COMPARATIVE ANALYSIS OF COLLEMBOLA ASSOCIATED WITH ORGANIC AND CONVENTIONAL AGROECOSYSTEMS

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ABSTRACT

COMPARATIVE ANALYSIS OF COLLEMBOLA ASSOCIATED WITH ORGANIC AND CONVENTIONAL AGROECOSYSTEMS

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Soil populations of Collembola (Pseudosinella violenta, Entomobrya unostrigata, Isotoma notabilis, Isotoma viridis, Isotomiella minor, Isotomurus tricolor, Folsomides americanus, Proisotoma minuta, Onychiurus encarpatus, Tullbergia yosiii) were monitored in organic and conventional sweet corn agroecosystems in 1982 and 1983, at the Rodale Research Center in Kutztown, Pennsylvania. The research site was under organic management for ten years previous. Agroecosystems differed with respect to weed management (cultivation, or atrazine and Lasso) and nitrogen source (bloodmeal, compost, or ammonium nitrate). Soil population density, species composition, extraction efficiency, horizontal distribution, vertical distribution, and population dynamics were evaluated. Conversion from organic to conventional management significantly reduced Collembola soil population densities. Bloodmeal-nitrogen significantly increased densities of most Collembola species, and ammonium nitrate significantly decreased densities. Most species were aggregated horizontally and vertically. Population dynamics varied with species.

Key words: Collembola, organic agroecosystem, conventional agroecosystem, cultivation, atrazine, Lasso, bloodmeal, compost, ammonium nitrate.

DEDICATION

This thesis is dedicated to Justin Thomas Cummings.

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INTRODUCTION

Farm-level agroecosystems are specialized units of biological organization, consisting of a community and its physical support system. Community interactions with the physical environment lead to characteristic trophic structure and nutrient cycles. Agroecosystems are dependent on grower-manipulated processes that effect biological and mineral utilization rates and relationships within the system (Loucks 1977).

Organic agriculture is designed to maximize intrinsic components and processes of the existing ecosystem. These components and processes are dependent on biological interactions within plant-nutrient cycles, and result in crop yield. In contrast, conventional agriculture maximizes extrinsic components that may deleteriously alter soil biological interactions. Examples of synthetic inputs include soluble fertilizers, pesticides and growth regulators.

Soil mesofauna and microfauna are important components of soil agroecosystems. With bacteria and fungi, they are responsible for nutrient cycling and humification of soil organic matter (Wallwork 1983). Soil animal population dynamics and, therefore, nutrient cycles, are a function of management practices in both conventional and organic agroecosystems. Agronomic practices such as tillage, rotations, and applications of manure, fertilizer, and pesticides, affect community ecology changes in biomass and species diversity. Organically managed farms may support a more stable and diverse community of soil organisms.

As production system inputs common to conventional agriculture become more costly and biologically limiting, methods common to organic farming systems should be investigated. The objectives of this research were to conduct a comparative analysis of biomass and species diversity of soil Collembola in an organic agroecosystem, and in a conventional system previously managed with organic methods. Other objectives were to determine the effect of agroecosystem management on their species occurence, distribution, and abundance. Collembola were selected because of their great soil abundance. This research is a prerequisite for determining the qualitative and quantitative role of Collembola and other soil fauna in agroecosystem humification of organic matter.

LITERATURE REVIEW

The Collembola are a diverse and abundant group of insects within the soil ecosystem. Fluctuating population parameters are a result of interactions between biological and environmental factors. These factors include food, predator relationships, and soil micro-climate and structure. Significant factors influencing Collembola soil populations will be discussed in following sections.

Biology of Soil Collembola

Collembola are small soil insects often associated with decaying organic matter in soil. Their mean population density is approximately 100,000 per cubic meter of soil, with a mean biomass of 6 grams per cubic meter. Christiansen (1964) reported a maximum density of 100,000,000 per square meter in an agricultural soil. Most estimates place soil Collembola densities at slightly less than or comparable to densities of soil Acarina.

Collembola are characterized by unique physiological and morphological criteria. These include the presence of a collophore and a furcula. Body length of most species is less than 1.0 mm, with a maximum length of 11.0 mm (Snider, pers. com.). The integument is often granulated, with characteristic setal patterns or covered with flattened scales. Eyes are absent, or consist of up to eight ocelli in a patch. Pigment is absent to distinct, with a range of colors and patterns.

The diet of Collembola consists of a variety of materials, including decaying plant residues, fungi, bacteria, arthropod feces, pollen, and algae. Specialists occur, but many species encountered in agricultural environments are ubiquitous.

Collembola reproduction is sexual or parthenogenic. Most sexual reproduction occurs indirectly; females pick up spermatophores deposited by males. Eggs are laid singly or in clumps, and require 5-10 days to hatch under optimal conditions (Schaller 1970). Periodic molting continues throughout life, with sexual activity often restricted to alternate instars. Number of instars ranges from two to greater than fifty. Development can be interrupted by cold or dry conditions. Life span varies with species and environment from four months to over one and one-half years (Schaller 1970).

Soil Moisture and Temperature--Soil temperature and moisture are among the most important environmental factors influencing the biology of soil Collembola. Effects of temperature and moisture are complex. They may be direct or indirect, and are probably interrelated (Christiansen 1964; Butcher et al. 1971). A wide range of temperature preferences have been reported for different species. Collembola are relatively resistant to low temperatures; however, this

varies greatly. Temperature regulates rate of development, and spatial distribution in soil. High temperatures during development may result in changes in form and histological structure, known as ecomorphosis (Christiansen 1964).

Most Collembola require relative humidities greater than 89% (Christiansen 1964). Many species fail to survive in culture at humidities less than 100%, but this depends on the life stage and physiological state. Butcher et al. (1971) summarized the effects of low humidity. Responses included migration, greater mortality, decrease in rate of reproduction, construction of protective cells, inactivity, ecomorphosis, and phenotype changes. They also stressed that there exists an optimal unknown combination of temperature and humidity.

Somme (1976) described cold-hardiness of Isotoma hiemalis Schott, Entomobrya nivalis (L.) and Hypogastrura socialis (Uzel) from a coniferous forest in Norway. Mean chill-coma temperatures of these species were -7.1, -3.4, and -8.6 C, respectively. Supercooling points were between -25 and -16 C, depending on the presence of food in the gut. Supercooling points were greater than those common for other winter-active insects, and it was concluded that Collembola survive temperature extremes by migrating to below the snow cover.

Soil pH—Soil pH can influence populations of Collembola. Hale (1967) stated that although there are some pH preferences, most species are probably generalists, and a wide tolerance range exists. Butcher et al. (1971) defined a general pH tolerance range of 6.0 - 7.8, and stated that pH may affect reproduction. Christiansen (1964) reviewed this subject, and concluded that pH is probably more indicative of soil type, and is therefore indirectly associated with different Collembola species.

Spatial Distribution--Population densities of Collembola are most often concentrated in the uppermost soil horizons, where organic matter concentrations and pore space are maximal (Hale 1966; Kevan 1962). Morphological criteria have been used to predict vertical stratification of Collembola species in the soil profile. Generally, large darkly-pigmented species are most abundant in upper layers or at the surface, and small light-colored species are concentrated in the lower layers (Christiansen 1964; Bellinger 1954; Kevan 1962). Large concentrations of Collembola have been found to a soil depth of 20 cm (Christiansen 1964).

Vertical migration may occur daily or seasonally in response to changes in soil moisture and temperature (Hale 1966; Christiansen 1964). Poole (1961) monitored the vertical distribution of Collembola in a coniferous forest soil in North Wales, and estimated densities in soil, humus, and litter. Soil population densities were measured to a depth of 3.8 cm from the top of the mineral horizon, while the depths of the organic layers varied. Each family was found to have a characteristic vertical distribution.

In this study, the Entomobryidae (Entomobrya spp., Lepidocrytus spp.) were concentrated in the litter. Percent distribution in soil, humus, and litter layers was approximatley 15:15:70. Most species of Isotomidae were concentrated above the soil layer (95%) and were recognized as either humus or litter forms. At uncompacted sites, however, many Isotomidae were found below 7.5 cm in the mineral soil layer. Onychiuridae were concentrated in humus (50%) and soil (35%), and were recovered from depths of 7.5 cm at uncompacted sites.

Collembola exhibit an aggregated distribution pattern within and at the soil surface. The tendency to aggregate is attributed to many biological and environmental factors, including time of day, season, soil structure, organic

matter concentration, soil moisture, humidity, food concentration, microflora concentration, vegetation type, egg batch size, molting, and reproduction (Christiansen 1964; Butcher et al. 1971; Usher 1969; Joose and Verhoef 1974). Egg batch size has been suggested as a factor of aggregation. Poole (1961) concluded otherwise, and Hale (1966) was unable to prove that it was a major contributing factor. Joose and Verhoef (1974) concluded that aggregation is an important survival tool, especially during critical life stages.

Usher (1969) conducted an extensive study to determine the spatial distribution characteristics of Collembola species in a pine forest. He determined densities in sixteen 4cm X 4cm X 3cm soil samples, within a 16cm X 16cm block; each soil sample was vertically stratified to three 1-cm depth subsamples. In this way, distribution was subjectively analysed. Most species were found in aggregations of various size, but uniform and random distributions were also common. Different age classes and different color types of a species were found to have dissimilar distributions. Random, uniform or aggregated distributions occurred in favorable and unfavorable niches.

Population Dynamics--Many Collembola species are active throughout the year. They have seasonal fluctuations in population density reflecting reproductive cycles, mortality and migration. Trends in population dynamics are often masked by environmental conditions (Christiansen 1964). Hale (1967) provided a summary of seasonal population fluctuations of Collembola as a group. Most Collembola are included in one of two major categories: 1) species with population peaks in autumn and spring, and population declines in summer and winter; and 2) species with a summer or winter peak (Hale 1967; Christiansen 1964).

Takeda (1979) studied the life cycles and population dynamics of surface active Collembola species. He concluded that seasonal fluctuations in population densities were closely related to the length of life cycle and number of generations per year. These seasonal changes reflect reproductive cycles and mortality as influenced by the environment.

Solem and Sendstad (1978) monitored diel periodicity of surface-active Collembola in Norway with pitfall traps. Daily activity varied between two sampling years, although certain species were consistantly rythmic or arythmic each year. Temperature and rainfall were determined to be the most important factors influencing population dynamics.

Collembola Associated With Sweet Corn in Berks Co., PA

Seven Collembola families were recognized taxonomically (Christiansen and Bellinger 1980). Thirteen species from four families were collected from sweet corn in Berks County, Pennsylvania (Appendix 1). Most species were members of the family Isotomidae. Only one species of Onychiuridae was collected with sufficient regularity for statistical evaluation. Occurance of species from the family Entomobryidae was seasonal. Sminthuridae were rarely collected. Certain Collembola species will be discussed in this section to introduce readers to species variability.

Isotoma (Desoria) notabilis Schaffer (Isotomidae)-- I. notabilis is a moderately sized, pigmented Collembola; body color is pale to medium grey-blue. Eye patches are dark, but not well developed. The furcula is well developed, and maximum body length is 1.0 mm (Christiansen and Bellinger 1980). This species is most likely parthenogenic, but sexual dimorphism is difficult to detect. Under controlled laboratory conditions the life cycle is completed in one month or less,

at greater than 14 C (Sharma and Kevan 1963). Field conditions probably support one generation per season (Loring 1979). I. notabilis is probably the most common member of its genus in North America. This species prefers a moist habitat, and is most often found in soil litter, or in greenhouse soil. Soil flora, nematodes, and organic debris are part of the diet (Christiansen and Bellinger 1980). The mandibular plate is well-developed, indicating herbivory, although carnivory has also been reported (Sharma and Kevan 1963).

Isotomiella minor (Schaffer) (Isotomidae)--I. minor is a white, eyeless litter species. A distinct taxonomic characteristic is the lack of a post-antennal organ. The furcula is well-developed; maximum body length is 1.1 mm. This is the only Nearctic species (Christiansen and Bellinger 1980). Van der Drift (1959) reported that this species has a wide ecological tolerance. The diet includes fungi and plant debris (Poole 1959).

Tullbergia (Tullbergia) yosiii Rusek (Onychiuridae)--T. yosiii is a small, elongate euedaphic species with a maximum body length of 0.7 mm. Both furcula and pigment are absent. This uncommon species has been found in soils of the Central and Eastern United States. Males have not been reported (Christiansen and Bellinger 1980). Species biology has not been summarized. Tullbergia krausbaueri (Borner), a closely related species, is commonly used in laboratory studies. T. krausbaueri is a slow-moving, widely distributed euedaphic species. Milne (1960) assumed a sex ratio of 1:1, but lack of sexual dimorphism prevented confirmation. Peterson (1971) collected eggs from isolated females, indicating parthenogenesis. In culture, a complete life cycle of T. krausbaueri lasts seven to nine weeks, and adults survive for more than six months (Milne 1960). Diet has not been reported; however, this author has successfully raised individuals of

T. yosiii with brewers yeast. Field conditions probably result in one generation of T. yosiii per season.

Pseudosinella violenta Folsom (Entomobryidae)--P. violenta is a large, active and aggresive species with a well-developed furcula. The body is scaled and without pigment or eyes. This species is widely distributed in the United States. Christiansen and Bellinger (1980) report maximum body length in cave and soil forms of 2.1 and 1.6 mm, respectively. Soil forms are active at the surface and favor high humidity. This species is commonly found under rocks, rotting leaves, in ant nests and in greenhouse soil (Davis and Harris 1936). Laboratory culture has been successful with a diet of plant roots, corn grain and leaves, peanuts, and wheat. Extensive damage to sugar cane has resulted from root grazing by this species (Davis and Harris 1936). Reproduction is assumed to be sexual. Davis and Harris observed a female:male sex ratio of 65:35. At laboratory temperatures of 25-37 C, sexual maturity was reached in 16 to 22 days after hatching.

Entomobrya (Entomobrya) unostrigata Stach (Entomobryidae)--E. unostrigata is a large, pigmented species; maximum body length is 2.5 mm. Its body color ranges from white to orange-yellow or pale green. A dark-colored dorsal stripe is usually present. The furcula is well-developed. Individuals are reported from California and Michigan. This species was introduced to California and has been spreading east since 1938 (Christiansen and Bellinger 1980).

Impact of Agricultural Practices on Collembola

Soil Tillage--Effects of soil mixing on populations of soil animals can be beneficial or detrimental. A common result is an initial reduction in densities, followed by recolonization and altered species composition. These changes are attributed to alteration of environmental conditions resulting from soil disturbance. Abrasive forces of cultivation implements and destruction of habitats by compaction contribute to mortality of Collembola and other soil animals (Edwards and Lofty 1975; Wallwork 1976; Critchley et al. 1979; Aritajat et al. 1977). Soil microclimate is less stable after cultivation, and extremes in soil moisture and temperature result from changes in soil structure and ground cover (Wallwork 1976; Critchley et al. 1979).

Species balance is often altered after cultivation. Certain species may be eliminated and others significantly increased due to altered physical habitat and predator-prey relationships (Critchley et al. 1979; Edwards and Lofty 1969). Surface-dwelling species of Collembola are usually more negatively influenced than edaphic species (Edwards and Lofty 1976; Moore, et al. 1983).

Recolonization of soil animals after cultivation results when organic matter is redistributed evenly within a more aerated horizon. The homogeneous soil profile allows deeper penetration of Collembola. Increased pore space provides a more suitable habitat (Edwards and Lofty 1975; Wallwork 1976; Christiansen 1964).

Aritajat et al. (1977) evaluated the impact of soil compaction on populations of Collembola in silt loam and clay soils. Initial densities were greatest in the silt loam. After two weeks, Collembola densities in silt loam were significantly less than when the soil was disturbed. Densities were not

significantly different during a 1 - 6 month period after disturbance. Nine months after manipulation, compacted soil supported a significantly lower density of Collembola than the undisturbed sites.

Soil compaction in clay soil resulted in highly significant reductions of Collembola populations for three months. Six months after compaction, no differences were found in populations associated with the different soil types. Sheals (1956) and Andren and Lagerlof (1980) reported similar population recovery rates in agroecosystems after cultivation.

Crop Nutrition--The addition of crop nutrients or pesticides to soil ecosystems often disturbs populations of fauna and flora, including Collembola. Disturbance enhances or suppresses population characteristics of Collembola through the following modes of action:

1. Direct toxic, repellent or attractant properties of the amendment,
2. Alteration of plant cover (crop and weed species, and productivity),
3. Alteration of soil physical or chemical properties,
4. Addition of Collembola, predators or prey to the site with the amendment.

Reactions to a variety of agricultural materials have been summarized (Appendix 2 and 3). These relationships are often species or habitat specific and are difficult to generalize.

Fertilizer application often results in increased soil population densities of Collembola. Enhancement of soil population densities of Collembola has been attributed to organic matter accumulation in soil (Behan et al. 1978). This is a result of greater plant productivity. Soil organic matter provides a food source for Collembola, and improves soil physical and chemical properties.

Edwards and Lofty (1969) reported slight increases in soil densities of Collembola after application of fertilizer containing nitrogen, phosphorous and potassium. In contrast, Collembola soil populations did not appear to respond to four years of ammonium sulfate, superphosphate, and potassium chloride application to fallow, corn and wheat treatments (Artemjeva and Gatilova 1975).

Behan et al. (1978) studied the effects of urea application in a Quebec black spruce humus, on soil populations of Collembola and other fauna. Densities of Collembola and related taxa decreased immediately after urea application. The relative abundance of species, however, remained constant. After treatment, Collembola migrated to deeper soil horizons. Three hypotheses were offered to explain the vertical migration:

1. Urea was toxic to Collembola,
2. Urea killed the original moss cover, causing greater temperature fluctuations in upper soil layers,
3. Microphytophagous Collembola were attracted to greater densities of ureolytic organisms in lower layers that resulted from urea applications.

Relatively few studies are concerned with direct effects of fertilizer constituents on soil fauna. Moursi (1962a) reported that Onychiurus armatus Tullberg, a soil species, was attracted to a current of nitrogen gas (less than 4.1 ml/hour) passed through a humus substrate. Greater dosages repelled this species. Moursi (1962b) evaluated the toxicity of hydrogen sulfide and ammonia gases to several species of Collembola from different habitats. Ammonia was toxic to Onychiurus granulosus Stach, a soil species, and less toxic to Isotoma thermophila Axelson, a manure inhabitant. Hydrogen sulfide was toxic to the soil

species O. granulosus, and less toxic to the compost species Hypogastrura bengtssoni (Agren). Results indicated that ammonia and hydrogen sulfide can be highly toxic but specific reactions depended on species habitat.

The addition of manure or composted organic materials to soil often results in enhancement of Collembola density and species diversity (Chernova et al. 1971; Atlavinyte 1971; Edwards and Lofty 1969; Artemjeva and Gatilova 1975; Weil and Kroonjte 1979; Aleinikova and Utrobina 1975; Morris 1927; Davidson 1979). Manure or compost may result in an increased food supply for Collembola as well as increasing species diversity and establishing other arthropods at the site. Weil and Kroontje (1979) observed that applications of poultry manure to agricultural soil significantly increased Collembola density but did not alter seasonal variation. They reported a significant positive correlation of soil organic matter content with densities of Entomobryidae and Hypogastruridae, but not Isotomidae.

Weed Management--Herbicides are used to manage weeds in most conventional agroecosystems. Atrazine has been shown to significantly influence soil populations of Collembola. Fox (1964) observed reductions in Collembola soil density in grassland soil after applicatioin of atrazine. A decrease in population growth rate was directly attributed to toxicity, and indirectly to reduction of plant cover. Soil populations of Collembola, in corn treated with atrazine, were monitored by Popovici et al. (1977). Atrazine was applied to soil at two rates: 5 kg ai/ha and 8 kg ai/ha. Densities were evaluated in the upper 10 cm of soil. At the lower rate, Collembola densities were reduced 80% one month after treatment, and 59% after four months. At the higher application rate, densities were 95% lower after one month, and 80% reduced after four months.

Isotomidae, the most dominant and most frequently recovered taxon, was found to be most resistant to atrazine.

Subajga and Snider (1981) cultured Folsomia candida (Willem) and Tullbergia granulata Mills with diets of brewers yeast treated with atrazine at approximate field concentration. Mortality and length of instar duration were significantly increased. Egg production was significantly reduced, but egg viability was not affected.

Recovery of Collembola from Soil

Assessment of soil mesoarthropod populations, particularly Collembola, most often relies on dynamic extraction methods that depend on active responses of the animal to some stimuli. In contrast, mechanical methods of extraction depend on characteristic properties of the insect and sampling medium, with the animal playing a passive role.

Dynamic methods of Collembola extraction from soil samples include Berlese (1905) and Tullgren (1918) funnels. Berlese funnels rely on dessication as a stimulus, whereas Tullgren funnels commonly rely on a lightbulb or other heat source to provide temperature and light stimuli. Murphy (1962) provides a detailed description of funnel modifications and mechanical methods of extraction. Extraction efficiency by Tullgren funnels depends on modifications made by the investigator, and also varies with soil type, sample size and bulk density. Efficiency is often less than 50% of the mesoarthropods contained in the sample (Murphy 1962).

Peterson (1978) determined extraction efficiency using various methods. High-gradient funnel and cannister extractors were found to be 80-90% efficient for Collembola in ten days of extraction, with initial and final soil temperatures

of 20 C and 40 C. Other efficiencies reported were as follows: Isotoma notabilis 90-100%; Isotomiella minor < 90%; Lepidocrytus lignorum 75%; Onychiurus spp. 85%; and Tullbergia sp. < 50%. Tamura (1976), however, determined that Tullgren funnels were only 6% efficient for Collembola, in 42 hours of extraction.

Of total mesoarthropods, Peterson (1978) found that Collembola migrate from samples most quickly, with 50% of total extraction occurring before the third day of extraction. In contrast, Block (1966) reported 58% of the Collembola extracted occurred during the initial 24-36 hours of extraction from a mineral soil.

Loring et al. (1981) reported efficiencies of 3% and 82% extraction for Tullbergia granulata and the Isotomidae, respectively, from funnels similar to those used in this research. Samples were extracted for approximately three days, or the time required for thorough sample drying to occur.

Role of Collembola in Nutrient Cycling

Soil arthropods play an important role in the decomposition of soil organic matter and subsequent release of plant nutrients in forest ecosystems (Wallwork 1983). Only recently has research focused on the role of mesoarthropods in agroecosystems (Atlavinyte 1971; Chernova et al. 1971; Golebiowska and Ryszkowski 1977; Ghilarov 1978; Stinner and Crossley 1980). In 1954, Bellinger described mesoarthropod activity to be of significance in determining "the character and fertility of organic constituents of soil". A recent summary of Canadian research needs concluded that soil fauna are important in agricultural systems. This justification was based upon the role of soil fauna in nutrient cycling (Marshall et al. 1982).

Soil mesoarthropods are direct or indirect catalysts of organic matter decomposition (Crossley 1977; Reichle 1977; Macfadyen 1963). Litter decomposes and nutrients are mineralized at a rate directly related to the density of soil invertebrates (Edwards et al. 1970; Addison and Parkinson 1978). This is a result of increased organic matter surface area made available for microbial decomposers. Estimates of the direct effects of Collembola on organic matter decompostion are reported as percent litter consumption or breakdown. In a Central Sweden pine forest, Persson (1983) estimated that soil animals mineralized or excreted about 30% of the annual net mineralization of nitrogen in soil. In oak leaf litter, Anderson et al. (1983) reported that Collembola were responsible for enhancement of mineral nitrogen losses. Loss of ammonia-nitrogen was significantly correlated with animal fresh weight, and Collembola were found to have a greater effect than most other mesofauna.

