1 - less than .45 mm; 2 - .45-.55 mm; 3 - .55-.65 mm; 4 - .65-.75 mm; 5 - .75-.85 mm; 6 - .85-.95 mm; 7 - .95-1.05 mm; 8 - over 1.05 mm.

APPENDIX II

SIZE STRUCTURES OF COLLEMBOLA IN THE THREE HABITATS

TABLE 28.--*Pseudosinella violenta*, Percent of Animals in each Size Class on Every Sampling Dates

Dates	Grassland									No-till Corn No Herbicide									No-till Corn With Paraquat								
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
May 6	-	13	-	-	-	-	13	62	12	-	14	-	-	14	-	14	44	14	-	14	-	-	-	14	43	29	
May 20	-	44	-	23	-	-	-	-	33	-	29	28	-	-	-	14	29	-	-	-	25	25	-	-	-	50	
Jun 3	5	37	5	-	-	-	8	25	20	14	14	29	29	-	-	14	-	-	-	25	25	-	-	50	-	-	
Jun 17	5	16	13	16	13	13	-	8	16	14	14	15	29	-	14	14	-	-	-	20	20	20	40	-	-	-	
Jul 4	-	17	7	7	23	16	-	7	23	-	18	28	18	18	-	18	-	-	-	25	-	-	25	25	-	25	
Jul 22	9	46	6	12	9	3	3	3	9	16	22	17	6	-	6	11	22	-	28	15	-	-	-	29	-	28	
Aug 7	6	20	24	20	4	2	12	-	12	6	20	13	7	7	7	20	13	7	-	13	20	20	7	20	7	7	
Sep 19	4	22	16	14	11	10	14	5	4	6	30	10	18	10	10	10	4	2	8	26	10	17	13	3	13	-	
Oct 1	4	9	12	18	6	9	26	8	8	5	8	21	13	11	18	8	8	8	3	18	12	16	9	14	7	14	
Oct 20	5	5	10	10	20	20	25	5	-	12	-	13	13	25	13	12	12	-	-	-	34	-	-	33	33	-	
Nov 11	-	12	12	13	37	13	-	13	-	-	20	-	20	-	20	20	20	-	-	-	13	13	12	25	25	-	
Dec 15	-	-	-	14	14	-	29	29	14	-	-	-	50	-	50	-	-	-	-	-	-	50	50	-	-	-	

NOTE: Size Class: 1 - less than .45 mm; 2 - .45-.55 mm; 3 - .55-.65 mm; 4 - .65-.75 mm; 5 - .75-.85 mm; 6 - .85-.95 mm; 7 - .95-1.05 mm; 8 - 1.05 -1.10 mm; 9 - over 1.10 mm.





MICHIGAN STATE UNIV. LIBRARIES



31293104918846