Collembola and other soil fauna indirectly regulate rate of organic matter decomposition by grazing on microflora, resulting in a more controlled linear nutrient release throughout the growing season (Reichle 1977). Nutrient release from organic matter, however, may not be a function of grazing activity (Anderson et al. 1983). Soil animals may disrupt microbial immobilization and amplify existing variations in soil organic matter and litter (Anderson et al. 1983). This may account for the enhancement of metabolic activity in soil that is observed when Collembola are present, and microenvironment abiotic factors are not limiting (Addison and Parkinson 1978).

Other indirect effects of Collembola feeding activities include the dissemination of fungal spores and the elimination of mycostasis and bateriostasis, production of feces and complex humic substances, and substrate-soil mixing.

Persson (1983) suggested that microbial-feeding animals control microbial biomass and thus control nitrogen availability. Anderson et al. (1983) described this as a disruption of the normal time course of nitrogen mineralization by microorganisms. Nitrogen is transferred to Collembola biomass with a more rapid turnover than that of other mesoarthropods.

Collembola influence microbial colonizing ability by selective grazing on microbial species (Parkinson and Visser 1979; Hanlon and Anderson 1979). Nutrient assimilation by Collembola may reduce nutrient losses by leaching during transfer from one nutrient pool to another (Hanlon and Anderson 1979). Collembola may therefore influence species composition of microflora, and either increase or decrease rates of decomposition and mineral release.

Alternative Farming Methods

Increased production costs associated with present-day conventional agriculture have resulted in a renewed interest in alternative farming methods, especially regarding plant nutrient cycles and pest management. A diversity of European-based farming systems have been developed during this century. Boeringa (1980) described six commercial alternative methods of farming:

1. Arbeitsgemeinschaft fur naturgemassen Qualitatsanbau von Obst und Gemuse (ANOG);
2. Biodynamic;
3. Lemaire-Boucher;
4. Macrobiotic;
5. Organic-biological; and
6. Howard-Balfour.

Each method has a unique philosophy regarding practices of cultivation, plant nutrient source and handling, and emphasizes certain soil chemical properties and reactions. A philosophy of maximization of biological processes and minimal system disruption is a common characteristic of most alternative methods.

ANOG (Working Party for the Natural Cultivation of Fruit and Vegetables) is a type of agriculture founded in Germany in 1962 (Boeringa 1980). The objective of this Party is the production of agricultural products with high biological value. Biological value emphasizes nutritional quality, and is achieved with "Bodenruhe" (soil rest). Tillage is minimal and the soil is covered by a green manure crop or organic matter. The use of organic fertilizers and certain pesticides is permitted.

Biodynamic agriculture is practiced by commercial growers in Western, Central and Northern Europe, and in North America. Steiner (1958) introduced the concept of Anthroposophy, which links grower and crop with cosmic forces; this philosophy is the foundation of biodynamic agriculture. Unique fertilizer preparations are utilized, and lunar rythyms are observed (Boeringa 1980).

Lemaire-Boucher agriculture is practiced in France and Belgium. Calmagol, compost, organic fertilizers and legumes are incorporated to maintain a "balanced soil". Calmagol is a unique product that contains the coral algae Lithothamnian calcareum, and is applied to soil as a catalyst for elemental transmutations. Elemental transmutations are microbiological processes that respond to the nutritional requirements of the crop (Boeringa 1980).

Macrobiotic agriculture is practiced in Western, Central and Northern Europe, and was founded in Germany in the early 1900's by Kraft (Boeringa 1980). Very briefly, this system of crop production relies on the synchronization

of macro-element (e.g. N, P, K) and trace-element supply with crop species and cosmic forces. Unique compost preparations are required (Boeringa 1980).

Organic-biological agriculture is commercially practiced in Switzerland, Belgium, the Netherlands and West Germany. This method was developed by Rusch in 1955 (Boeringa 1980), and stresses the microbiological relationships between plants, herbivores and the soil. Fertilizers or pesticides that disturb these relationships are avoided.

Howard-Balfour agriculture is practiced in England and in North America on a commercial scale. Howard (1943) and Balfour (1943) introduced this method, emphasizing the use of manure, compost, crop rotation, and crop-mycorrhizal interactions for yield and nutritional maintenance (Boeringa 1980). Organic farming in North American is derived from this method (Harwood 1982).

In 1980, USDA defined current North American alternative farming systems as organic farming:

> a production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives. To the maximum extent feasible, organic farming systems rely upon crop rotations, crop residues, animal manures, legumes, green manure, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients and to control insects, weeds and other pests.

Harwood (1983) reviewed the development of organic farming in this country, and outlined philosophies associated with the development of regenerative agriculture. Regenerative agriculture encompasses most philosophies that unite alternative farming systems, but also stresses "the intimate connection between soil fertility, the health and growth of crops and the health of both animals and people who consume those crops." The concept of decentralized national agricultural systems is also stressed.

Management System Inputs

Nitrogen Fertilizers--The nitrogen cycle consists of a well-known series of reactions. Soil nitrogen is in a continuous biological and chemical cycle of mineralization and immobilization between organic and inorganic soil nitrogen fractions. Inorganic soil nitrogen includes the soluble mineral forms NO_3, NH_4, and N_2. Organic soil nitrogen exists as insoluble, low molecular weight (amino acids, amides, amines) and high molecular weight compounds (proteins, nucleic acids) (Mengel and Kirkby 1982).

Organic nitrogen fertilizers, such as bloodmeal and compost, are mineralized to NH_3 and NO_3 after application to soil. In contrast, soluble inorganic nitrogen fertilizers, such as ammonium nitrate, do not require mineralization, and provide an available supply of NH_3 and NO_3. These mineral forms of nitrogen are removed from the soil solution by plant uptake, or are often incorporated into soil organic matter or leached from the site. Discussion of nitrogen fertilizers will be limited to bloodmeal, compost, and ammonium nitrate.

Bloodmeal was one of many organic ammoniates popular with growers in the early 1900's. Bloodmeal is a slaughterhouse by-product. It is dried and pulverized to a powder for use in animal feeds or as fertilizer. Bloodmeal is currently popular with home gardeners, but high cost restricts its use in large agricultural operations. In 1983, approximately 5,556 tons of bloodmeal were applied to agricultural crops in the United States (USDA 1983).

Bloodmeal is approximately 13% nitrogen, but analysis varies with source (Table 1). Approximately 97% of the total nitrogen in bloodmeal is water insoluble, due to a high content (89%) of crude protein (Rubins and Bear 1942).

Table 1. Nutritional analysis of nitrogen fertilizers applied to sweet corn.

Plant nutrient	Fertilizer analysis		
	Bloodmeal[1]	Compost[1,2]	NH_4NO_3
N	13.23%	1.75%	33.5%[3]
P	1.74%	0.97%	
K	0.79%	0.60%	
S	0.43%		
Mg	0.14%		
Ca	2.00%		
Na	0		
B	3 ppm[4]		
Zn	46 ppm		
Mn	7 ppm		
Fe	2080 ppm		
Cu	9 ppm		
Al	140 ppm		
NH_4		0.35%	
NO_3		0.12%	78.0%[5]
NH_3			22.0%[5]

[1]Private laboratory analysis

[2]Analysis of compost applied to sweet corn in 1982

[3]Manufacturer's analysis

[4]Parts per million

[5]Percent by weight

Bloodmeal application results in increased soil auxin concentration (Hamence 1948), but other side affects from its application are not known.

In 1938 (USDA), agriculturalists considered bloodmeal a readily available source of nitrogen. Bloodmeal was a preferred nitrogen fertilizer in greenhouses for its quick and noninjurious action, and ease of distribution. A demand for bloodmeal as livestock feed caused prices to increase at that time. In 1950, Owen et al. determined that the nitrification rate of bloodmeal was comparable to other slaughterhouse-derived nitrogen sources, such as bone- and hoof-and-horn-meal. They reported a nitrification rate of 68% in 65 days for bloodmeal in a laboratory study. Mineralization after 65 days appeared to stop. At this time, most of the remaining nitrogen became incorporated in soil humus, and decomposition continued at a reduced rate. Rubins and Bear (1942) also studied nitrification rates of bloodmeal. Sixty percent of bloodmeal-N was converted to NO_3 in 20 days, and 66% was mineralized in 40 days. In contrast, urea ($CO(NH_2)_2$), a conventional nitrogen source, was 87% mineralized in 20 days, and 88% minerlized in 40 days.

Compost is a mixture of variable ratios of plant and animal wastes, that has been mixed together, aerated, and partially decomposed in order to increase nutrient availability and reduce bulk. Composting originated in India as a method of utilizing human wastes for crop fertilizers; many technique modifications exist (Howard 1943). Most composting in this country is utilized as a method of sewage disposal, or by home gardeners and commercial growers for fertilizer (Gouleke 1972). In 1983, approximatley 23,915 tons of compost were used in the United States (USDA 1983).

Compost used in this M.S. research was composed of turkey, chicken, and horse manure with bedding, and leaves from a nearby city. At application, this compost contained approximately 1.75% nitrogen in 1982, and 1.00% nitrogen in 1983 (Table 1). Less than 0.50% of the nitrogen was immediately available. Nitrogen in manure and compost is mineralized at a general rate of 20 to 50% 20% and 10% respectively, in the first three years following application to soil (Harmsen and Van Schreven 1955; Mengel and Kirkby 1982). Decomposition rate is dependent on source, environment, and proportion of non-hydrolyzable substances in the materials.

Soil flora and fauna are responsible for decomposition of residues and release of plant nutrients in the composting process. Nishio (1983) hypothesized that greater that 30% of the nitrogen release from compost might have passed through the microbial biomass. Nishio also observed significant fluctuations of microbial biomass in soil after compost application. Compost is an excellent medium for Collembola providing near-optimal moisture and food requirements. Each stage of decomposition is distinquished by a change in Collembola species predominance.

Chernova (1963) described Collembola succession during the leaf-composting process in surface and deeper layers. Early stages of decomposition in the surface, during spring, were dominated by Isotoma olivacea Tullberg. After partial decomposition, Proisotoma minuta Tullberg was most dominant, and was replaced in riper compost by Isotoma notabilis and later Onychiurus armatus. In deeper layers, decomposition began with P. minuta, and then followed the same succession of species. Chernova et al. (1971) later noted changes in rate of oxygen-uptake of Collembola dependent upon stage of compost decay.

Gisin (1952) studied Collembola of leaf compost at three sites. Each site was composed of a unique array of Collembola species in succession with decay stage. Attempts to innoculate different compost sites with species from another site were not successful, indicating that each site represented a distinct habitat and that the Collembola species were habitat-specific.

Ammonium nitrate is a soluble nitrogen fertilizer. Approximately 2,170,000 tons were used in conventional agroecosytems in the United States in 1983 (USDA 1983). Ammonium nitrate contains approximately 35% nitrogen (Table 1), and is a source of readily available nitrate and ammonium ions. Plant uptake of nitrate is often greater than uptake of ammonium under field conditions. Ammonium may be partially adsorbed on soil colloids before plant uptake.

Herbicides--Herbicides are used to manage weeds in most conventional agroecosystems. Atrazine is a selective herbicide used to control broadleaf and grassy weeds in corn, sorghum, and other crops. Selective weed control is achieved with rates of 2.24-4.48 kg/ha. Atrazine is absorbed through roots and foliage, and accumulates in apical meristems and leaves, acting as a photosynthetic inhibitor. Limited studies have shown some minor fungicidal and nematocidal activity.

Atazine is readily adsorbed on organic matter and clay; leaching is limited. Most decomposition occurs by microbial organisms which may utilize it as a source of energy and nitrogen. Residues may persist in soil longer than 12 months, where soil adsorptive capacities are high (WSSA 1983).

Alachlor (Lasso) is an herbicide used to control annual grasses and certain broadleaf weeds and yellow nutsedge. It is absorbed mainly by germinating plant

shoots and secondarily by roots, and is translocated throughout the plant, inhibiting protein synthesis. Alachlor is adsorbed by soil colloids, and is broken down mainly by microbial organisms. Other biocidal properties are not reported. Average persistence from recommended rates is approximately 6-10 weeks, depending on site conditions (WSSA 1983).

MATERIALS AND METHODS

Research Site Description

A research site at the Rodale Research Center in east-central Pennsylvania was used to monitor the influence of agroecosystem management on soil population densities of Collembola associated with sweet corn in 1982 and 1983. This Center is near Kutztown, in Maxatawny Township, Berks County (Figure 1). The site was part of a five-year vegetable rotation study (VRS), initiated in 1982 in a field that had been under organic management for ten years, and was considered a stable organic system (Figure 2). The objective of the study is to determine nitrogen contribution of a legume sod in organic and conventional agroecosystems. Agroecosystem was the main factor in a randomized split-split plot design. Systems were further divided into eight crop rotation sequences (Figure 3).

Crop rotation sequences were unique with respect to nitrogen source, which was sub-divided to four rates of application. Rotations incorporated leguminous crops, or the nitrogen fertilizers bloodmeal, compost, or ammonium nitrate. Application rates were zero, low, moderate and high. The zero-rate units served as agroecosystem controls. Some rotations incorporated double-

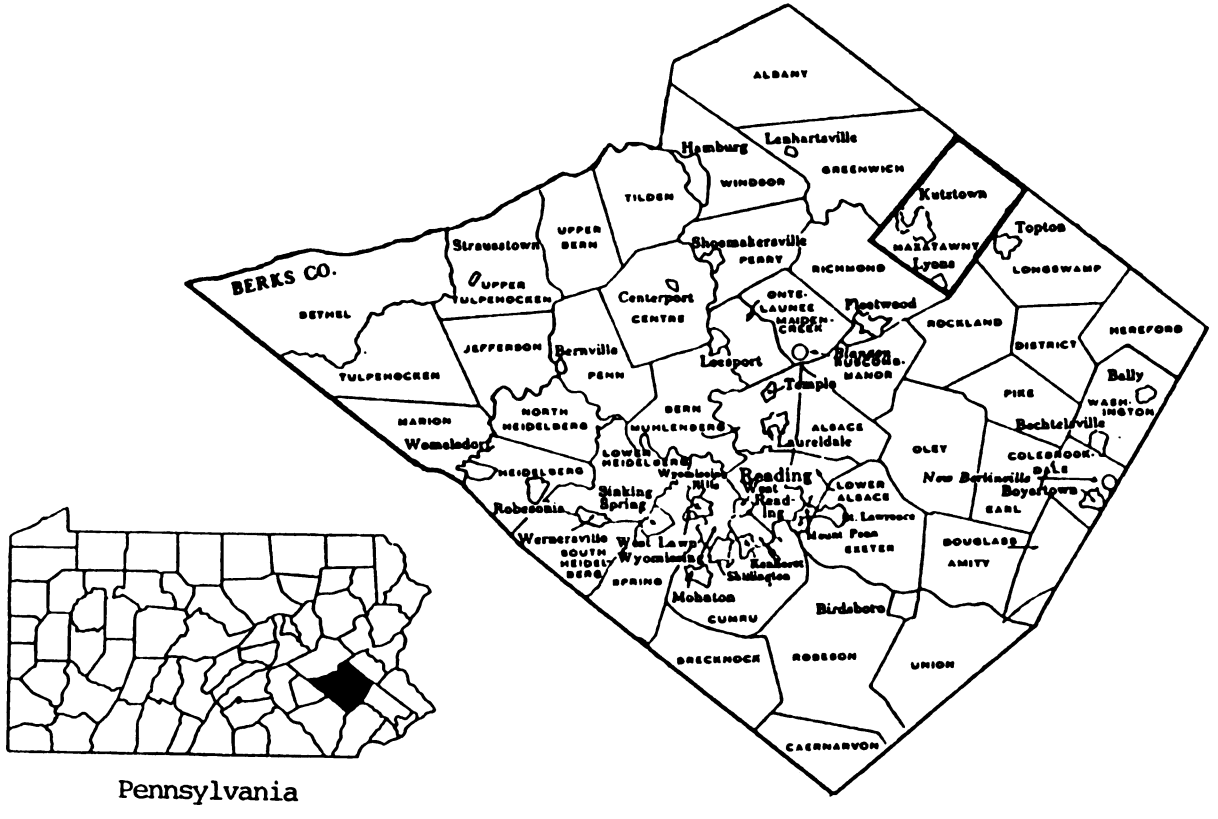


Figure 1. Location of the Rodale Research Center in Berks County, Pennsylvania.

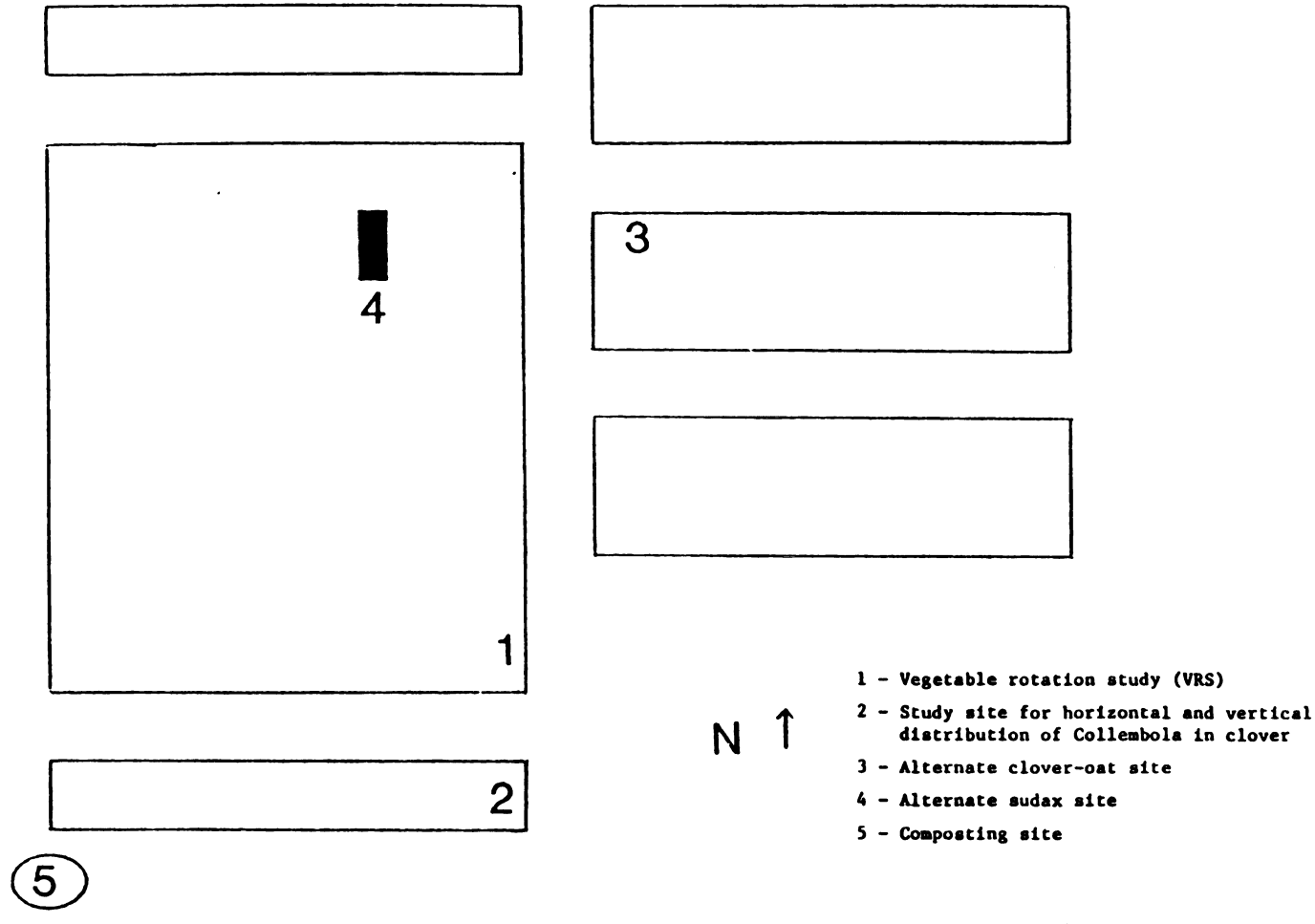


Figure 2. Rodale Research Center fields in which soil populations of Collembola were monitored.

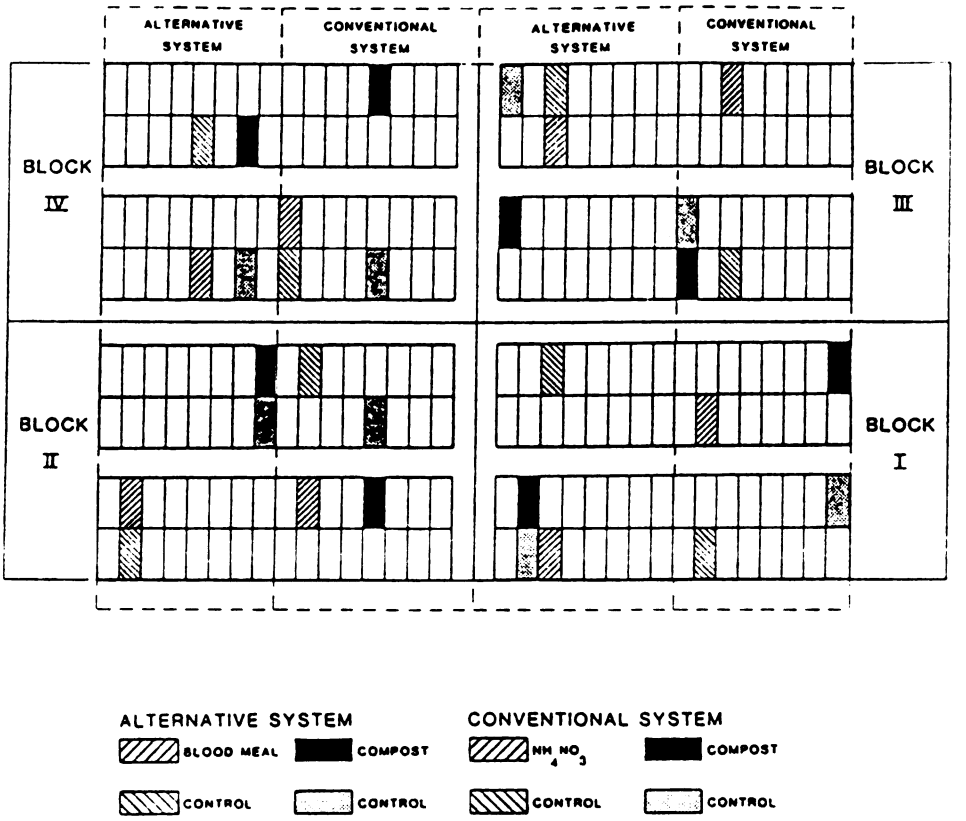


Figure 3. Experimental design of the vegetable rotation study at the Rodale Research Center, and selected rotation sequences utilized for this M.S. research.

cropping with Chinese cabbage. Each experimental unit (5m X 10m) was replicated four times in two adjacent research fields. This soil is a Fogelsville silt loam, but clay differences are apparent across replications. The site is directly south of a 8-10% slope, on a Berks shaley silt loam. Small grains were planted on the slope.

Organic and conventional agroecosystems differed with respect to method of weed control, and nitrogen source. The organic agroecosystem used cultivation for weed control, and the conventional system recieved applications of the herbicides atrazine (1983) or atrazine and Lasso (1982). Atrazine was applied at a rate of 0.49 kg ai/ha in 1983, and 1.22 kg ai/ha in 1982. Lasso was applied at a rate of 4.8 liters/ha in 1982 only.

Two rotation sequences in each agroecosystem at zero- and moderate-nitrogen fertilization rates, were selected as experimental units for this research (Figure 3). These rotations included a Chinese cabbage double-crop which was transplanted after sweet corn harvest. The organic system rotations used the nitrogen sources bloodmeal (13%) or compost (circa 1.50%). Conventional system nitrogen sources were compost or ammonium nitrate (33.5%). Fertilizers were applied at a moderate rate of 80 kg N/ha. The volume of fertilizer applied was dependent on nitrogen content of the material (Table 2).

Sweet corn (cv Merit) was seeded on May 19, 1982. Row spacing was 75.0 cm; equivalent plant population was 44,000/hectare. Each experimental unit consisted of six 10 M rows; data collection was confined to center rows. Rainfall prevented 1983 seeding until June 2; a short-season cultivar, Stardust, was planted. Chinese cabbage (cv Hikoshima Spring) was double-cropped after sweet corn harvest each season. Field operations were performed as timely as possible (Table 3 and 4).

Table 2. Per cent nitrogen, and rate of application to sweet corn, of bloodmeal, compost, and NH_4NO_3 fertilizers.

		Nitrogen Application		
			Fertilizer (kg)	
Fertilizer	N (%)	kg/ha	Plot	Hectare
Compost				
1982[1]	1.75	80	54.0	12,000
1983[2]	1.00	80	80.6	17,900
Bloodmeal	13.00	80	3.3	738
NH_4NO_3	33.50	80	1.3	285

[1] 54% moisture

[2] 56% moisture

Table 3. Schedule of field operations and soil sampling in sweet corn (1982).

Date	Julian date	Operation
April 24	114	Entire field moldboard plowed
May 1	121	Entire field disk plowed and culti-packed
May 6	126	Compost applied in organic system
May 10	130	Compost incorporated
May 19-20	139	Sweet corn seeded
May 26-27	146	Atrazine and Lasso applied to conventional system
June 9	160	Bloodmeal applied (sidedress) in organic system; applied NH_4NO_3 (1/2 rate) in conventional system
June 10	161	Bloodmeal incorporated
June 24	175	Cultivated all plots; remaining NH_4NO_3 applied to conventional system.
July 1	182	Collembola soil populations sampled
July 1-2	182	Organic system sweet corn weeded
July 7-8	188	Sweet corn hilled, both systems
July 21	202	Collembola soil populations sampled
July 24-27	205	Irrigated entire field (2.54 cm)
August 3	215	Collembola soil populations sampled
August 16-19	228	Sweet corn harvested

Table 4. Schedule of field operations and soil sampling in sweet corn (1983).

Date	Julian date	Operation
March 17	76	Collembola soil population sampled
May 6	126	Entire field mowed and moldboard plowed
May 12	132	Entire field disked
May 14	134	Entire field disked
June 1	151	All nitrogen fertilizers applied (NH_4NO_3 at 1/2 rate)
June 1	151	Entire field harrowed
June 2	152	Entire field cultivated; corn seeded
June 9	159	Atrazine applied to conventional system
June 11	161	Rotary hoed all plots
June 13	163	Rotary hoed organic system
June 23	173	Collembola soil population sampled
June 27	177	Cultivated organic system
July 1	182	NH_4NO_3 applied (sidedress at 1/2 rate) in conventional system; cultivate organic system
July 6-9	187	Entire field irrigated (2.54 cm)
July 11	192	Collembola soil population sampled
July 12	193	Cultivated organic system
July 12-15	193	Entire field irrigated (2.54 cm)
July 19-22	200	Entire field irrigated (2.54 cm)
August 1-4	213	Entire field irrigated (2.54 cm)
August 2	214	Collembola soil population sampled
August 9	221	Began sweet corn harvest
August 15	225	Collembola soil population sampled

Quantification of Collembola Soil Populations

Collembola populations were sampled on four dates in 1982 (July 1, July 21, August 3, September 5), and five times in 1983 (March 17, June 23, July 11, August 2, August 15). Sampling was completed prior to sweet corn harvest and cabbage transplanting, except on September 5, 1982. On most sampling dates, soil sampling began in the early morning and was completed before 12:00 noon.

Five in-row soil cores, 5.08 X 15.24 cm, were taken from alternate middle rows within each experimental unit. A stainless-steel corer was rotated into the soil between plants, to a depth of 15.24 cm. Diameter of the corer gradually increased over a short length, in order to relieve soil compression. Samples were inverted into plastic quart containers, and a lid was placed on each container. Samples were stored in the field for a short length of time in styrofoam coolers.

On each sampling date, 160 cores were collected. Eighty Tullgren funnels were available for extraction, therefore, two replications of 40 cores each were stored at 4 C for 24 hours before extraction. The remaining 80 soil cores were extracted immediately for 24 hours. Extraction and storage time was increased to 48 hours on March 17, 1983, only.

Soil samples were inverted and uniformly spread onto squares of window-screening in each funnel. A four-ounce collection jar, filled with 1% glycerin-95% ethanol, was placed directly beneath each funnel. Hooded 25-watt light bulbs were lowered over each funnel, and soil temperature was maintained at a maximum of 27 C with a rheostat. Collection jars were capped and removed after 24 hours, and dried soil cores were discarded. This process was repeated with stored samples.

Alcohol-specimens were rough-sorted to major taxa using a dissecting microscope at low power. After an initial period of identifying slide-mounted specimens with a phase-contrast microscope, most species were recognizable in alcohol with a high-power dissecting microscope. Specimens were frequently slide-mounted, however, to verify identification. Collembola were identified to family (Onychiuridae, Isotomidae, Entomobryidae and Sminthuridae) on the first sampling date in 1982, and to species on subsequent dates, according to Christiansen and Bellinger (1980) (Appendix 1). Other Collembola families were not collected from this site. Soil population densities of Collembola were extremely low on September 5, 1983, after sweet corn harvest, field preparation, cabbage transplanting and irrigation. These samples were not sorted due to time restrictions.

Certain experimental procedures were standard throughout this research. Soil densities of Collembola are reported as the mean number per $cm^3 \times 10^{-2}$, unless otherwise stated. Soil samples were taken to a depth of 15.24 cm, with a diameter of 5.08 cm. Other sampling procedures and the use of Tullgren funnels were standard throughout this investigation.

Extraction Efficiency—Tullgren funnel efficiency was determined in 1982 and in 1983, for both stored and immediately extracted samples. On August 23, 1982, eight soil cores were taken from an untreated sweet corn plot in the vegetable rotation study (Figure 3). Four cores were extracted immediately and four cores were stored at 4 C for 24 hours before extraction. Tullgren funnel collection jars were changed at 6-and 24-hour intervals. After 72 hours of extraction, dry soil cores were mixed with saturated sugar solution, to collect soil-trapped Collembola, and determine extraction efficiency. Collembola remaining in the

soil sample floated to the top of the sugar solution, and were collected with a 400-mesh sieve. On this date, only families were identified.

On August 15, 1983, twelve soil cores were taken from the same untreated sweet corn plot. Movement of Collembola from soil samples was monitored for 72 hours at 12-hour intervals. Collembola were extracted from fresh soil cores, and from cores stored at 4 C for 24-and 48-hours. Numbers extracted per 12-hour period were recorded, but efficiency was not determined. Data were analyzed factorially.

Standardization Procedure--Soil population density estimates obtained from stored soil samples or from samples extracted 48 hours (March 17, 1983), were adjusted to approximate densities achieved with 24 hours of extraction of fresh samples. The cumulative per cent Collembola extracted from soil cores in 72 hours, at 12-hour intervals, was plotted with extraction time. Treatments were fresh extraction, 24-and 48-hours of storage. Correlation coefficients and line equations were determined for each common species. A unique constant was obtained, from regression statistics, for each species extraction rate. Soil population densities of Collembola that were determined from stored samples, or from samples extracted for 48 hours, were multiplied by the respective species constant. This procedure standardized soil densities between replications and dates, and reduced variation caused by dissimilarities in replication handling.

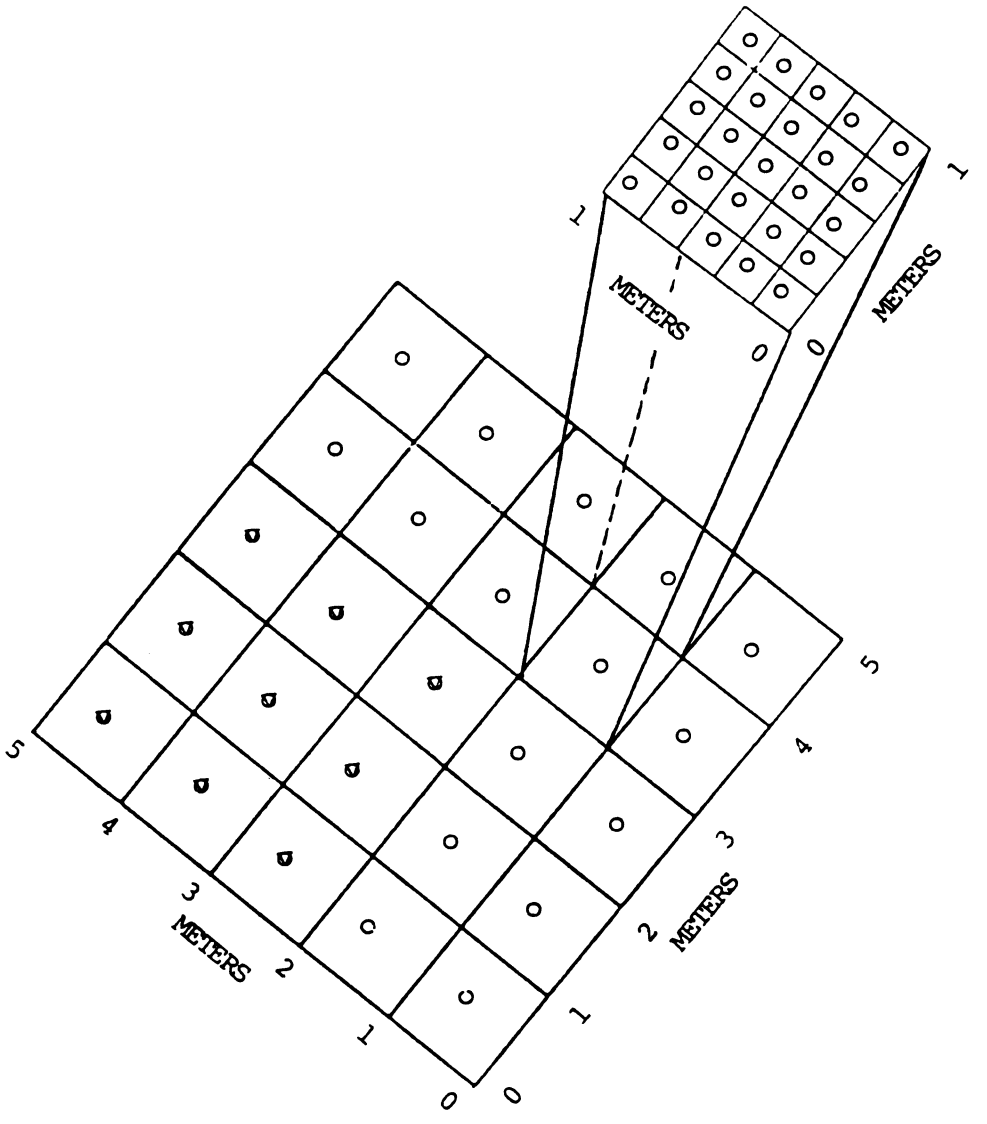
Spatial Distribution and Population Dynamics

A field test conducted at the Rodale Research Center was used to evaluate horizontal, vertical, and seasonal distribution of soil Collembola. Soil samples were taken at approximately 2-week intervals from March 24 to August 25, 1983, in a non-irrigated weedy clover field (Figure 2). This site was plowed and

reseeded in early June, necessitating relocation of the sampling area. Beginning June 16, therefore, samples were taken from a different research field that was seeded with a mixture of clover and oats earlier in the season (Figure 2).

Horizontal and vertical distribution of soil Collembola was initially determined March 24. On this date, soil samples were taken at two sampling densities: 1 core/M^2 (25 cores/25M^2) and 1 core/0.04 M^2 (25 cores/1M^2) (Figure 4). Three 5M X 5M grid areas were randomly marked in the field, and one soil core was taken per square meter. One square meter within each 5M X 5M grid was further divided into 25 sub-units (0.04 M^2 each) and one core was taken from each sub-unit. Nine cores in the upper left corner of each replicate were vertically stratified to 5.08 cm segments, and extracted individually to determine vertical distribution of Collembola. On remaining sampling dates, a 3 M X 3 M area was randomly selected in the field. One core was taken from each square meter, to monitor horizontal and seasonal distribution. On the last two sampling dates, limited soil moisture in the clover-oats field necessitated sprinkling the area with water prior to sampling. Soil samples were taken one hour after this irrigation.

Low soil moisture content at the clover-oats site also prevented accurate stratification of soil cores for estimation of vertical distribution. Separate soil cores were collected, therefore, from an alternate site. Cores were taken from a nearby irrigated and untreated sudax plot within the vegetable rotation study (Figure 2), and stratified to 5.08 cm layers before extraction. Although this site was irrigated, plant cover was similar to the clover-oat site.



o - one soil core

ø - one soil core, stratified vertically

Figure 4. Sampling design for the determination of Collembola spatial distribution in soil (1983).

Goodness of fit tests were utilized for distribution determination. Prominence values and relative prominence values were calculated for each species on each sampling date as follows:

Eq. 1. Prominence value = AD x $\sqrt{AF}$ = PV

Eq. 2. Absolute density = absolute numbers per unit sample = AD

Eq. 3. Absolute frequency = $(n_i/n_t) \times 100$ = AF

where,

n_i = number of samples containing a species

n_t = number of samples collected.

Soil temperature and gravimetric soil moisture to a depth of 15.24 cm were recorded each sampling date.

Collembola Associated with Compost

On March 23, 1983, compost samples were taken from an undisturbed pile at the Rodale Research Center, to identify the number and population density of Collembola species present in compost (Figure 2). On June 22, populations were sampled again at the same site. On this date, cores were taken at 15.2 and 30.5 cm depths from the perimeter, at approximately mid-pile height. Collembola were extracted immediately in Tullgren funnels, and species were determined.

Environmental Monitoring

Daily minimim and maximum air temperature at the Rodale Research Center were recorded in 1982 and 1983 (Appendix 4 and 5). In 1983, soil temperature and moisture to a depth of 15.24 cm was monitored weekly in the clover-oat and irrigated sweet corn sites (Appendix 6 and 7). Precipitation was monitored both seasons (Appendix 8 and 9). Soil nutrient status was determined prior to initial cultivation and after harvest in 1982 only (Appendix 10).

Agroecosystem Analysis

Two-way analysis of variance was used to detect differences in soil population densities among sampling dates and treatments. This analysis was performed with the sum of soil Collembola densities on all dates in 1982 and 1983. Analysis of variance was performed on densities of the most prominent Collembola groups. Soil densities of Entomobryidae, Isotomidae, Isotoma notabilis, Isotomiella minor, Folsomides americanus Denis, and Tullbergia yosiii were analysed independently. Treatment means were separated with orthogonal comparisons.

Orthogonal Comparisons--Orthogonal comparisons provide investigators with a statistical method for answering specific questions concerning a set of data. This analysis partitions the degrees of freedom and sums of squares for treatment effects into pertinent single degrees of freedom. Advantages of orthogonal comparisons for the purpose of separating treatment means are:

1. Sensitivity is great,
2. Specific questions that are designed into the treatments can be examined.

Three rules must be met in order for planned comparisons to be considered orthogonal, or independent:

1. Coefficients within each comparison set must sum to zero ($c_{i1} = 0$),
2. The sum of the products of the corresponding coefficients of any two comparisons must sum to zero ($c_{i1}c_{i2} = 0$),
3. There are exactly (t - 1) comparisons in one complete orthogonal table,

where,

c_{ij} = coefficients of a comparison

t = number of treatments.

A table of orthogonal coefficients may be constructed by asking planned questions, or stating hypotheses, regarding relationships and interactions of the data. Treatments are arranged horizontally as a table heading, as in Table 5. Each comparison, or hypothesis, appears as a different line in the table, and consists of positive or negative coefficients that contrast, or separate, treatment totals. Each comparison has one degree of freedom.

In this investigation, a table of orthogonal comparisons was constructed that meets all rules of the analysis (Table 5). Questions regarding agroecosystem effects in 1982 and 1983 were:

1. In the absence of a nitrogen input, were soil population densities of Collembola significantly different in organic and conventional agroecosystems?,
2. Were soil population densities of Collembola influenced by organic system nitrogen input?,
3. Were soil population densities of Collembola influenced by conventional system nitrogen input?,
4. In the presence of nitrogen input, were soil population densities of Collembola significantly different in organic and conventional agroecosystems?,
5. Disregarding agroecosystem, were soil populations of Collembola influenced by nitrogen input?,
6. Was treatment randomization effective in reducing population differences caused by experimental design in the organic system?,

Table 5. Orthogonal comparisons utilized for separation of Collembola population mean densities in sweet corn agroecosystems.

	Sweet corn agroecosystem							
	Organic				Conventional			
Comparison	Control	Bloodmeal	Control	Compost	Control	NH_4NO_3	Control	Compost
1	+1	--	+1	--	-1	--	-1	--
2	--	+1	--	-1	--	--	--	--
3	--	--	--	--	--	+1	--	-1
4	--	+1	--	+1	--	-1	--	-1
5	+1	-1	+1	-1	+1	-1	+1	-1
6	+1	--	-1	--	--	--	--	--
7	--	--	--	--	+1	--	-1	--

7. Was treatment randomization effective in reducing population differences caused by experimental design in the conventional system?

Sums of squares were calculated for each comparison:

Eq. 1. $SS = (c_i Y_{i.})^2 / r\, c_i^2$

where,

c_i = comparison coefficients (Table 5),

$Y_{i.}$ = treatment totals,

r = number of replications.

Mean squares are equal to each sum of squares, since each comparison has only one degree of freedom. An F-test was conducted by dividing each mean square by the mean square error, and using a common table of the F distribution for significance determination (Steel and Torrie 1980).

RESULTS

Quantification of Collembola Soil Populations

Extraction Efficiency--The portion of the Collembola population recovered from soil cores in Tullgren funnels increased with time in the 1982 test (Table 6). The mean extraction efficiency for Collembola, from fresh soil samples, was 42% after 24 hours. Extraction for 48 hours resulted in recovery of 79% of the population. After 78 hours of extraction, 83% were recovered. Sample storage at 4 C for 24 hours resulted in increases of 55%, 10%, and 10% of the number of Collembola recovered from samples extracted for 24, 48 and 78 hours respectively. Extraction efficiency varied among Collembola families (Table 6). In this experiment, F. americanus was mistakenly identified and included in data for the Onychiuridae.

Table 6. Extraction efficiency of Tullgren funnels for the determination of Collembola soil population densities.

	Collembola recovered (%)[1]					
	Immediate extraction (hrs)			Stored @ 4° C 24 hours (hrs)		
Taxon	24	48	78	24	48	78
Onychiuridae[2]	31	67	74	55	83	88
Isotomidae[3]	69	97	100	81	100	100
Entomobryidae	53	93	93	92	96	97
Total collembola	42	79	83	65	87	91

[1]August 16, 1982

[2]Includes Folsomides americanus (Isotomidae)

[3]Excludes F. americanus

The rate of extraction of Collembola with the Tullgren funnel varied with storage conditions and species in 1983. Storage of soil samples did not significantly alter extraction rates of most Collembola taxa. Significant (P=0.05) differences in extraction rate due to storage were observed for I. minor (Table 7). Greater densities of this species were obtained from soil cores stored at 4 C for 24 hours before extraction. Densities were 2.5 and 3.3 times greater from stored samples when compared with fresh samples, after 12- and 48-hours of extraction, respectively.

The length of the extraction period significantly (P=0.06) influenced density estimates of most species (Table 7). Collembola extraction efficiency was greatest in samples stored at 4 C for 24-hours (Figure 5). Storage at this temperature for 48-hours, however, lowered population density estimates.

Extraction rate of I. notabilis fluctuated with hours of extraction (Figure 6). After 48 hours of extraction, densities were greatest from samples stored 24 hours. This trend reversed after 60 hours of extraction, however, when fresh extraction yielded greatest densities of this species. Optimal extraction rates for I. minor, T. yosiii, and P. violenta were achieved after 24-hours of sample storage at 4 C (Figures 7, 8, and 9). Sample storage, however, depressed the extraction rate of F. americanus; greatest population densities of this species were obtained with fresh extraction (Figure 10).

Standardization Procedures--The number of Collembola extracted from soil cores in Tullgren funnels increased with extraction hours. This positive correlation was significant (P = 0.06) for most species (Table 8). When soil populations were low, or if individuals were extracted only during the initial 12

Table 7. Influence of soil sample storage, and length of Tullgren extraction, on determination of Collembola soil population density.

	Sample storage (df=2)		Extraction (hrs) (df=5)	
Taxon	F-statistic	Significance	F-statistic	Significance
P. violenta	0.95	NS[1]	10.24	0.01
Isotomidae	0.25	NS	9.25	0.01
I. notabilis	0.07	NS	1.40	NS
I. minor	3.92	0.05	2.16	NS
F. americanus	0.71	NS	7.77	0.01
T. yosiii	2.57	NS	1.57	NS

[1]Level of significance is greater than 0.05.

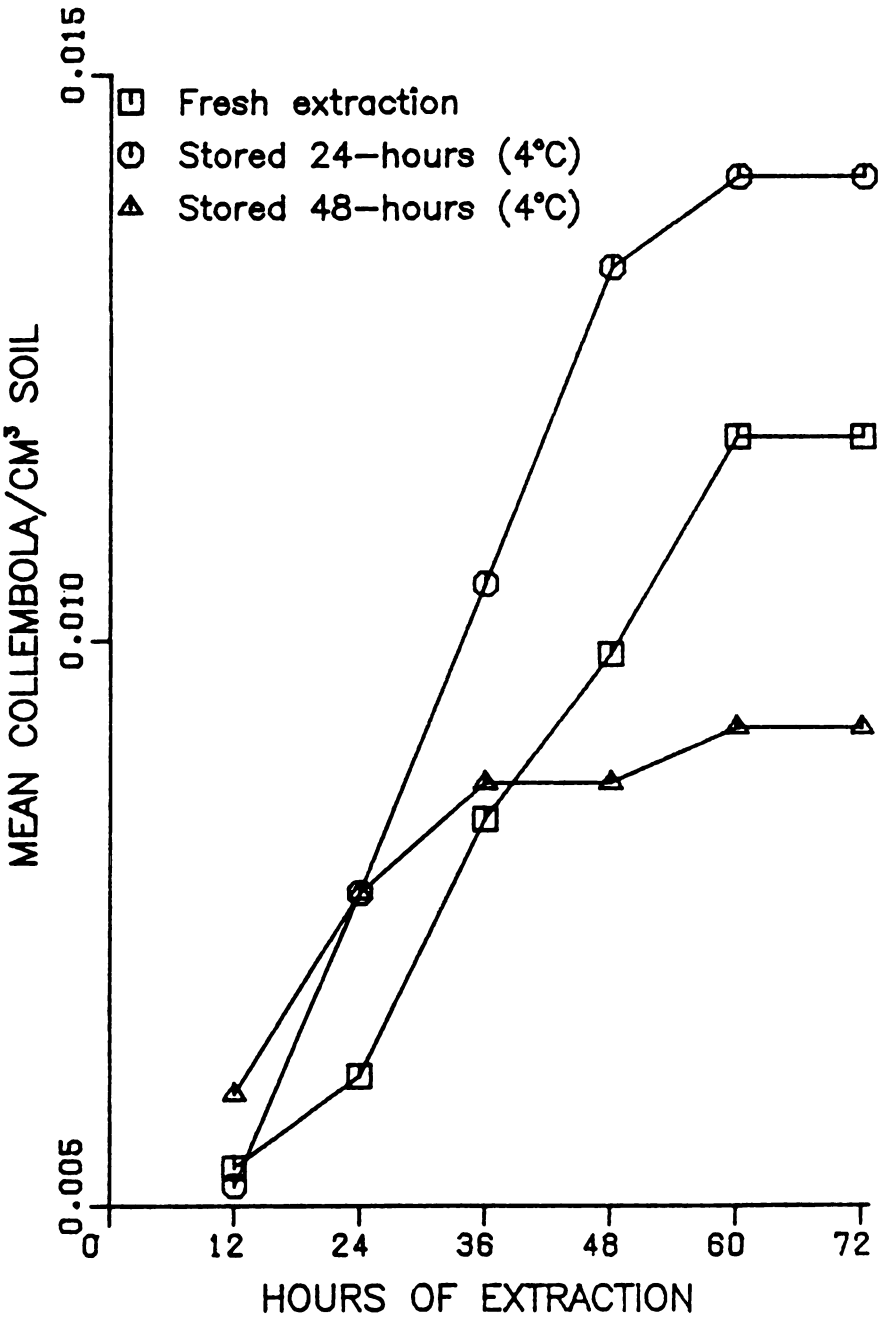


Figure 5. Extraction rate of Collembola from fresh and stored soil samples in Tullgren funnels.

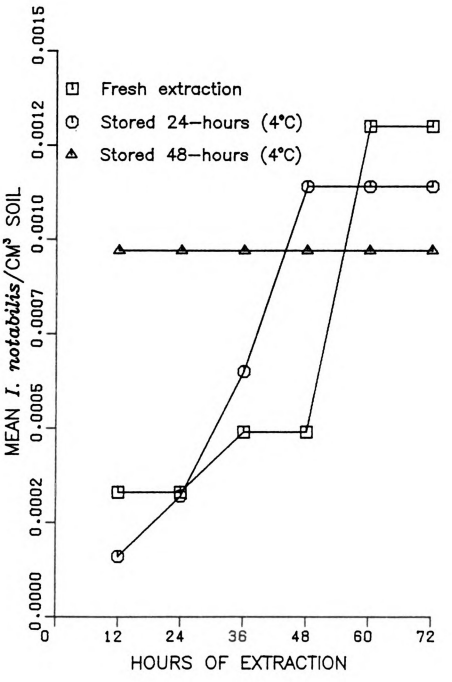


Figure 6. Extraction rate of I. notabilis from fresh and stored soil samples in Tullgren funnels.

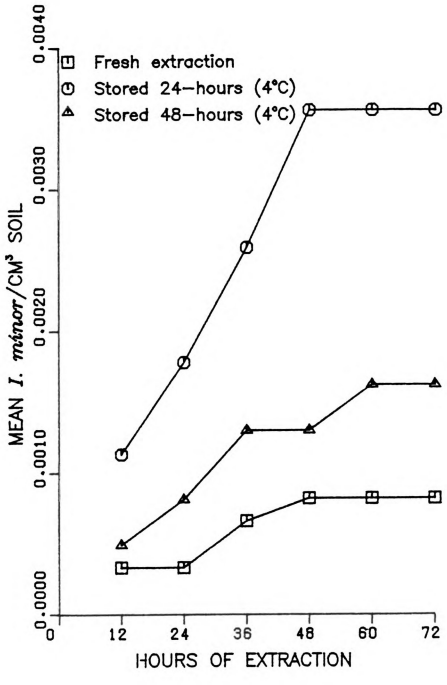


Figure 7. Extraction rate of I. minor from fresh and stored soil samples in Tullgren funnels.

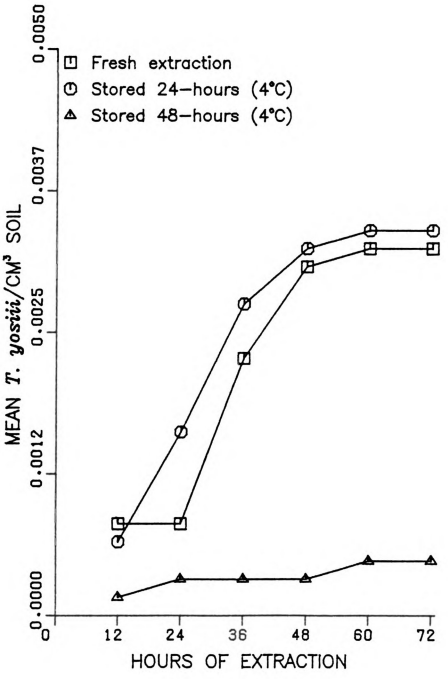


Figure 8. Extraction rate of T. yosiii from fresh and stored soil samples in Tullgren funnels.

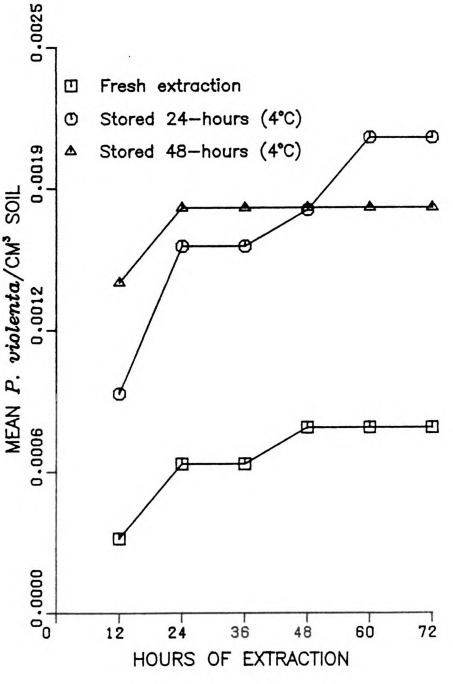


Figure 9. Extraction rate of P. violenta from fresh and stored soil samples in Tullgren funnels.

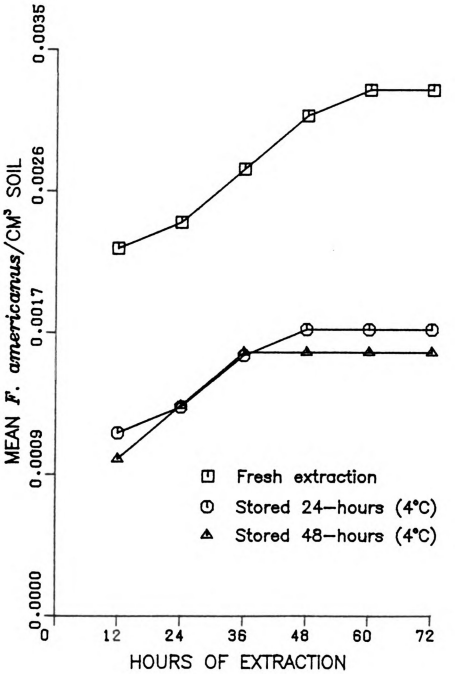


Figure 10. Extraction rate of F. americanus from fresh and stored soil samples in Tullgren funnels.

Table 8. Regression equations for soil population densities of Collembola extracted by Tullgren funnels, and compared with hours of extraction and sample storage.

Taxon	Storage at 4° C	Regression equation	R	K^1 (hrs)^2 24	48
Entomobryidae	0	Y = 0.57 + 0.01 X	0.369[a]		0.76
	24	Y = 1.50 + 0.03 X	0.929[b]	0.39	
	48	Y = 2.42 + 0.01 X	0.655		0.31
P. violenta	0	Y = 0.57 + 0.01 X	0.365[a]	0.39	0.76
	24	Y = 1.50 + 0.03 X	0.929[b]	0.39	
	48	Y = 2.50 + 0.01 X	0.655		0.29
Isotomidae	0	Y = 5.22 + 0.08 X	0.983[c]		0.79
	24	Y = 3.88 + 0.15 X	0.954[b]	0.98	
	48	Y = 6.99 + 0.07 X	0.361[a]		0.69
I. notabilis	0	Y = -0.12 + 0.03 X	0.892[a]		0.45
	24	Y = -0.03 + 0.03 X	0.939[b]	0.98	
	48[d]				
F. americanus	0	Y = 3.17 + 0.03 X	0.976[b]		0.85
	24	Y = 0.89 + 0.03 X	0.851[a]	2.30	
	48	Y = 1.60 + 0.02 X	0.831[a]		1.67
I. minor	0	Y = 0.33 + 0.02 X	0.908[a]		0.66
	24	Y = 1.32 + 0.07 X	0.937[b]	0.24	
	48	Y = 0.58 + 0.03 X	0.953[b]		0.34
I. yosii	0	Y = 0.33 + 0.07 X	0.929[b]		0.34
	24	Y = 0.85 + 0.07 X	0.923[b]	0.82	
	48	Y = 0.23 + 0.01 X	0.917[b]		3.45
Total Collembola	0	Y = 6.37 + 0.17 X	0.973[b]		0.72
	24	Y = 6.48 + 0.24 X	0.956[b]	0.84	
	48	Y = 9.95 + 0.09 X	0.856[a]		0.73

[1]Multiplicative constant for standardization of Collembola soil densities. K is utilized to obtain a Collembola soil density that approximates fresh extraction for 24 hours, if the soil sample was stored for 24 or 48 hours, or if the sample was extracted for 48 hours.

[2]Hours of extraction

[a]P = 0.05

[b]P = 0.01

[c]P = 0.001

[d]Individuals were not collected after 12 hours of extraction.

hours of extraction, a relationship between estimated soil density and extraction rate was not noticeable. For these reasons, a significant relationship between extraction rate and hours was not observed for P. violenta and I. notabilis (Table 8).

Spatial Distribution and Population Dynamics

Soil population densities of I. notabilis, I. minor, and Tullbergia yosiii associated with clover fit a negative binomial distribution (P=0.05) on most sampling dates, at both sampling densities. Poisson distributions (P=0.05) were common when soil densities were low.

Soil densities and prominence values associated with these species fluctuated seasonally. Population densities of I. notabilis were greatest on June 1 (Table 9). This species made up the greatest proportion of the Collembola population on this date, when relative prominence and soil density were 38.07 and 5.87 respectively (Appendix 11). Densities declined when the sampling site was relocated to a drier clover-oats field on June 16. The horizontal distribution of I. notabilis was random 50% of the season and clumped on remaining sample dates (P=0.05). Random distribution was most prominent late in the season (Table 9). I. notabilis was the second most prominent species encountered in clover in the 1983 season (Appendix 10).

Soil densities of I. minor peaked on June 1, at a density of 0.42, however, soil densities fluctuated greatly during the sampling period (Table 10). Relative prominence of this species on June 1 was 36.8, and most often ranked greater than third place (Appendix 11). Soil populations of this species fit a negative binomial distribution (P=0.05) on all dates except July 1 and July 28. On these dates the distribution was random (P=0.05, Table 10).

Table 9. Seasonal horizontal soil distribution of I. notabilis in clover, and clover-oats, to a soil depth of 15.24 cm.

Sampling date[a] (Julian date)		I. notabilis per 1×10^{-2} cm^3	s^2	Kolmogorov-Smirnov Statistic[b]	Distribution[c]
March 24	(83)[d]	0.25	6.72	0.0697	Nb
April 7	(97)[d]	0.09	0.13	0.0444	Nb
April 26	(116)[d]	0.03	0.02	0.8562	Poi
May 12	(133)[d]	0.32	1.29	0.1008	Nb
June 1	(152)[d]	0.40	1.34	0.0525	Nb
June 16	(167)[e]	0.02	0.02	0.4999	Poi
July 1	(182)[e]	0.04	0.03	0.0245	Nb
July 15	(196)[e]	0.01	0.03	0.0618	Nb
July 28	(209)[e]	0.04	0.03	0.0690	Poi
August 11	(223)[e]	0.02	0.02	0.0500	Poi
August 25	(237)[e]	0.01	0.01	0.0059	Poi

[a] 1983

[b] P=0.05

[c] Nb = Negative binomial; Poi = Poison

[d] Weedy clover site (Figure 2)

[e] Clover-oats site (Figure 2)

Table 10. Seasonal horizontal distribution of I. minor in clover, and clover-oats, to a soil depth of 15.24 cm.

Sampling date[a] (Julian date)		I. minor per 1×10^{-2} cm^3	s^2	Kolmogorov-Smirnov Statistic[b]	Distribution
March 24	(83)[d]	0.14	0.44	0.0807	Nb
April 7	(97)[d]	0	0		
April 26	(116)[d]	0.22	0.54	0.0847	Nb
May 12	(133)[d]	0.05	0.08	0.0354	Nb
June 1	(152)[d]	0.42	2.98	0.1259	Nb
June 16	(167)[e]	0	0		
July 1	(182)[e]	0.01	0.01	0.0060	Poi
July 15	(196)[e]	0	0		
July 28	(209)[e]	0.01	0.01	0.0060	Poi
August 11	(223)[e]	0	0		
August 25	(237)[e]	0.03	0.07	0.0600	Nb

[a] 1983

[b] P=0.05

[c] Nb = Negative binomial; Poi = Poison

[d] Weedy clover site (Figure 2)

[e] Clover-oats site (Figure 2)

T. yosiii was the most prominent species in clover during the sampling period (Appendix 11). Relative prominence peaked at 78.8 on April 7. Soil densities were greatest on March 24, when the density was 1.21, and then declined during the sampling period (Table 11). T. yosiii soil densities were aggregated (P=0.05) on all dates except August 11, when distribution was random (P=0.05).

On March 24, soil population densites of I. notabilis, I. minor, and T. yosiii were aggregatelly distributed for both of the sampling densities (Figures 11 - 19). Population density fluctuations within the sampling area form distinct aggregations.

Other Collembola species were commonly collected at low densities, or only infrequently from the clover sites (Appendix 11). Sminthuridae were collected infrequently, but more often than from the cultivated sweet corn site. Soil Entomobyidae densities were low initially, but this was often the only Collembola group collected later in the season. A diversity of Isotomidae were collected on most dates.

Population distribution of I. notabilis, I. minor, and T. yosiii were aggreated (P=0.05) at soil depths of 0-5.08, 5.08-10.16, and 10.16-15.24 cm. When low population densities were recovered, vertical distribution most often trended towards randomness. I. notabilis population densities were greatest at the soil surface on March 24, and at 10.16-15.24 and 5.08-10.16 cm on June 22 and July 25, respectively. Individuals were collected from the surface layer only on September 1 (Table 12). This species had the greatest relative prominence at 5.08-15.24 cm on June 22, at 0-10.16 cm on July 26, and at 0-5.08 cm on September 1 (Appendix 12).

Table 11. Seasonal horizontal distribution of T. yosiii in clover, and clover-oats, to a soil depth of 15.24 cm.

Sampling date[a] (Julian date)		T. yosiii per 1×10^{-2} cm^3	s^2	Kolmogorov-Smirnov Statistic[b]	Distribution
March 24	(83)[d]	1.21	15.61	0.1062	Nb
April 7	(97)[d]	0.47	2.64	0.1206	Nb
April 26	(116)[d]	0.09	0.29	0.0914	Nb
May 12	(133)[d]	0.40	3.55	0.0948	Nb
June 1	(152)[d]	0.19	0.65	0.1194	Nb
June 16	(167)[e]	0.04	0.07	0.0582	Nb
July 1	(182)[e]	0.14	0.29	0.1009	Nb
July 15	(196)[e]	0.03	0.05	0.1200	Nb
July 28	(209)[e]	0.06	0.11	0.0620	Nb
August 11	(223)[e]	0.01	0.01	0.0060	Poi
August 25	(237)[e]	0.01	0.03	0.0618	Nb

[a] 1983

[b] P=0.05

[c] Nb = Negative binomial; Poi = Poison

[d] Weedy clover site (Figure 2)

[e] Clover-oats site (Figure 2)

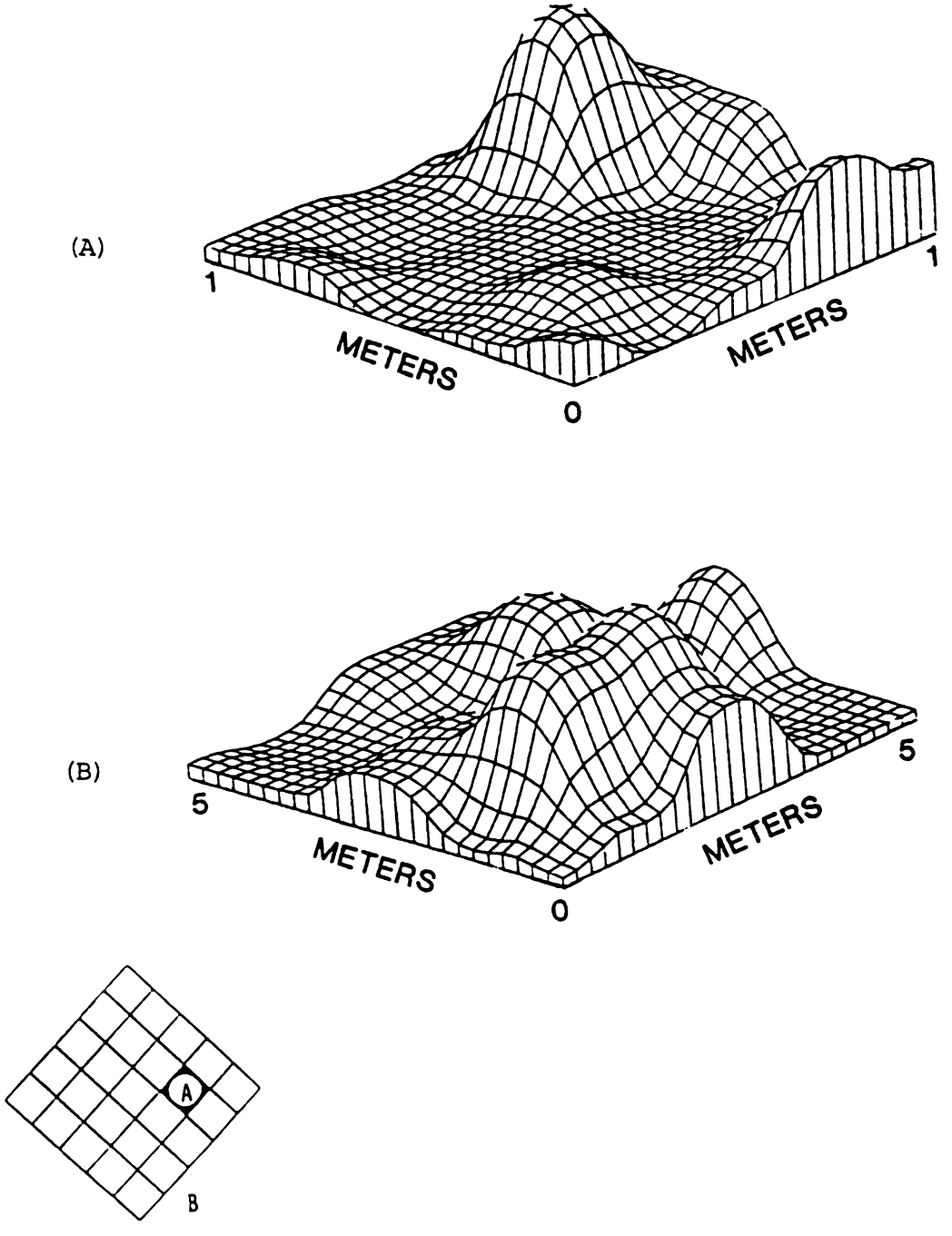


Figure 11. Horizontal soil population distribution of I. notabilis in clover on March 24, 1983, at two sampling densities: (A) 25 samples/M^2, and (B) 1 sample/M^2 (Replication I).

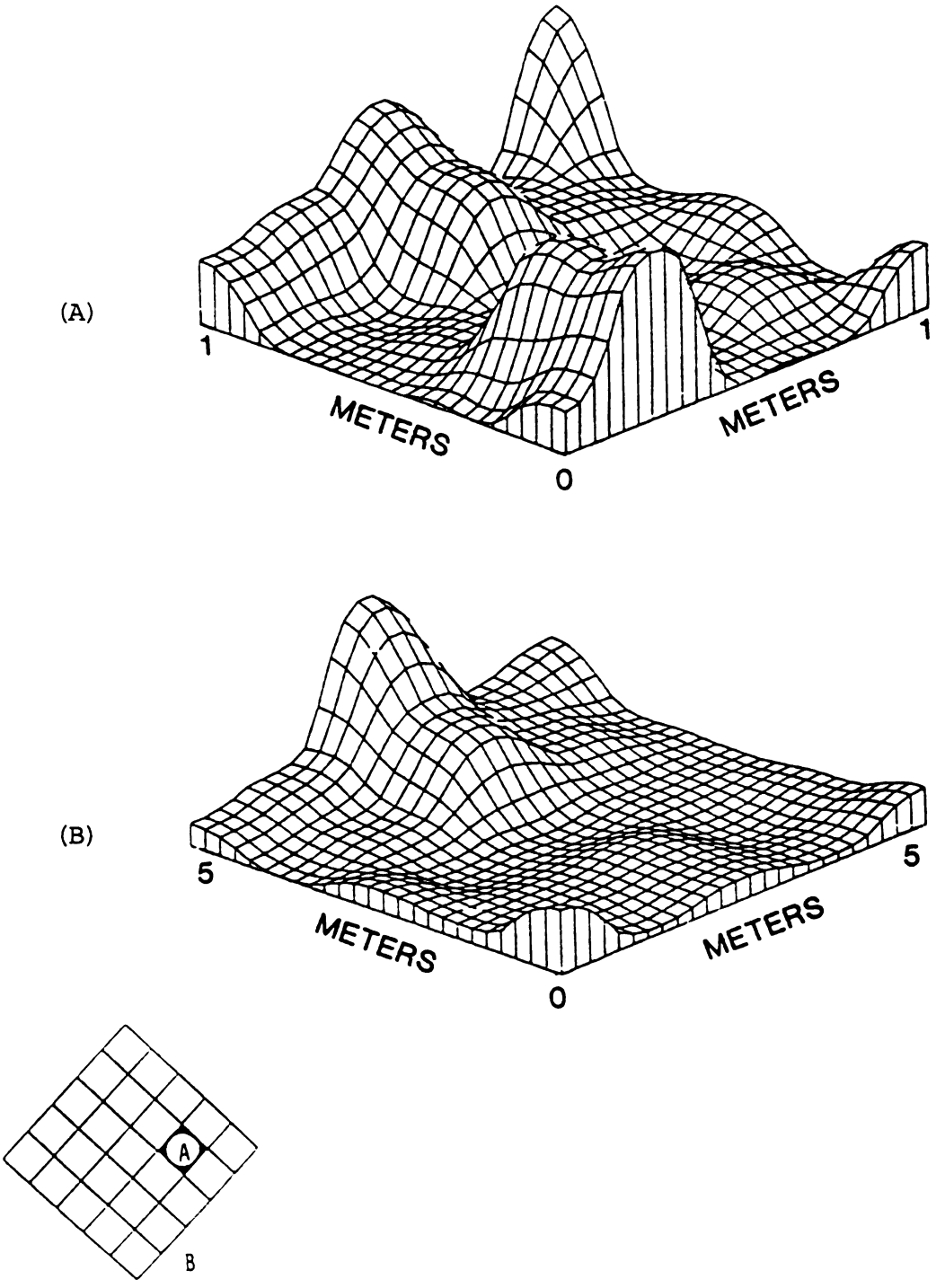


Figure 12. Horizontal soil population distribution of I. notabilis in clover on March 24, 1983, at two sampling densities: (A) 25 samples/M^2, and (B) 1 sample/M^2 (Replication II).

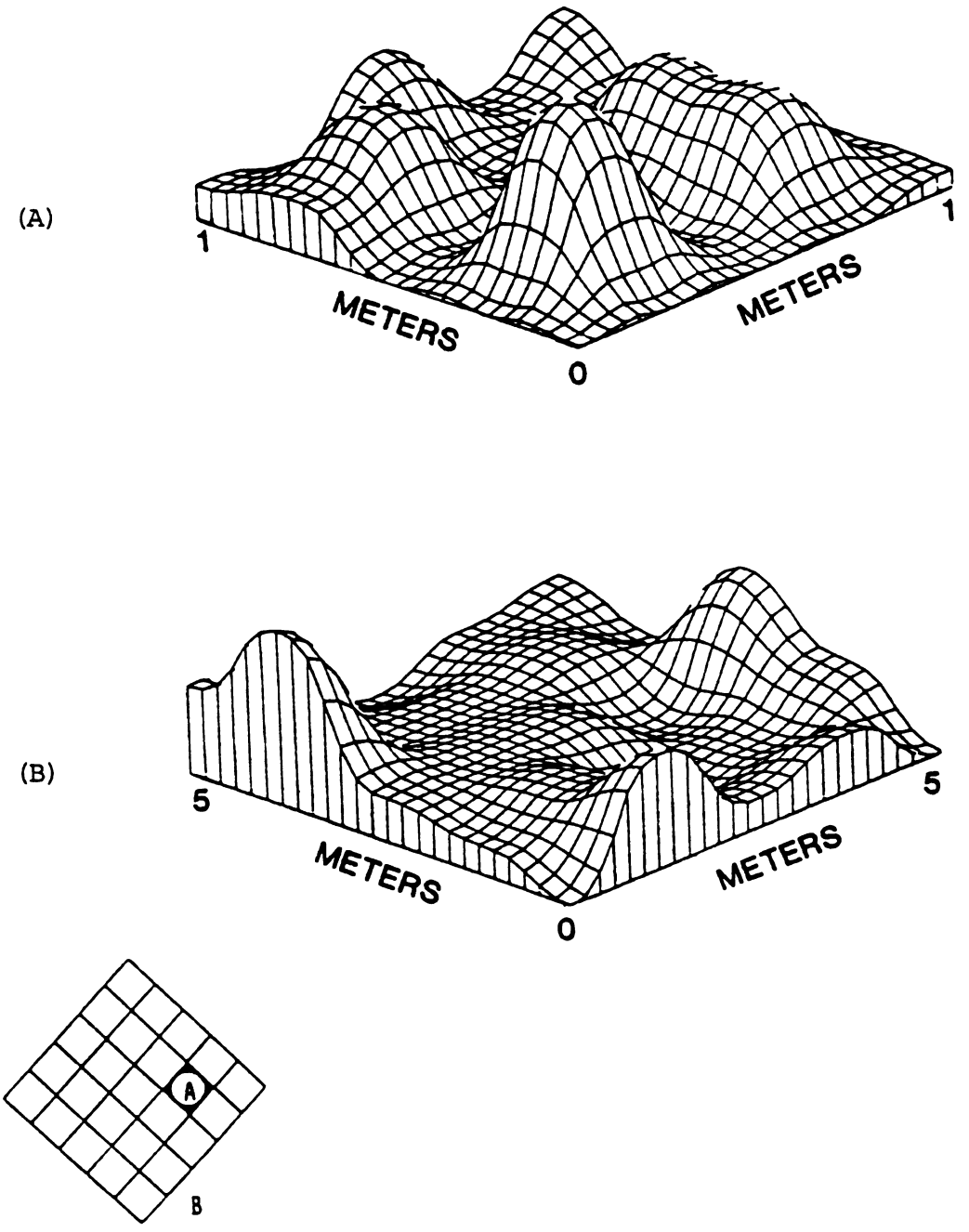


Figure 13. Horizontal soil population distribution of I. notabilis in clover on March 24, 1983, at two sampling densities: (A) 25 samples/M^2, and (B) 1 sample/M^2 (Replication III).

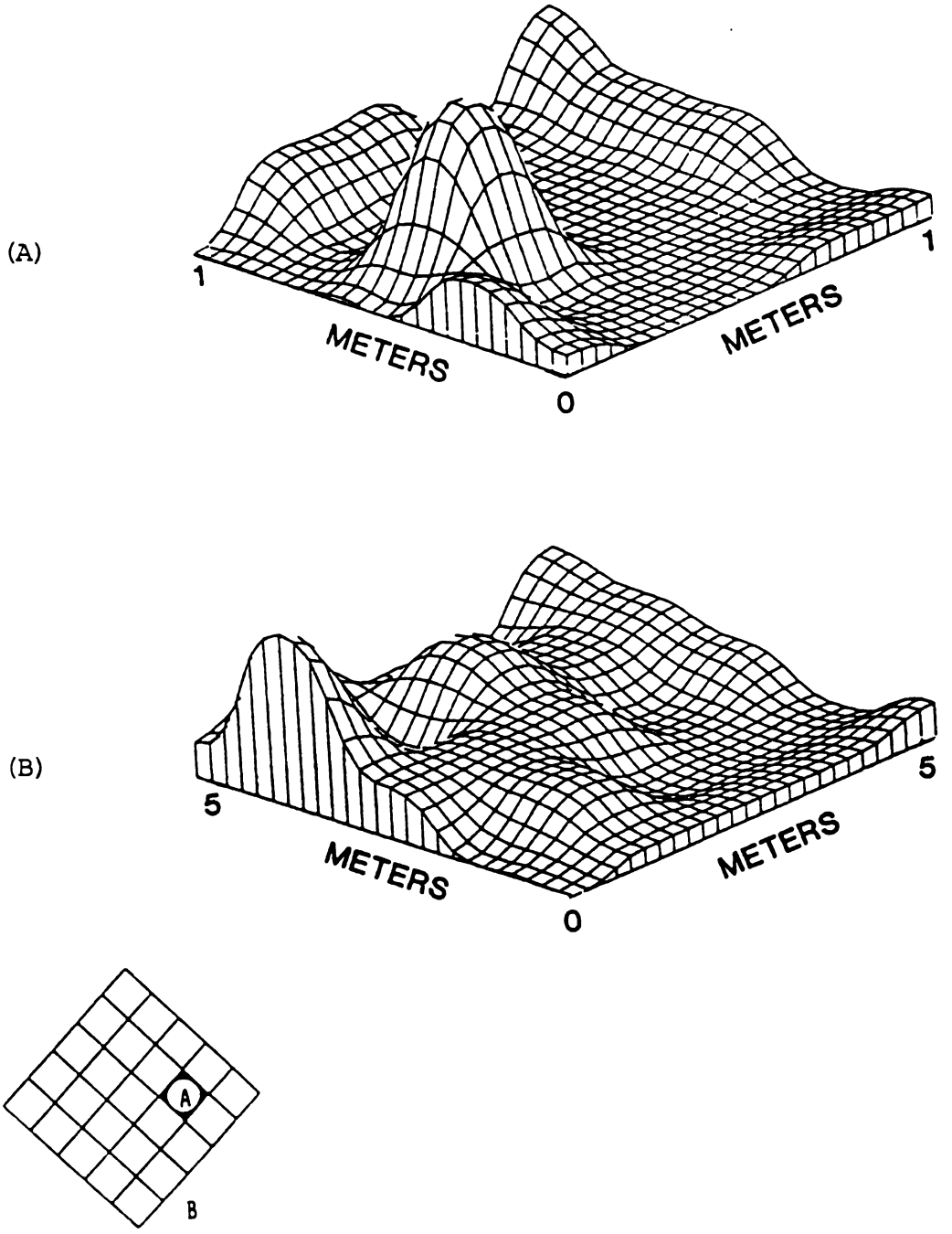


Figure 14. Horizontal soil population distribution of I. minor in clover on March 24, 1983, at two sampling densities: (A) 25 samples/M^2, and (B) 1 sample/M^2 (Replication I).

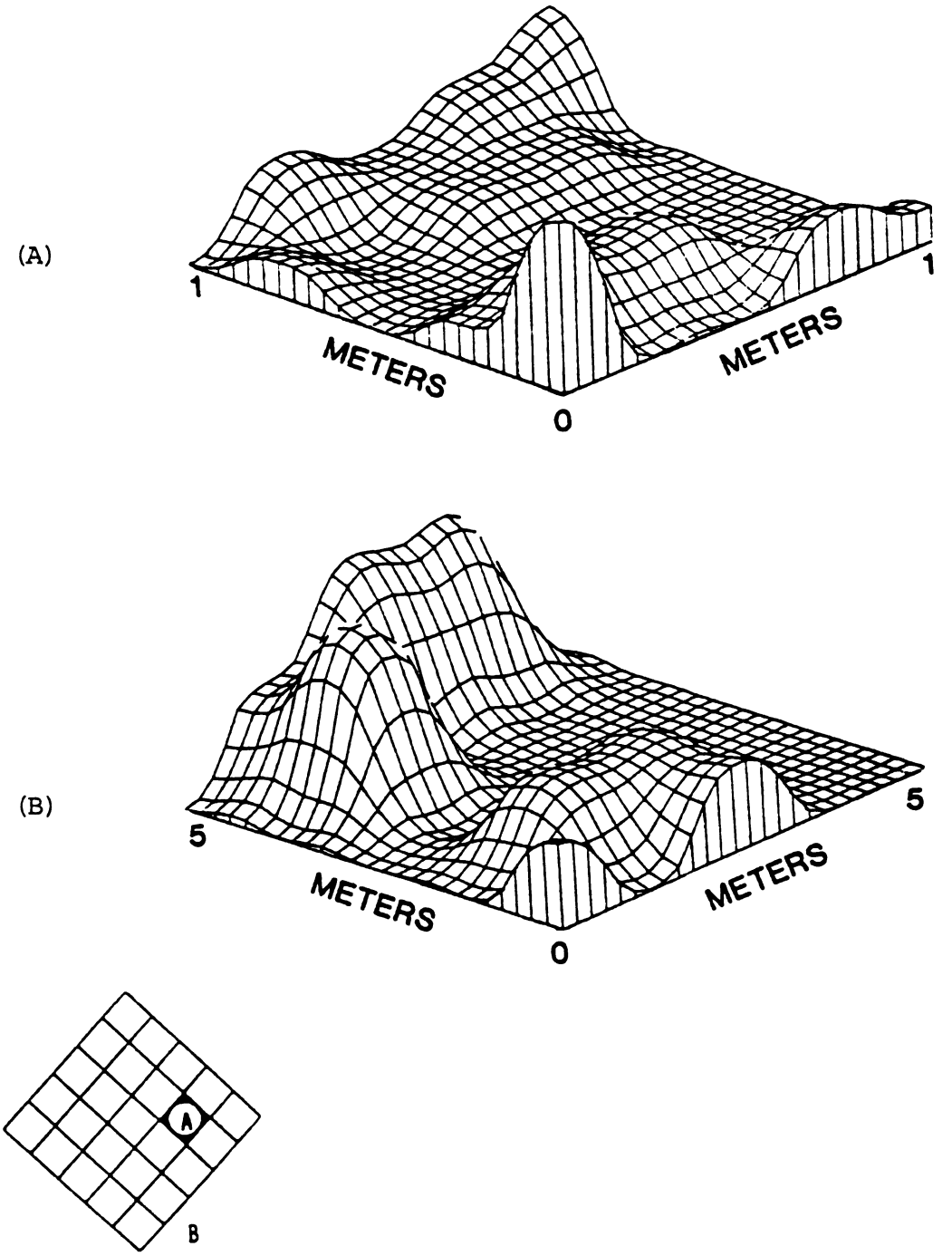


Figure 15. Horizontal soil population distribution of I. minor in clover on March 24, 1983, at two sampling densities: (A) 25 samples/M^2, and (B) 1 sample/M^2 (Replication II).

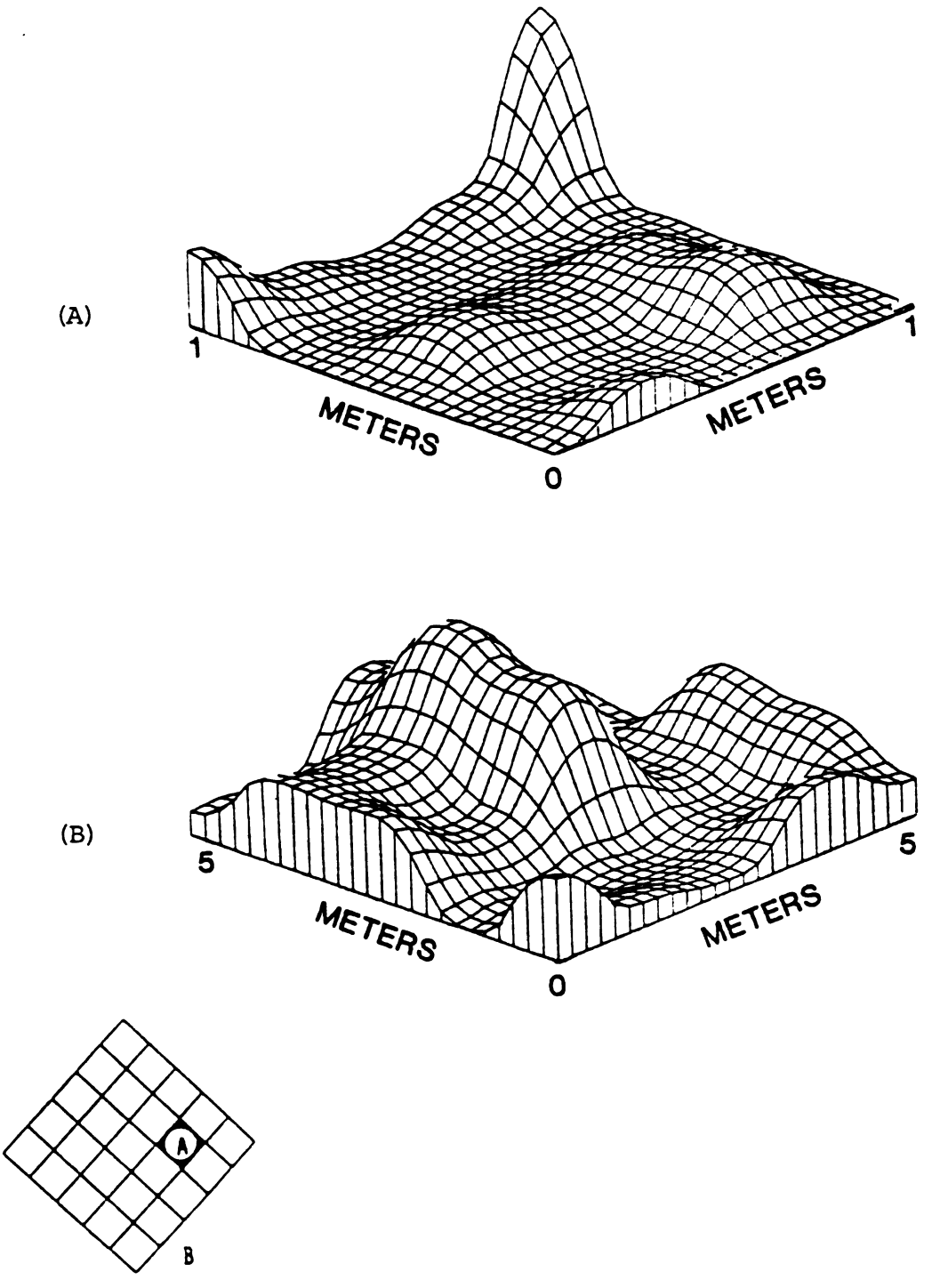


Figure 16. Horizontal soil population distribution of I. minor in clover on March 24, 1983, at two sampling densities: (A) 25 samples/M^2, and (B) 1 sample/M^2 (Replication III).

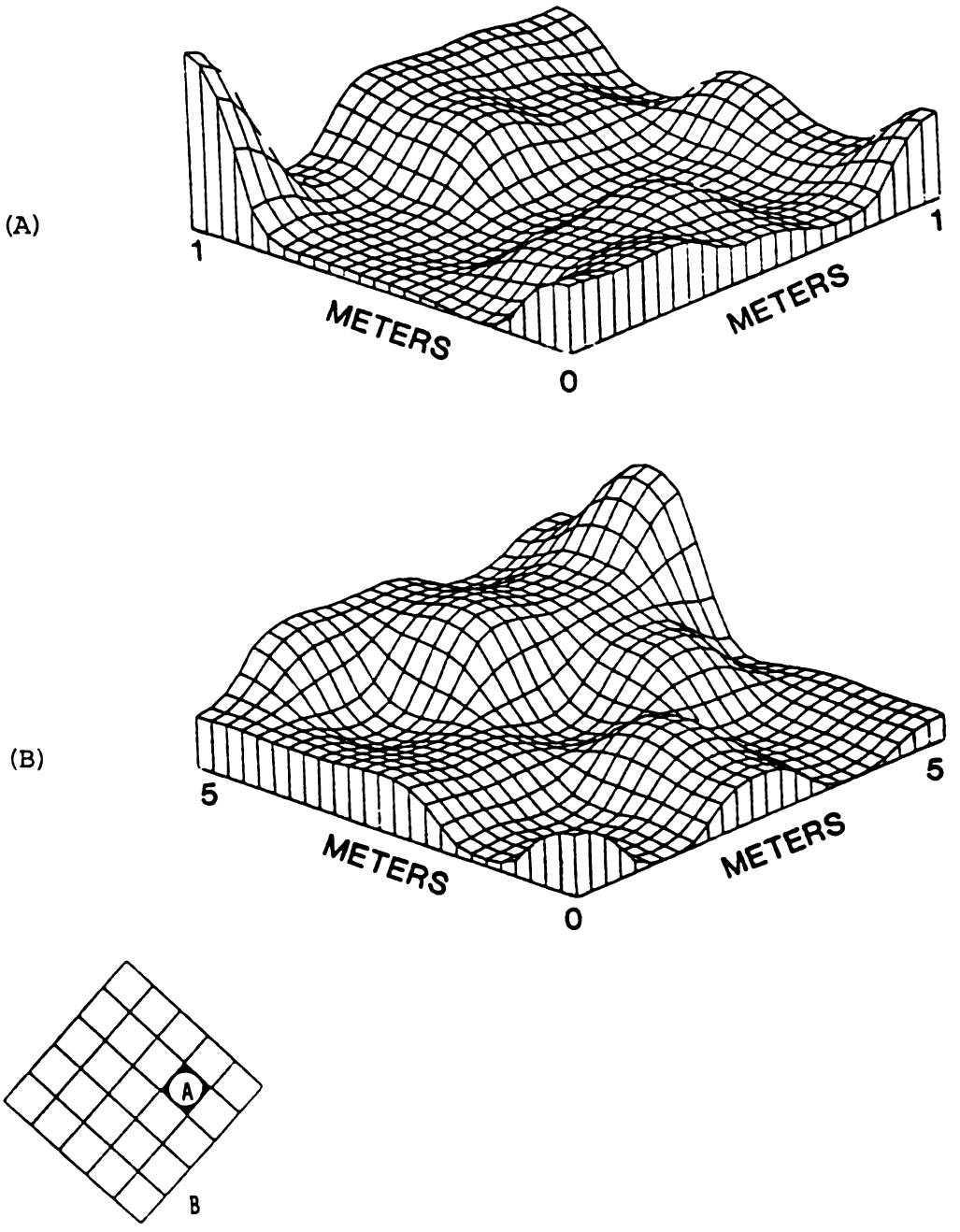


Figure 17. Horizontal soil population distribution of T. yosiii in clover on March 24, 1983, at two sampling densities: (A) 25 samples/M^2, and (B) 1 sample/M^2 (Replication I).

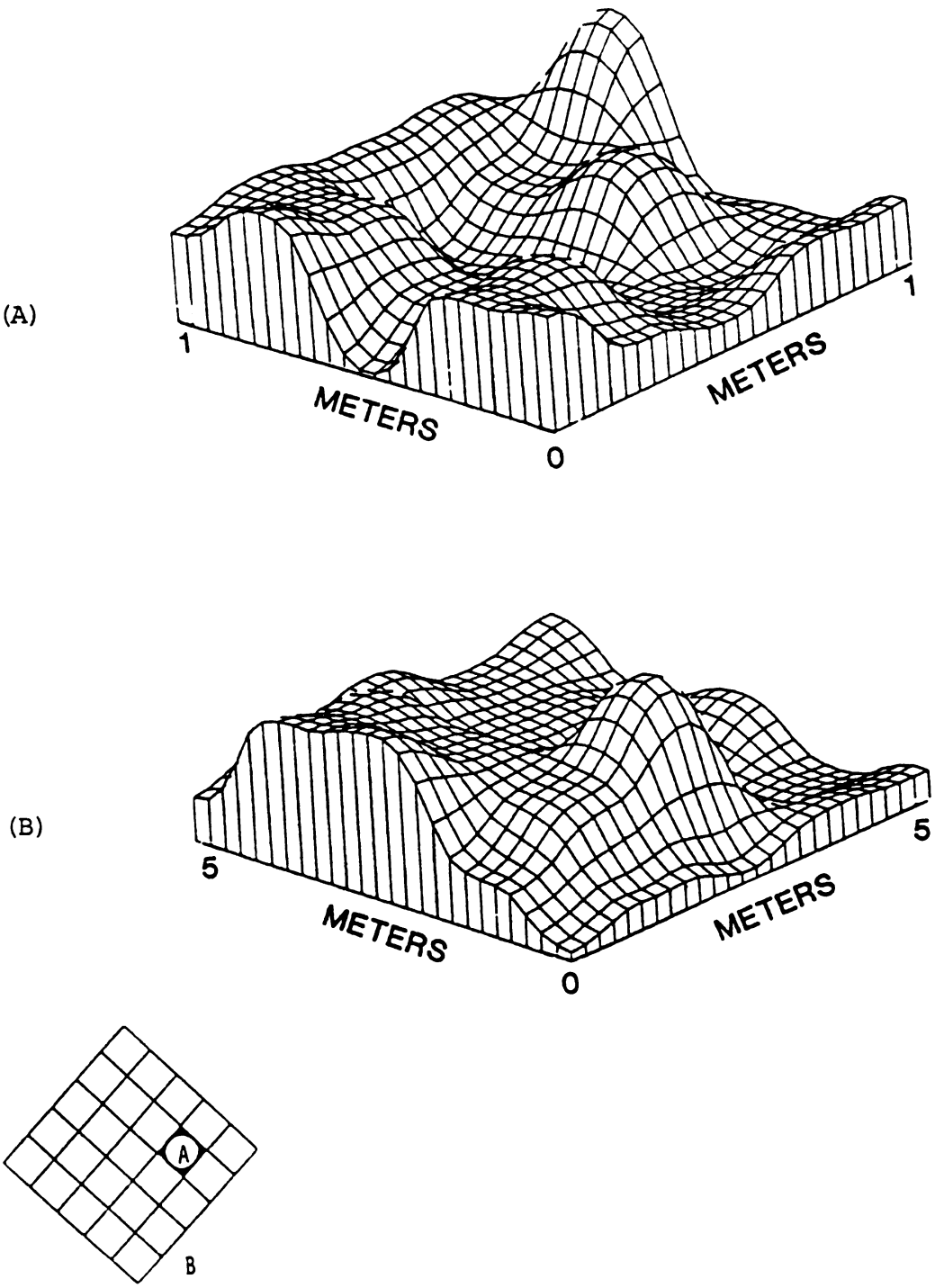


Figure 18. Horizontal soil population distribution of T. yosiii in clover on March 24, 1983, at two sampling densities: (A) 25 samples/M^2, and (B) 1 sample/M^2 (Replication II).

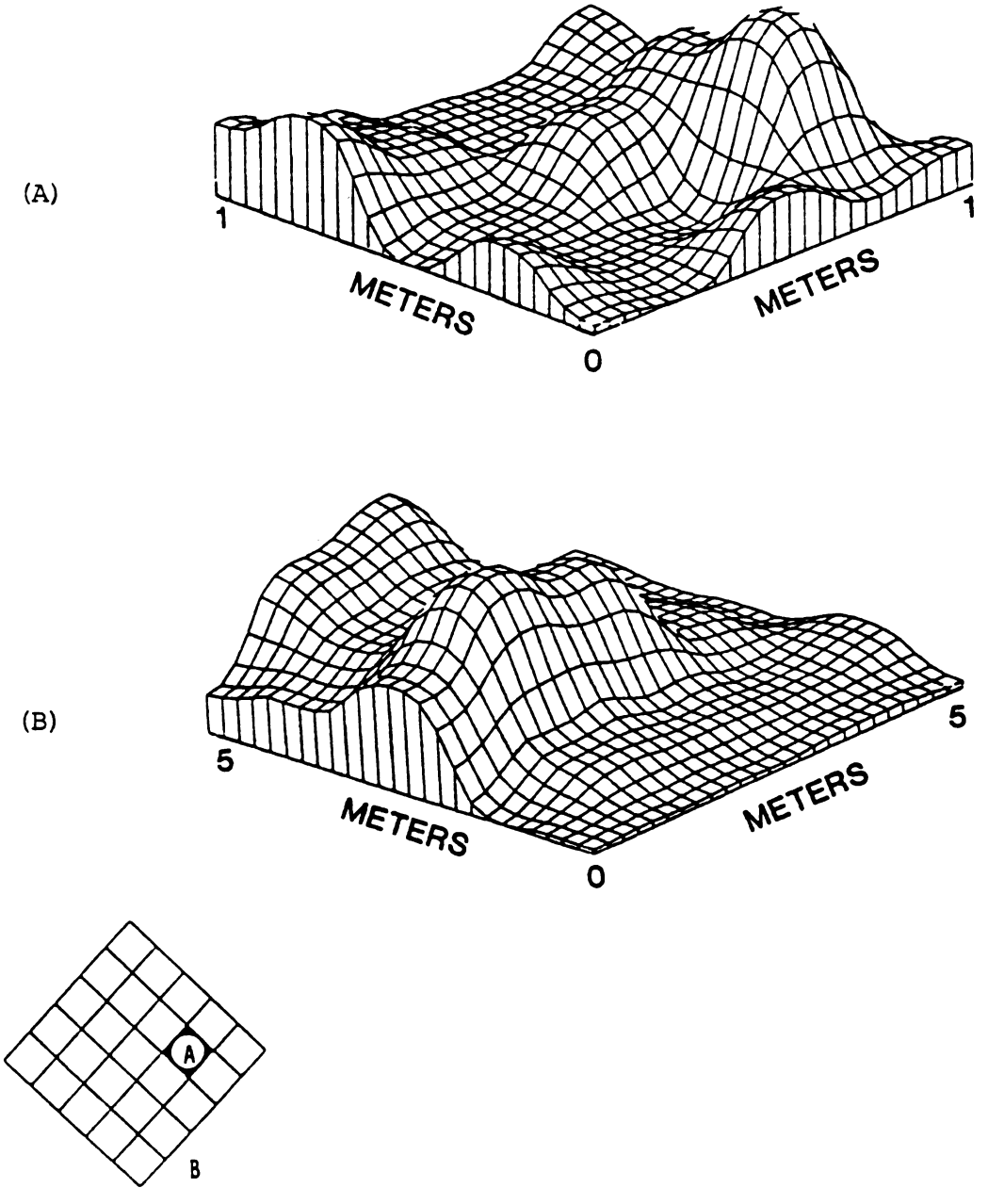


Figure 19. Horizontal soil population distribution of T. yosiii in clover on March 24, 1983 at two sampling densities: (A) 25 samples/M^2, and (B) 1 sample/M^2 (Replication III).

Soil population densities of I. minor were greatest at a soil depth of 10.16-15.24 cm on March 24, and at the surface on June 22 and July 25 (Table13). Individuals were not collected on September 1. I. minor was often the third most prominent species at each soil depth (Appendix 12). Soil population densities of T. yosiii were concentrated at a soil depth of 5.08-10.16 cm on March 24 and June 22 (Table 14). On July 26, however, densities were greatest at a soil depth of 10.16-15.24 cm. On September 1, a low population density was recovered from the surface only. This species was most prominent at all depths on March 24, at the soil surface on June 22, and at the 10.16-15.24 cm depth on July 26 (Appendix 12). Fluctuations in vertical distribution of I. notabilis, I. minor and T. yosiii were apparent during the season (Figures 20 - 22).

Collembola Associated With Compost

Compost samples were collected on March 28 and June 22 (Table 15). P. violenta, E. unostrigata and Lepidocrytus pallidus Reuter were recovered from compost samples on both sampling dates. P. violenta, the most common Entomobryidae in the Rodale Research Center sweet corn research plots, was found at the greatest density on June 22, at a compost depth of 15.24-30.48 cm. In contrast, this species was not recovered from sudax plots on the same date. The low density on March 28 corresponds to a season low in sweet corn on March 17.

I. notabilis and P. minuta were recovered from compost on both sampling dates. I. viridis and I. minor were detected on June 22 only, and I. uniens on March 28 only. I. notabilis, the most common isotomid associated with sweet corn plots, was concentrated in the compost surface on June 22; density at the 15.24-30.48 cm layer on this date was 0.50. This corresponds to the greatest

Table 12. Seasonal vertical distribution of *I. notabilis* in clover, and sudax, to a soil depth of 15.24 cm.

Sampling date[a] (Julian Date)		Soil depth (cm)	*I. notabilis* per 1×10^{-2} cm^3	s^2	Kolmogorov-Smirnov Statistic[b]	Distribution[c]
March 24	(83)[d]	0 - 5.08	0.28	3.09	0.0486	Nb
		5.08 - 10.16	0.05	0.13	0.0439	Nb
		10.16 - 15.24	0.01	0.03	0.0618	Nb
June 22	(173)[e]	0 - 5.08	0.45	0.39	0.9088	Poi
		5.08 - 10.16	0.10	0.11	0.0654	Poi
		10.16 - 15.24	1.54	146.08	0.1723	Nb
July 25	(206)[e]	0 - 5.08	0.06	0.04	0.1178	Poi
		5.08 - 10.16	0.13	0.30	0.0636	Nb
		10.16 - 15.24	0.08	0.15	0.1788	Nb
Sept. 1	(243)[e]	0 - 5.08	0.03	0.02	0.1065	Poi
		5.08 - 10.16	0			
		10.16 - 15.24	0			

[a] 1983

[b] P=0.05

[c] Nb = Negative binomial; Poi = Poison

[d] Weedy clover site (Figure 2)

[e] Irrigated sudax site (Figure 2)

Table 13. Seasonal vertical distribution of I. minor in clover, and sudax, to a soil depth of 15.24 cm.

Sampling date[a] (Julian Date)		Soil depth (cm)	I. minor per 1×10^{-2} cm^3	s^2	Kolmogorov-Smirnov Statistic[b]	Distribution[c]
March 24	(83)[d]	0 - 5.08	0.02	0.03	0.0420	Nb
		5.08 - 10.16	0.04	0.07	0.0582	Nb
		10.16 - 15.24	0.07	0.10	0.0916	Nb
June 22	(173)[e]	0 - 5.08	0.29	0.89	0.1900	Nb
		5.08 - 10.16	0.05	0.15	0.1525	Nb
		10.16 - 15.24	0.11	0.53	0.1260	Nb
July 25	(206)[e]	0 - 5.08	0.13	0.52	0.1049	Nb
		5.08 - 10.16	0.05	0.06	0.0766	Poi
		10.16 - 15.24	0.06	0.12	0.1294	Nb
Sept. 1	(243)[e]	0 - 5.08	0			
		5.08 - 10.16	0			
		10.16 - 15.24	0			

[a] 1983

[b] P=0.05

[c] Nb = Negative binomial; Poi = Poison

[d] Weedy clover site (Figure 2)

[e] Irrigated sudax site (Figure 2)

Table 14. Seasonal vertical distribution of T. yosiii in clover, and sudax, to a soil depth of 15.24 cm.

Sampling date[a] (Julian Date)		Soil depth (cm)	T. yosiii per 1×10^{-2} cm^3	s^2	Kolmogorov-Smirnov Statistic[b]	Distribution[c]
March 24	(83)[d]	0 - 5.08	0.61	4.18	0.0845	Nb
		5.08 - 10.16	0.80	2.09	0.1305	Nb
		10.16 - 15.24	0.43	2.59	0.0706	Nb
June 22	(173)[e]	0 - 5.08	0.52	5.91	0.1023	Nb
		5.08 - 10.16	0.06	0.04	0.1179	Poi
		10.16 - 15.24	0.26	0.56	0.0581	Nb
July 25	(206)[e]	0 - 5.08	0.02	0.02	0.0288	Poi
		5.08 - 10.16	0.15	0.53	0.2077	Nb
		10.16 - 15.24	0.10	0.11	0.0656	Poi
Sept. 1	(243)[e]	0 - 5.08	0.03	0.06	0.1337	Nb
		5.08 - 10.16	0			
		10.16 - 15.24	0			

[a] 1983

[b] P=0.05

[c] Nb = Negative binomial; Poi = Poison

[d] Weedy clover site (Figure 2)

[e] Irrigated sudax site (Figure 2)

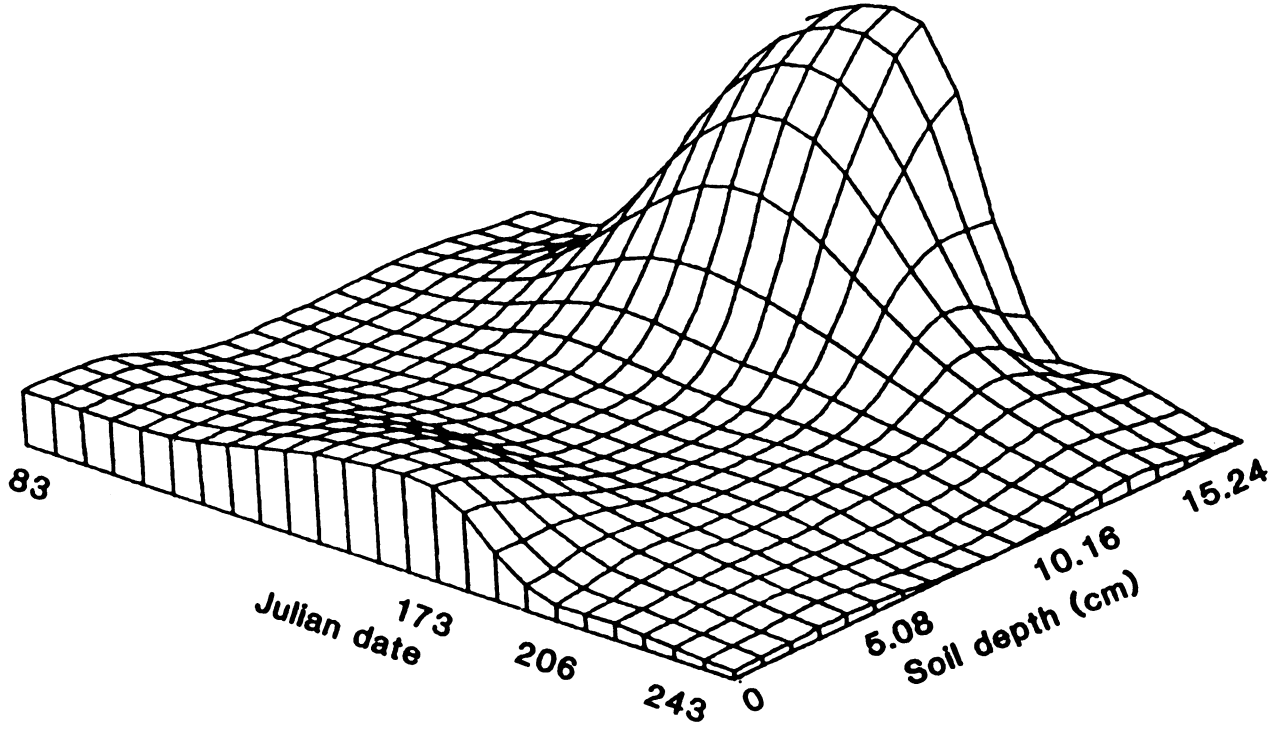


Figure 20. Seasonal vertical soil distribution of I. notabilis in clover and irrigated sudax.

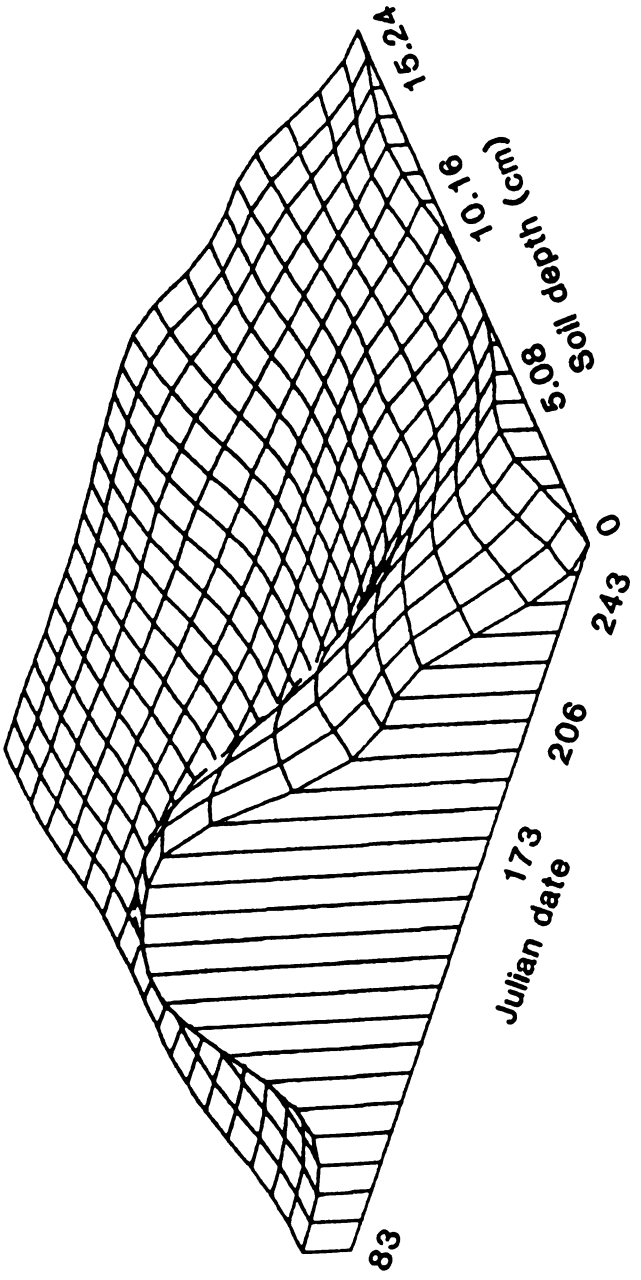


Figure 21. Seasonal vertical soil distribution of I. minor in clover and irrigated sudax.

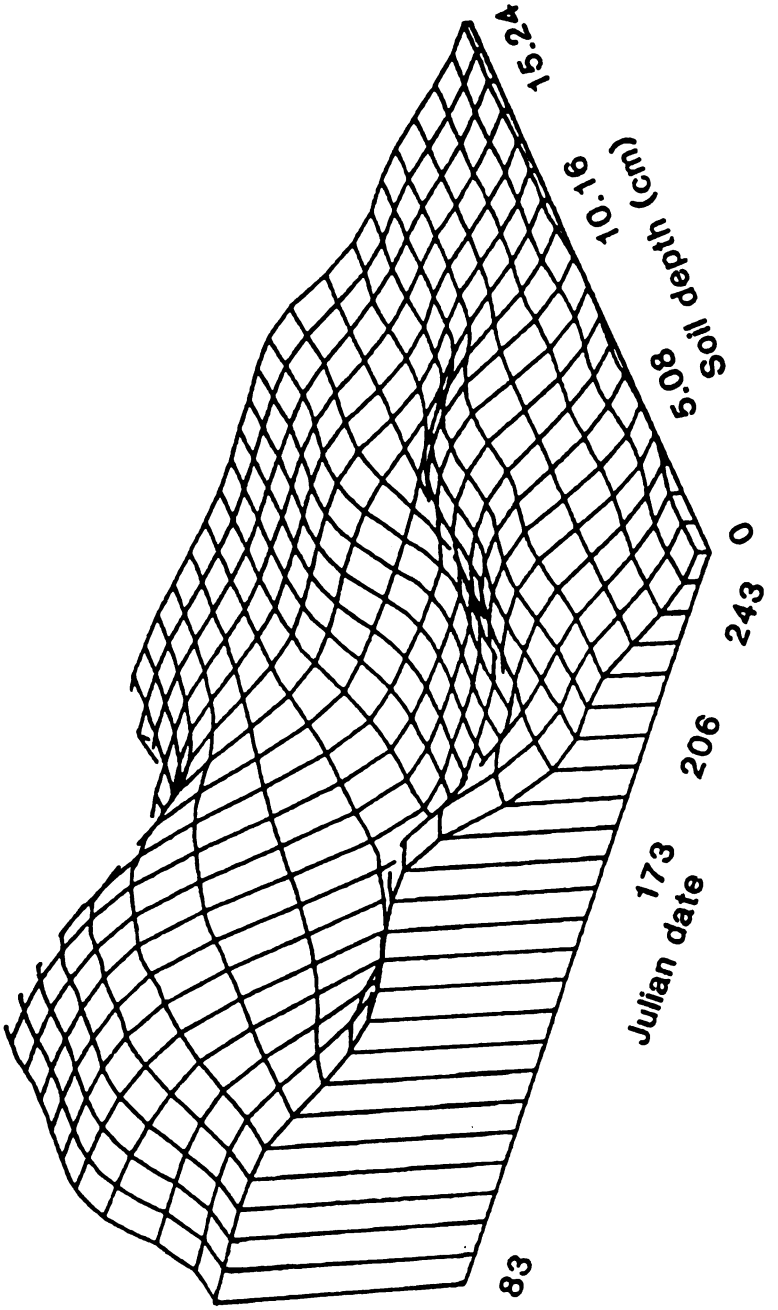


Figure 22. Seasonal vertical soil distribution of T. yosiii in clover and irrigated sudax.

Table 15. Population densities of Collembola species associated with compost.

	Collembola per 1 x 10^{-2} cm^3 compost		
	Sampling depth (cm)		
	March 28	June 22	
Taxon	0 - 15.24	0 - 15.24	15.24 - 30.48
Entomobryidae			
P. violenta	0.05	1.31	3.90
E. unostrigata	0.03	0.03	0
L. pallidus	0.11	0.03	0.03
Isotomidae			
I. notabilis	0.36	1.68	0.52
F. americanus	0	0	0
P. minuta	0.42	0.08	0.10
I. viridis	0	0.03	0
I. minor	0	0.37	0.41
I. uniens	0.28	0	0
Onychiuridae			
O. encarpatus	0	1.08	0.23
T. yosiii	0.07	0	0
Hypogastruridae	0.15	0.08	0.53

density in sweet corn on June 23. The surface density in compost on March 28 was 0.40.

O. encarpatus was collected from compost on June 22 only. Population density of O. encarpatus was 1.08 at the compost surface, and 0.23 at the 15.24-30.48 cm compost depth. T. yosiii, the most common Collembola associated with sweet corn, was only collected from compost on March 28. Population density at the compost surface was 0.07. This species was collected in greatest numbers from sweet corn on March 17.

Hypogastruridae were collected from compost on both dates. The greatest population density occurred on June 22 at a compost depth of 15.24-30.48 cm; density at this depth was 0.50. Density at the surface was 0.15 on this date.

Agroecosystem Analysis

Seasonal population fluctuations resulted in significant differences in soil densities among sampling dates (Table 16). Sweet corn agroecosystem management significantly influenced soil population densities of Collembola (P=0.001); the families Entomobryidae (P=0.02) and Isotomidae (P=0.001); and the species I. notabilis (P=0.001) and T. yosiii (P=0.01). These population differences are the result of agricultural inputs unique to organic and conventional systems, and will be described in the following section.

Orthogonal Comparisons--In the absence of a nitrogen input, total soil population densities of Collembola were significantly (P=0.005) greater in the organic than in the conventional agroecosystem (Table 17). Population densities were also significantly (P=0.001) greater in the organic than in the conventional agroecosystem for Entomobryidae (Table 18); Isotomidae (P=0.01), I. notabilis (P=0.001, Table 19); and T. yosiii (P=0.05, Table 20).

Table 16. Variation in population densities of seven Collembola taxa associated with seasonal trends and agroecosystem treatment.

	Anova table[1]			
	Sample date[2]		Agroecosystem treatment[3]	
Taxon	F statistic	Significance level	F statistic	Significance level
Entomobryidae	13.29	0.001	2.54	0.02
Isotomidae	3.19	0.01	4.75	0.001
I. notabilis	8.04	0.001	9.38	0.001
F. americanus	4.38	0.001	1.13	0.34
I. minor	1.03	0.40	1.15	0.33
T. yosiii	25.54	0.001	3.16	0.01
Total Collembola	11.27	0.001	4.91	0.001

[1]Two-way randomized block design

[2]df = 6

[3]df = 7

Table 17. Influence of organic and conventional agroecosystems on Collembola soil population densities in sweet corn, in the absence of a nitrogen input.

Treatment	Orthogonal[1] Coefficients	Soil population density[2] Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	+1	203	6.4
Treatment	—	—	—
Compost			
Control	+1	152	4.7
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	-1	87	2.7
Treatment	—	—	—
Compost			
Control	-1	107	3.3
Treatment	—	—	—

[1]Orthogonal comparison 1 (Table 5)
F = 8.2 P = 0.005

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 18. Influence of organic and conventional agroecosystems on Entomobryidae soil population densities in sweet corn, in the absence of a nitrogen input.

Treatment	Orthogonal[1] Coefficients	Soil population density[2] Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	+1	22	0.7
Treatment	—	—	—
Compost			
Control	+1	15	0.5
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	-1	8	0.3
Treatment	—	—	—
Compost			
Control	-1	7	0.2
Treatment	—	—	—

[1]Orthogonal comparison 1 (Table 5)
F = 12.7 P = 0.001

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 19. Influence of organic and conventional agroecosystem management on soil population density of Isotomidae, I. notabilis, F. americanus, and I. minor in sweet corn in the absence of a nitrogen input.

Treatment	Orthogonal[1] Coefficients	Soil population density[2]							
		Total				Mean			
		ISO	IIN	IFA	IIM	ISO	IIN	IFA	IIM
Organic									
Agroecosystem[3]									
Bloodmeal									
Control	+1	72	27	16	4	2.6	1.0	0.6	0.1
Treatment	—	—	—	—	—	—	—	—	—
Compost									
Control	+1	60	20	18	4	2.1	0.7	0.6	0.1
Treatment	—	—	—	—	—	—	—	—	—
Conventional									
Agroecosystem[4]									
Ammonium nitrate									
Control	-1	28	8	8	2	1.0	0.3	0.3	0.1
Treatment	—	—	—	—	—	—	—	—	—
Compost									
Control	-1	42	9	22	3	1.5	0.3	0.8	0.1
Treatment	—	—	—	—	—	—	—	—	—

[1]Orthogonal comparison 1 (Table 5)
Isotomidae (ISO): $F = 6.2$ $P = 0.01$
I. notabilis (IIN): $F = 10.5$ $P = 0.001$
F. americanus (IFA): $F = 0.01$ $P = 1.00$
I. minor (IIM): $F = 1.25$ $P = 0.26$

[2]Summation of 1982 and 1983 soil densities per 1×10^{-2} cm^3 soil, to a soil depth of 15.24

[3]Weed populations were managed by cultivation.

[4]Weed populations were managed with herbicides.

Table 20. Influence of organic and conventional agroecosystems on T. vosiii soil population densities in sweet corn, in the absence of a nitrogen input.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	-1	27	1.0
Treatment	--	---	---
Compost			
Control	+1	41	1.5
Treatment	--	---	---
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	-1	22	0.8
Treatment	--	---	---
Compost			
Control	-1	19	0.7
Treatment	--	---	---

[1] Orthogonal comparison 1 (Table 5)
F = 3.79 P = 0.05

[2] Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3] Weed populations managed by cultivation.

[4] Weed populations managed by herbicide application.

In the organic agroecosystem, populations of Collembola were significantly (P=0.007) greater in soil recieving bloodmeal-nitrogen than in soil recieving compost-nitrogen (Table 21). This trend was also apparent (Tables 22, 23, and 24) with Entomobryidae (P=0.50); Isotomidae (P=0.02), I. notabilis (P=0.001), F. americanus (P=0.20); and T. yosiii (P=0.01). For the conventional agroecosystem, population densities of Collembola were greater (P=0.12) in soil with compost input than with ammonium nitrate input (Table 25). This trend was also observed (Tables 26, 27 and 28) with Entomobryidae (P=0.58); Isotomidae (P=0.33), I. minor (P=0.45); and T. yosiii (P=0.11). Soil populations of I. notabilis and F. americanus were almost equal in response to these nitrogen sources (Table 27).

In the presence of nitrogen input, soil population densities of Collembola were significantly (P=0.001) greater in the organic than in the conventional agroecosystem (Table 29). This soil population difference was also observed (Tables 30, 31 and 32) with Entomobryidae (P=0.23); Isotomidae (P=0.001), I. notabilis (P=0.001), F. americanus (P=0.06), I. minor (P=0.45); and T. yosiii (P=0.02).

Disregarding agroecosystem weed management, soil population densities of Collembola were not significantly (P=0.32) influenced by nitrogen input (Table 33). This trend was observed (Tables 34, 35 and 36) for Entomobryidae (P=0.60); Isotomidae (P=1.0), F. americanus (P=0.29), I. minor (P=0.24); and T. yosiii (P=0.44). Soil populations of I. notabilis were significaty (P=0.06) greatest in soil recieving nitrogen input, when compared to soil populations in the absence of nitrogen input (Table 35).

Table 21. Influence of organic agroecosystem nitrogen source on soil population densities of Collembola in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	—	—
Treatment	+1	262	8.2
Compost			
Control	—	—	—
Treatment	-1	154	4.8
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—

[1] Orthogonal comparison 2 (Table 5)
F = 7.3 P = 0.007

[2] Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3] Weed populations managed by cultivation.

[4] Weed populations managed by herbicide application.

Table 22. Influence of organic agroecosystem nitrogen source on soil population densities of Entomobryidae in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	—	—
Treatment	+1	18	0.6
Compost			
Control	—	—	—
Treatment	-1	15	0.5
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—

[1]Orthogonal comparison 2 (Table 5)
F = 0.50 P = 0.50

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 23. Influence of organic agroecosystem nitrogen source on soil population density of Isotomidae, I. notabilis, F. americanus, and I. minor in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total ISO	Total IIN	Total IFA	Total IIM	Mean ISO	Mean IIN	Mean IFA	Mean IIM
Organic Agroecosystem[3]									
Bloodmeal									
Control	--	---	---	---	---	---	---	---	---
Treatment	+1	95	49	37	4	3.4	1.7	1.3	0.1
Compost									
Control	--	---	---	---	---	---	---	---	---
Treatment	-1	59	25	22	3	2.1	0.9	0.8	0.1
Conventional Agroecosystem[4]									
Ammonium nitrate									
Control	--	---	---	---	---	---	---	---	---
Treatment	--	---	---	---	---	---	---	---	---
Compost									
Control	--	---	---	---	---	---	---	---	---
Treatment	--	---	---	---	---	---	---	---	---

[1] Orthogonal comparison 2 (Table 5)
Isotomidae (ISO): F = 5.6 P = 0.02
I. notabilis (IIN): F = 12.2 P = 0.001
F. americanus (IFA): F = 1.70 P = 0.20
I. minor (IIM): F = 0.59 P = 0.45

[2] Summation of 1982 and 1983 soil densities per 1 x 10^{-2} cm^3 soil, to a soil depth of 15.24

[3] Weed populations were managed by cultivation.

[4] Weed populations were managed with herbicides.

Table 24. Influence of organic agroecosystem nitrogen source on soil population densities of *T. vosii* in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	—	—
Treatment	+1	52	1.9
Compost			
Control	—	—	—
Treatment	-1	27	1.0
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—

[1] Orthogonal comparison 2 (Table 5)
F = 7.1 P = 0.01

[2] Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3] Weed populations managed by cultivation.

[4] Weed populations managed by herbicide application.

Table 25. Influence of conventional agroecosystem nitrogen source on soil population densities of Collembola in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	—	—
Treatment	+1	74	2.3
Compost			
Control	—	—	—
Treatment	-1	137	4.3

[1]Orthogonal comparison 3 (Table 5)
F = 2.49 P = 0.12

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 26. Influence of conventional agroecosystem nitrogen source on soil population densities of Entomobryidae in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	—	—
Treatment	+1	11	0.4
Compost			
Control	—	—	—
Treatment	-1	14	0.4

[1] Orthogonal comparison 3 (Table 5)
F = 0.31 P = 0.58

[2] Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3] Weed populations managed by cultivation.

[4] Weed populations managed by herbicide application.

Table 27. Influence of conventional agroecosystem nitrogen source on soil population density of Isotomidae, I. notabilis, F. americanus, and I. minor in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total ISO	IIN	IFA	IIM	Mean ISO	IIN	IFA	IIM
Organic Agroecosystem[3]									
Bloodmeal									
Control	—	—	—	—	—	—	—	—	—
Treatment	—	—	—	—	—	—	—	—	—
Compost									
Control	—	—	—	—	—	—	—	—	—
Treatment	—	—	—	—	—	—	—	—	—
Conventional Agroecosystem[4]									
Ammonium nitrate									
Control	—	—	—	—	—	—	—	—	—
Treatment	+1	25	7	13	0.6	0.9	0.2	0.5	0.02
Compost									
Control	—	—	—	—	—	—	—	—	—
Treatment	-1	40	9	15	2	1.4	0.3	0.5	0.1

[1]Orthogonal comparison 3 (Table 5)
Isotomidae (ISO): F = 0.98 P = 0.33
I. notabilis (IIN): F = 0.06 P = 1.00
F. americanus (IFA): F = 0.03 P = 1.00
I. minor (IIM): F = 0.57 P = 0.45

[2]Summation of 1982 and 1983 soil densities per 1 x 10^{-2} cm^3 soil, to a soil depth of 15.24

[3]Weed populations were managed by cultivation.

[4]Weed populations were managed with herbicides.

Table 28. Influence of conventional agroecosystem nitrogen source on soil population densities of T. yosiii in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	—	—
Treatment	+1	15	0.5
Compost			
Control	—	—	—
Treatment	-1	31	1.1

[1]Orthogonal comparison 3 (Table 5)
F = 2.55 P = 0.11

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 29. Influence of organic and conventional agroecosystem nitrogen sources on soil population densities of Collembola in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	--	---	---
Treatment	+1	262	8.2
Compost			
Control	--	---	---
Treatment	+1	155	4.8
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	--	---	---
Treatment	-1	74	2.3
Compost			
Control	--	---	---
Treatment	-1	137	4.3

[1]Orthogonal comparison 4 (Table 5)
F = 13.4 P = 0.001

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 30. Influence of organic and conventional agroecosystem nitrogen sources on soil population densities of Entomobryidae in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	—	—
Treatment	+1	18	0.6
Compost			
Control	—	—	—
Treatment	+1	15	0.5
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	—	—
Treatment	-1	11	0.4
Compost			
Control	—	—	—
Treatment	-1	14	0.4

[1]Orthogonal comparison 4 (Table 5)
F = 1.40 P = 0.23

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 31. Influence of organic and conventional agroecosystem nitrogen inputs on soil population densities of Isotomidae, I. notabilis, F. americanus, and I. minor in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total ISO	IIN	IFA	IIM	Mean ISO	IIN	IFA	IIM
Organic Agroecosystem[3]									
Bloodmeal									
Control	—	—	—	—	—	—	—	—	—
Treatment	+1	95	49	37	4	3.4	1.7	1.3	0.1
Compost									
Control	—	—	—	—	—	—	—	—	—
Treatment	+1	60	25	22	3	2.1	0.9	0.8	0.1
Conventional Agroecosystem[4]									
Ammonium nitrate									
Control	—	—	—	—	—	—	—	—	—
Treatment	-1	25	7	13	0.6	0.9	0.2	0.5	0.02
Compost									
Control	—	—	—	—	—	—	—	—	—
Treatment	-1	40	8	15	2	1.4	0.3	0.5	0.1

[1] Orthogonal comparison - (Table 5)
Isotomidae (ISO): $F = 17.5$ $P = 0.001$
I. notabilis (IIN): $F = 38.4$ $P = 0.001$
F. americanus (IFA): $F = 3.86$ $P = 0.06$
I. minor (IIM): $F = 0.60$ $P = 0.45$

[2] Summation of 1982 and 1983 soil densities per 1×10^{-2} cm^3 soil, to a soil depth of 15.24

[3] Weed populations were managed by cultivation.

[4] Weed populations were managed with herbicides.

Table 32. Influence of organic and conventional agroecosystem nitrogen sources on soil population densities of T. yosiii in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	---	---
Treatment	+1	52	1.9
Compost			
Control	—	---	---
Treatment	+1	27	1.0
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	---	---
Treatment	-1	15	0.5
Compost			
Control	—	---	---
Treatment	-1	31	1.1

[1]Orthogonal comparison 4 (Table 5)
F = 5.80 P = 0.02

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 33. Influence of nitrogen input on soil population densities of Collembola in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	+1	203	6.4
Treatment	-1	262	8.2
Compost			
Control	+1	152	4.7
Treatment	-1	154	4.8
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	+1	87	2.7
Treatment	-1	74	2.3
Compost			
Control	+1	107	3.3
Treatment	-1	137	4.3

[1]Orthogonal comparison 5 (Table 5)
F = 0.99 P = 0.32

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 34. Influence of nitrogen input on soil population densities of Entomobryidae in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	+1	22	0.7
Treatment	-1	18	0.6
Compost			
Control	+1	15	0.5
Treatment	-1	15	0.5
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	+1	8	0.3
Treatment	-1	11	0.4
Compost			
Control	+1	7	0.2
Treatment	-1	14	0.4

[1]Orthogonal comparison 5 (Table 5)
F = 0.27 P = 0.60

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 35. Influence of nitrogen input on soil population densities of Isotomidae, I. notabilis, F. americanus, and I. minor in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total				Mean			
		ISO	IIN	IFA	IIM	ISO	IIN	IFA	IIM
Organic Agroecosystem[3]									
Bloodmeal									
Control	+1	72	27	16	4	3.0	1.0	0.6	0.1
Treatment	-1	95	49	37	4	3.0	1.7	1.3	0.1
Compost									
Control	+1	60	20	18	4	2.0	0.7	0.6	0.1
Treatment	-1	60	25	22	3	2.0	0.9	0.8	0.1
Conventional Agroecosystem[4]									
Ammonium nitrate									
Control	+1	28	8	8	2	1.0	0.3	0.3	0.1
Treatment	-1	25	7	13	0.6	0.9	0.2	0.5	0.02
Compost									
Control	+1	42	8	22	3	1.5	0.3	0.8	0.1
Treatment	-1	40	8	15	2	1.4	0.3	0.5	0.1

[1]Orthogonal comparison 3 (Table 5)
Isotomidae (ISO): F = 0.08 P = 1.00
I. notabilis (IIN): F = 3.52 P = 0.06
F. americanus (IFA): F = 1.51 P = 0.29
I. minor (IIM): F = 1.44 P = 0.24

[2]Summation of 1982 and 1983 soil densities per 1 x 10^{-2} cm^3 soil, to a soil depth of 15.24

[3]Weed populations were managed by cultivation.

[4]Weed populations were managed with herbicides.

Randomization of sweet corn research plots in the organic system did not limit density differences between control treatments. Population density differences were apparent (Tables 37, 38, 39 and 40) for Collembola (P=0.20); Entomobryidae (P=0.10); Isotomidae (P=0.41), I. notabilis (P=0.30), I. minor (P=0.15); and T. yosiii (P=0.15). F. americanus densities in control treatments were equal (P=1.00, Table 39).

Treatment randomization in the conventional agroecosystem limited variation of most Collembola soil population densities attributable to experimental design. Soil population densities of Collembola were similar (P=0.60) in control treatments (Table 41). Densities were alike (Tables 42, 43 and 44) for Entomobryidae (P=1.00); I. notabilis (P=1.0), I. minor (P=0.44); and T. yosiii (P=1.00). Randomization was not as effective for I. notabilis (P=0.13) and F. americanus (P=0.22, Table 43).

DISCUSSION

Quantification of Collembola Soil Populations

Extraction efficiency for most Collembola taxa was comparable to other investigations. Soil densities of Collembola represented 42% of actual soil densities. Sampling efficiency can be influenced by rate of sample drying, soil temperature gradient, and length of extraction. Extraction was least efficient when samples were refrigerated 48 hours prior to extraction, or extracted for only 24 hours.

Efficiency for Onychiuridae was high (74%) when the extraction period was extended to 78 hours. In contrast, Loring et al. (1981) recovered 3% of T. granulata in similar Tullgren funnels after circa three days of extraction. They

Table 36. Influence of nitrogen input on soil population densities of T. vosiii in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	+1	27	1.0
Treatment	-1	52	1.9
Compost			
Control	+1	41	1.5
Treatment	-1	27	1.0
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	+1	23	0.8
Treatment	-1	15	0.5
Compost			
Control	+1	19	0.7
Treatment	-1	31	1.1

[1]Orthogonal comparison 5 (Table 5)
F = 0.62 P = 0.44

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 37. Influence of organic agroecosystem treatment randomization on soil population densities of Collembola in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	+1	203	6.4
Treatment	—	—	—
Compost			
Control	-1	152	4.7
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—

[1] Orthogonal comparison 6 (Table 5)
F = 1.70 P = 0.20

[2] Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3] Weed populations managed by cultivation.

[4] Weed populations managed by herbicide application.

Table 38. Influence of organic agroecosystem treatment randomization on soil population densities of Entomobryidae in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	+1	22	0.7
Treatment	—	—	—
Compost			
Control	-1	15	0.5
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—

[1] Orthogonal comparison 6 (Table 5)
F = 2.60 P = 0.10

[2] Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3] Weed populations managed by cultivation.

[4] Weed populations managed by herbicide application.

Table 39. Influence of organic agroecosystem treatment randomization on soil population densities of Isotomidae, I. notabilis, F. americanus, and I. minor in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]							
		Total				Mean			
		ISO	IIN	IFA	IIM	ISO	IIN	IFA	IIM
Organic Agroecosystem[3]									
Bloodmeal									
Control	+1	72	27	16	4	2.6	1.0	0.6	0.1
Treatment	—	—	—	—	—	—	—	—	—
Compost									
Control	-1	60	20	18	4	2.1	0.7	0.6	0.1
Treatment	+1	---	---	---	---	---	---	---	---
Conventional Agroecosystem[4]									
Ammonium nitrate									
Control	--	—	—	—	—	—	—	—	—
Treatment	—	—	—	—	—	—	—	—	—
Compost									
Control	—	—	—	—	—	—	—	—	—
Treatment	—	—	—	—	—	—	—	—	—

[1]Orthogonal comparison 6 (Table 5)
Isotomidae (ISO): F = 0.70 P = 0.41
I. notabilis (IIN): F = 1.10 P = 0.30
F. americanus (IFA): F = 0 P = 1.00
I. minor (IIM): F = 2.1 P = 0.15

[2]Summation of 1982 and 1983 soil densities per 1 x 10^{-2} cm^3 soil, to a soil depth of 15.24

[3]Weed populations were managed by cultivation.

[4]Weed populations were managed with herbicides.

Table 40. Influence of organic agroecosystem treatment randomization on soil population densities of T. yosiii in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	+1	27	1.0
Treatment	—	—	—
Compost			
Control	-1	41	1.5
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—

[1]Orthogonal comparison 6 (Table 5)
F = 2.10 P = 0.15

[2]Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3]Weed populations managed by cultivation.

[4]Weed populations managed by herbicide application.

Table 41. Influence of conventional agroecosystem treatment randomization on soil population densities of Collembola in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	+1	87	2.7
Treatment	—	—	—
Compost			
Control	-1	107	3.3
Treatment	—	—	—

[1] Orthogonal comparison 7 (Table 5)
F = 0.25 P = 0.62

[2] Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3] Weed populations managed by cultivation.

[4] Weed populations managed by herbicide application.

Table 42. Influence of conventional agroecosystem treatment randomization on soil population densities of Entomobryidae in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	+1	8	0.3
Treatment	—	—	—
Compost			
Control	-1	7	0.2
Treatment	—	—	—

[1] Orthogonal comparison 7 (Table 5)
F = 0.04 P = 1.00

[2] Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3] Weed populations managed by cultivation.

[4] Weed populations managed by herbicide application.

Table 43. Influence of conventional agroecosystem treatment randomization on soil population densities of Isotomidae, I. notabilis, F. americanus, and I. minor in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2] Total ISO	IIN	IFA	IIM	Mean ISO	IIN	IFA	IIM
Organic Agroecosystem[3]									
Bloodmeal									
Control	--	---	---	---	---	---	---	---	---
Treatment	—	---	---	---	---	---	---	---	---
Compost									
Control	—	---	---	---	---	---	---	---	---
Treatment	—	---	---	---	---	---	---	---	---
Conventional Agroecosystem[4]									
Ammonium nitrate									
Control	+1	28	8	8	2	1.0	0.3	0.3	0.7
Treatment	—	---	---	---	---	---	---	---	---
Compost									
Control	-1	42	8	22	3	1.5	0.3	0.8	0.1
Treatment	—	---	---	---	---	---	---	---	---

[1] Orthogonal comparison 7 (Table 5)
Isotomidae (ISO): F = 2.33 P = 0.13
I. notabilis (IIN): F = 0 P = 1.00
F. americanus (IFA): F = 1.50 P = 0.22
I. minor (IIM): F = 0.60 P = 0.44

[2] Summation of 1982 and 1983 soil densities per 1 x 10^{-2} cm^3 soil, to a soil depth of 15.24

[3] Weed populations were managed by cultivation.

[4] Weed populations were managed with herbicides.

Table 44. Influence of conventional agroecosystem treatment randomization on soil population densities of T. yosiii in sweet corn.

Treatment	Orthogonal Coefficients[1]	Soil population density[2]	
		Total	Mean
Alternative agroecosystem[3]			
Bloodmeal			
Control	—	—	—
Treatment	—	—	—
Compost			
Control	—	—	—
Treatment	—	—	—
Conventional agroecosystem[4]			
Ammonium nitrate			
Control	+1	23	0.8
Treatment	—	—	—
Compost			
Control	-1	19	0.7
Treatment	—	—	—

[1] Orthogonal comparison 7 (Table 5)
F = 0.17 P = 1.00

[2] Sum of all sampling dates in 1982 and 1983, per 1 x 10^{-2} cm^3 soil, to a depth of 15.24 cm.

[3] Weed populations managed by cultivation.

[4] Weed populations managed by herbicide application.

allowed soil samples to remain in the funnels until they were completely dry, and used the sugar-flotation method as a measure of extraction efficiency. T. granulata is closely related to T. yosiii, a species that predominated in sweet corn in this research. Peterson (1978) also extracted Tullbergia spp. less efficiently, recovering less than 50% with a high-gradient extracter in ten days. The Onychiuridae are typically small and slow-moving, causing density estimates based on Tullgren extraction to be much less than actual soil densities.

One-hundred percent of the Isotomidae were extracted from fresh samples in 78 hours. Loring et al. (1981) extracted 82% in three days, and Peterson (1978) extracted approximately 95% in ten days. Isotomidae are typically litter-dwelling, with longer legs than the Onychiuridae; however, this depends upon species. This may account for the greater extraction efficiency observed for isotomids. Soil Isotomidae may be more tolerant of low-moisture and high-temperature than onychiurids (Schaller 1970).

Entomobryidae were 93% extracted in 78 hours. Peterson (1978) obtained similar results for Lepidocrytus lignorum (Fabricius). Peterson extracted 75% of this species from soil samples in ten days of extraction. Members of this genus are typically active surface-dwellers, with a clothing of body scales that may enhance tolerance to low moisture and high temperatures. Species from this family were found at highest densities in sweet corn research plots late in the season, when soil moisture was low and temperature high. This resistance to adverse conditions may enhance extraction efficiency.

Measurement of extraction efficiency in this M.S. research may have been biased positively due to the inefficiency of the sugar-flotation method. This method is not as accurate as hand-sorting, for efficiency determination (Edwards

and Fletcher 1970). Insect exuviae, or Collembola that were dead before sampling, are not easily distinquished from recently killed individuals, and may be erroneously identified. This method is also less efficient for high-clay soil types typical of this research site. Estimates of soil densities based on Tullgren extraction are biased as a result of variable species reactions to the extraction process. Species most tolerant of dessication, and those that are fast-moving, are most efficiently extracted (Tamura 1976).

A steep temperature gradient within the soil sample during extraction improves efficiency (Macfadyen 1953). This gradient is maintained by a cooling device on lower portions of the sample, while a light source heats the sample from above. In this investigation, a temperature gradient in Tullgren funnels was difficult to maintain, especially when room temperature was high late in the season. Greatest temperature gradients, and greatest extraction efficiency, occurred when samples were placed in funnels after storage at 4 C.

Soil population density estimates were most accurate with increasing extraction time. Soil density estimates could have doubled if extraction time had been increased to 48 hours. Minimal extraction rates that were observed after 48 hours of sample refrigeration may have been the result of Collembola mortaility during storage. Sminthuridae are particularly susceptible to high carbon dioxide concentrations that occur in soil samples during storage (Snider, pers. comm.). Predation may also have been a factor during storage, but this factor was not investigated in this research. A population increase during storage due to egg-hatching is not likely to influence densities, as newly-hatched individuals are slow-moving and less tolerant of adverse soil moisture and temperature, and are not extracted as efficiently as adults.

Spatial Distribution and Population Dynamics

Fluctuations in soil densities of I. notabilis in clover suggest that two generations occurred in this season. Densities were high in March, and peaked again on May 12. Loring (1979) observed the same pattern for this species in Michigan field corn.

The population density increase was not maintained after relocation to the clover-oats site on June 16. This discrepancy suggests that I. notabilis populations at these clover sites were not following similar patterns in dynamics. Seasonal Collembola population trends at these clover sites should not be regarded as representative of one population, but as two discontinuous populations of the same species. This gap in population dynamics information applies to all Collembola species reported here. Soil populations of I. minor reacted in a similar way: a population increase was observed for this species just before relocation.

Seasonal dynamics of T. yosiii suggest that one generation occured in 1983 in clover. Densities were greatest on the first sampling date and declined afterwards. A population decrease was noted after site relocation. The same pattern of decline was observed in sweet corn.

Aggregated and random distributions observed for Collembola in this research have been reported by other investigators. Farrar and Crossley (1982) and Usher (1969) determined that soil microarthropods, including Collembola, were aggregately distributed in soybeans and in a coniferous soil, respectively. Random or less-highly aggregated distributions were observed in this and other studies when soil densities were low.

Usher (1969) hypothesized that soil aggregations occur in response to environmental niche distribution in soil. He observed that as soil densities increased, the number of aggregations increased with the number of individuals forming an aggregation. This implies that declining soil densities would result in fewer and smaller aggregations, leading to the random distribution pattern that was observed in clover at the Rodale Research Center late in the season when soil densities were low. This population decline may have been in response to unfavorable soil environmental conditions of increasing soil temperature and decreasing moisture. Collembola response to these unfavorable factors may have been increased mortality, decreased fecundity, or migration to a more favorable soil horizon.

The fact that Collembola were aggregated or randomly distributed in the clover ecosystem does not imply that the same pattern existed in the tilled sweet corn system. Farrar and Crossley (1982) found that microarthropod aggregations in tilled soybeans were smaller and less variable in area, in comparison to no-till beans. They suggested that tillage homogenized the soil and destroyed the environmental gradients that would give rise to aggregations.

Reformation of aggregations in soil would depend on the recolonizing abilities of Collembola species, formation of new environmental gradients, and the impact of any further disturbance. Cultivation and hilling operations performed in sweet corn may have favored aggregations within rows where samples were taken, influencing density estimation of species.

Vertical distribution of soil Collembola in clover and sudax fluctuated seasonally. Surface densities of I. notabilis were greatest during the first half of the season. Poole (1961) observed that this species was concentrated in the

litter layer of a coniferous forest soil in Wales. He reported high litter densities in the spring, with a gradual decline to a minimum density in July. Surface densities increased again in the fall. Vertical fluctuations observed in this research imply that this species migrated out of the sampling zone. Migration have been in response to less favorable soil moisture and temperature at the soil surface.

T. yosiii was concentrated in the clover surface at high densities early in the season, and steadily declined in sudax. Sampling did not detect vertical migration. In contrast, Poole (1961) reported that T. krausbaueri maintained a fairly constant vertical distribution during the season in a coniferous forest soil. This forest population, however, was not disturbed by cultivation, and environmental changes were buffered by the litter layer. Loring (1979) reported that the vertical distribution of T. granulata in Michigan field corn fluctuated seasonally. High surface densities in the spring declined after seeding and field preparation, then gradually increased to a peak in late September. At a soil depth of 5.08-10.16 cm, densities followed the same pattern. At a soil depth of 10.16-15.24 cm, densities remained fairly constant during the sampling period.

Agroecosystem Management

Soil insects respond to agroecosystem management. Dritschilo and Wanner (1980) observed greater ground beetle densities and species diversity in organic field corn in comparison to conventional corn. Collembola soil density and species prominence are influenced by crop rotation (Clemen and Pedigo 1970), and method of tillage (Loring et al. 1981). Soil aggregations of Collembola are smaller and less variable in tilled than in no-till soybeans (Farrar and Crossley 1982).

Agroecosystem management influenced soil Collembola species in sweet corn at the Rodale Research Center. Collembola populaions were altered by unique weed management and nitrogen fertilizers in the organic and conventional systems. Soil Collembola may serve as indicators of soil "health", or productivity potential. Disturbance of soil Collembola may indirectly influence crop nutrient cycles and crop response.

Weed management influences soil Collembola. Soil cultivation and atrazine decrease Collembola densities (Edwards and Lofty 1975; Critchley et al. 1979; Aritajat et al. 1977; Popovici et al. 1977; Subajga and Snider 1981). A favorable microhabitat and lack of herbicide residues, in this organic agroecosystem, contributed to a greater density of soil Collembola. Greater in-row weed populations were evident in the organic system. This may have buffered soil temperature and moisture fluctuations, creating a favorable habitat for Collembola. Atrazine and Lasso were applied to conventional sweet corn. Toxic effects of the herbicide and the absence of a weed cover contributed to low soil densities in conventional system soil.

The application of nitrogen-rich organic materials to agricultural soil enhances soil flora and fauna. Compost fertilizer increases soil microbial biomass (Nishio 1983), contributing to Collembola food source. Manure application increases soil densities of Collembola and other fauna (Weil and Kroontje 1979). Greater Collembola densities in the organic system in the presence of nitrogen were, therefore, expected. Soil populations of Collembola were greatest in the presence of bloodmeal-nitrogen. Bloodmeal is a concentrated source of proteinaceous nitrogen, providing a substrate for microorganisms. Compost also serves as a microbial substrate, innoculates the site with Collem-

bola, and improves soil structure. These beneficial effects of organic nitrogen positively influenced soil Collembola.

Soil Collembola populations in the conventional system reflect the application of herbicides and soluble fertilizers, and interactions occurring between these factors. Behan et al. (1978) hypothesized that urea may be toxic to Collembola, or cause a downward migration in soil; ammonium nitrate may have influenced Collembola in this manner. Soil Collembola densities were least in the presence of this fertilizer in the conventional system, implying a negative relationship between this conventional nitrogen input and soil Collembola. Collembola response to compost in both systems was similar. Atrazine, however, is temporarily adsorbed on negatively-charged organic matter. Compost application in the conventional system may provide adsorption sites for the herbicide, temporarily concentrating the herbicide at potential Collembola feeding sites. This may negatively influence Collembola.

Disregarding agroecosystem differences, nitrogen input did not influence soil Collembola. This is contrary to results observed with nitrogen input within systems. The opposite impact of organic and conventional nitrogen sources may have contributed to this lack of statistical difference.

Soil Collembola may be indicators of soil productivity. In the absence of soluble nitrogen fertilizers, soil flora and fauna are important agents of nitrogen mineralization. Environmental factors that are beneficial to these organisms also provide optimal crop growth potential. Optimal soil structure, moisture, organic matter content and chemical properties that are necessary for crop yield maintenance, have been positively correlated with Collembola population abundance (Weil and Kroontje 1979).

Soil Collembola enhance nitrogen mineralization (Anderson et al. 1983). High soil densities of Collembola, as observed in this organic system, may have enhanced nitrogen release from bloodmeal and compost, and indirectly influenced crop yield. Insoluble organic matter must be decomposed before nitrogen mineralization. Soil Collembola have a catalytic role in this process (Reichle 1977, Macfadyen 1963). A lesser soil density of Collembola or other organisms important to this process, may have limited nitrogen supply and crop yield. In contrast, the conventional ammonium nitrate fertilizer supplied a readily available source of crop nitrogen; soil Collembola were not necessary agents of nitrogen release in this system.

If the supply of soluble nitrogen fertilizers is limited, enhancement of decomposer organisms may contribute to crop yield maintenance. An agricultural system that is self-sustaining, and not dependent on conventional inputs, may also support abundant and diverse soil organism populations, which may be indicative of soil productivity and crop yield.

SUMMARY

Forty-two per cent of the soil Collembola were extracted from fresh soil samples in 24 hours, with Tullgren funnels. Extraction efficiency increased 55% when samples were stored at 4 C for 24 hours before extraction. Extraction efficiency varied with Collembola species. Rate of Collembola movement from soil samples in Tullgren funnels was positively correlated with length of extraction period.

Soil populations of Collembola in clover were aggregately distributed in the surface 15.24 cm, at normal to high densities. Distribution was random when soil

populations were low. Collembola were aggregately distributed in 5.08 cm vertical soil layers, to a depth of 15.24 cm. Tullbergia yosiii was the most prominent Collembola species in clover, followed by Isotoma notabilis and Isotomiella minor. Species prominence, however, varied seasonally. Compost piles and sweet corn research plots supported common Collembola species. Hypogastruridae were numerous in compost, but absent in soil samples.

Soil population densities of Collembola in sweet corn varied seasonally. Fluctuations in soil density on each sampling date were apparent. Agroecosystem management influenced soil populations of Collembola. Population densities in the organic system were greater than the conventional system. Within the organic system, densities were greater in the presence of bloodmeal-nitrogen than compost-nitrogen. Within the conventional system, densities were greater in the presence of compost-nitrogen, than ammonium nitrate. Randomization of research treatments limited population variation among plots in the conventional agroecosystem, but not in the organic system, however, this varied with species.

RECOMMENDATIONS

This research generated questions concerning the importance of soil Collembola in agroecosystems. These questions should be investigated in future research:

In an organic agroecosystem,

1. What percentage of organic matter decomposition is attributable to Collembola activity?
2. Do soil Collembola directly or indirectly influence crop yield?
3. Do soil Collembola influence the rate of nitrogen release from bloodmeal and compost?

4. Are soil Collembola indicators of crop yield, and what is the comparable role of other soil fauna?
5. During conversion from a conventional to an organic system, do initially low soil densities of Collembola limit crop yield?.

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LIST OF APPENDICES

Appendix 1. Log of Collembola species recovered from soil and compost at the Rodale Research Center, Berks County, Pennsylvania.

Entomobryidae

Pseudosinella violenta (Folsom)

Entomobrya (*Entomobrya*) *unostrigata* Stach

Lepidocrytus cinereus Folsom

Lepidocrytus pallidus Reuter

Lepidocrytus paradoxus Uzel

Isotomidae

Isotoma (*Desoria*) *notabilis* Schaffer

Isotoma (*Desoria*) *agrelli* Delamare

Isotoma (*Isotoma*) *viridis* Bourlet

Isotomurus (*Isotomurus*) *palustroides* Folsom

Isotomurus (*Isotomurus*) *tricolor* (Packard)

Isotomiella minor (Schaffer)

Folsomides americanus Denis

Proisotoma (*Proisotoma*) *minuta* (Tullberg)

Onychiuridae

Onychiurus (*Protaphorura*) *encarpatus* Denis

Tullbergia (*Tullbergia*) *yosiii* Rusek

Sminthuridae

Hypogastruridae

Appendix 2. Summary of literature concerning the agricultural impact on soil populations of Collembola.

Factor	Impact	Taxon	Parameter	Source[1]
Cultivation	(-)	Total	PD[2]	2,4,6,7,10,15
	(-)	Hemiedaphic	PD	7
	(-)	Sminthuridae	PD	11
	(-)	*S. elegans*	PD	
	(-)	Edaphic	PD	
	(-)	*B. parvula*	PD	
	(-)	*L. pallidus*	PD	
	(-)	*I. notablilis*	PD	
	(NC)[3]	*T. grandulata*	PD	10
Compaction	(-)	Total	PD	4
Fallow	(-)	Total	PD	2,15
Acidification	(+)	*T. krausbaueri*	PD	3
	(-)	Total	PD	3
Manure	(+)	Total	PD	2,5,6,12,17
	(+)	Species	Diversity	1,2,5,12,17
Manure plus fertilizer	(+)	Total	PD	12
Compost substrate	(+)	Total	PD	8
	(+)	Total	Activity	8
	(+)	Total	Metabolism	8
Fertilizer	(+)	Total	PD	6
	(NC)	Species	Diversity	6
	(NC)	Total	PD	2

continued

(Appendix 2, continued)

Increasing soil fertility	(+)	Species	Diversity	9
	(+)	Rare species	Diversity	9
	(+,-)	Total	PD	9
N_2 gas	(NC)	Total	Survival	13
CO_2 gas	(-)	Total	Survival	13
H_2S gas	(-)	Total	Survival	13
NH_3 gas	(-)	Total	Survival	13
Atrazine	(NC)	Edaphic	PD	11
	(NC)	*L. pallidus*	PD	11
	(NC)	*I. notablilis*	PD	11
	(+)	*S. elegans*	PD	11
	(-)	*F. candida*	Survival	16
	(+)	*F. candida*	Instar duration	16
	(-)	Isotomidae	PD	19
	(-)	Onychiuridae	PD	19
	(-)	Hypogastruridae	PD	19
	(-)	Symphypleona	PD	19
	(-)	Total	PD	19
Paraquat	(+)	Hemiedaphic	PD	7
	(-)	Euedaphic	PD	7
	(-)	Entomobryidae	PD	7
	(-)	*F. candida*	Survival	16
	(+,-)	*T. granulata*	Survival	16
DDT	(+)	Total	PD	15
	(+)	Euedaphic	PD	18
	(+)	Hemiedaphic	PD	18
BHC	(-)	Total	PD	15

continued

(Appendix 2, continued

Aldrin	(-)	Euedaphic	PD	18
	(-)	Hemiedaphic	PD	18
Dieldrin	(-)	Euedaphic	PD	18
	(-)	Hemiedaphic	PD	18
Telodrin	(-)	Euedaphic	PD	18
	(-)	Hemiedaphic	PD	18
Heptachlore	(-)	Euedaphic	PD	18
	(-)	Hemiedaphic	PD	18
Chlordane	(-)	Euedaphic	PD	18
	(-)	Hemiedaphic	PD	18
Carbaryl	(-)	Euedaphic	PD	18
	(-)	Hemiedaphic	PD	18
Parathion	(-)	Euedaphic	PD	18
	(-)	Hemiedaphic	PD	18
Diazinon	(-)	Euedaphic	PD	18
	(-)	Hemiedaphic	PD	18
Menazon	(NC)	Euedaphic	PD	18
	(NC)	Hemiedaphic	PD	18
DNOC	(NC)	Euedaphic	PD	18
	(-)	Hemiedaphic	PD	18
Simizine	(-)	Euedaphic	PD	18
	(-)	Hemiedaphic	PD	18

[1]See Appendix 3

[2]Soil population density

[3]No change in population parameter

Appendix 3. Sources of information used for the preparation of Appendix 2.

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12. Morrix, H. 1927. The insect and other invertebrate fauna of arable land at Rothamstead. Part II. Ann. Appl. Biol. 14:442-464.
13. Moursi, A. A. 1962. The lethal doses of CO_2, N_2, NH_3, and H_2S for soil arthropoda. Pedobio. 2:9-14.

continued

Appendix 3, continued

14. Moursi, A. A. 1970. Toxicity of ammonia on soil arthropods. Bull. Ent. Soc. Egypt., Econ. Serv. 4:241-244.

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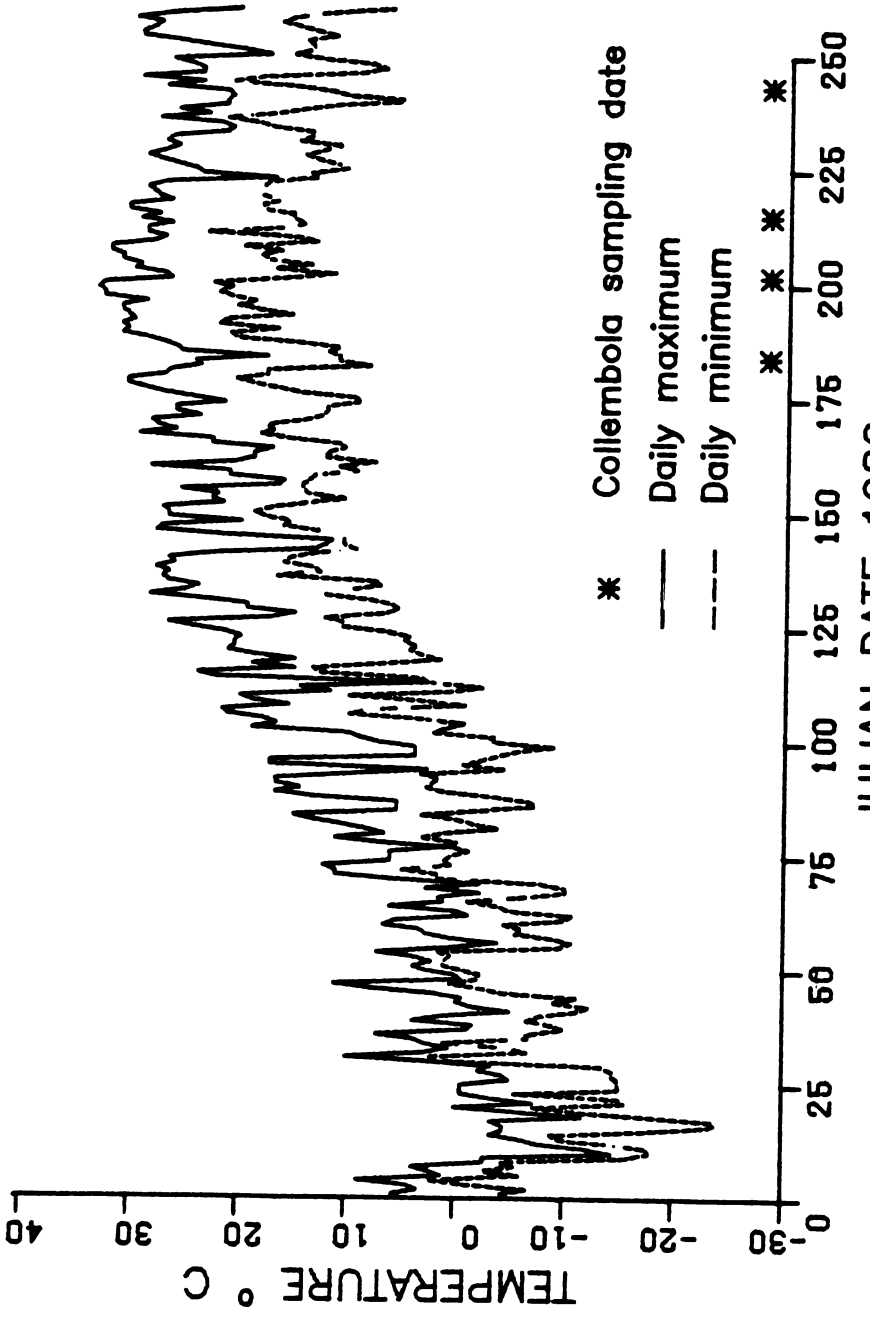
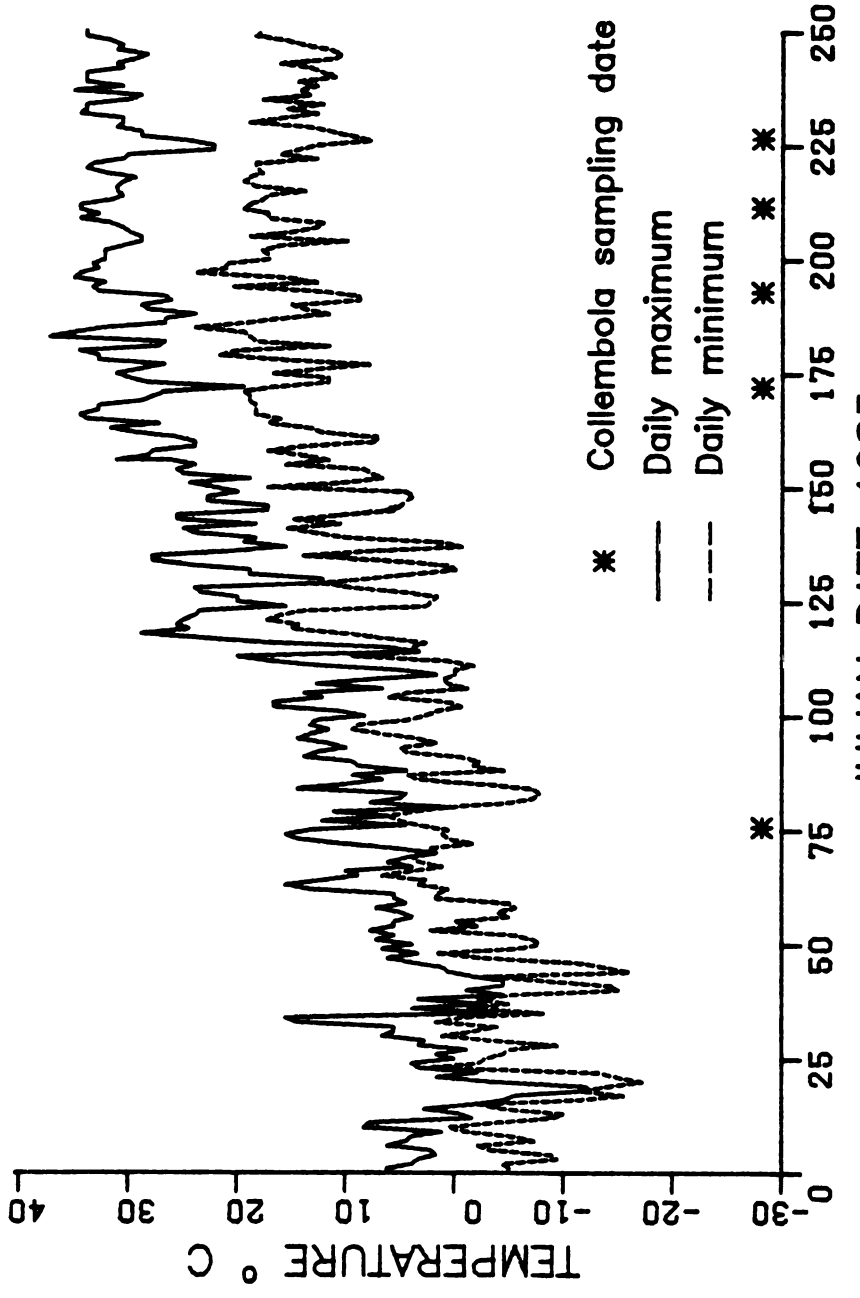
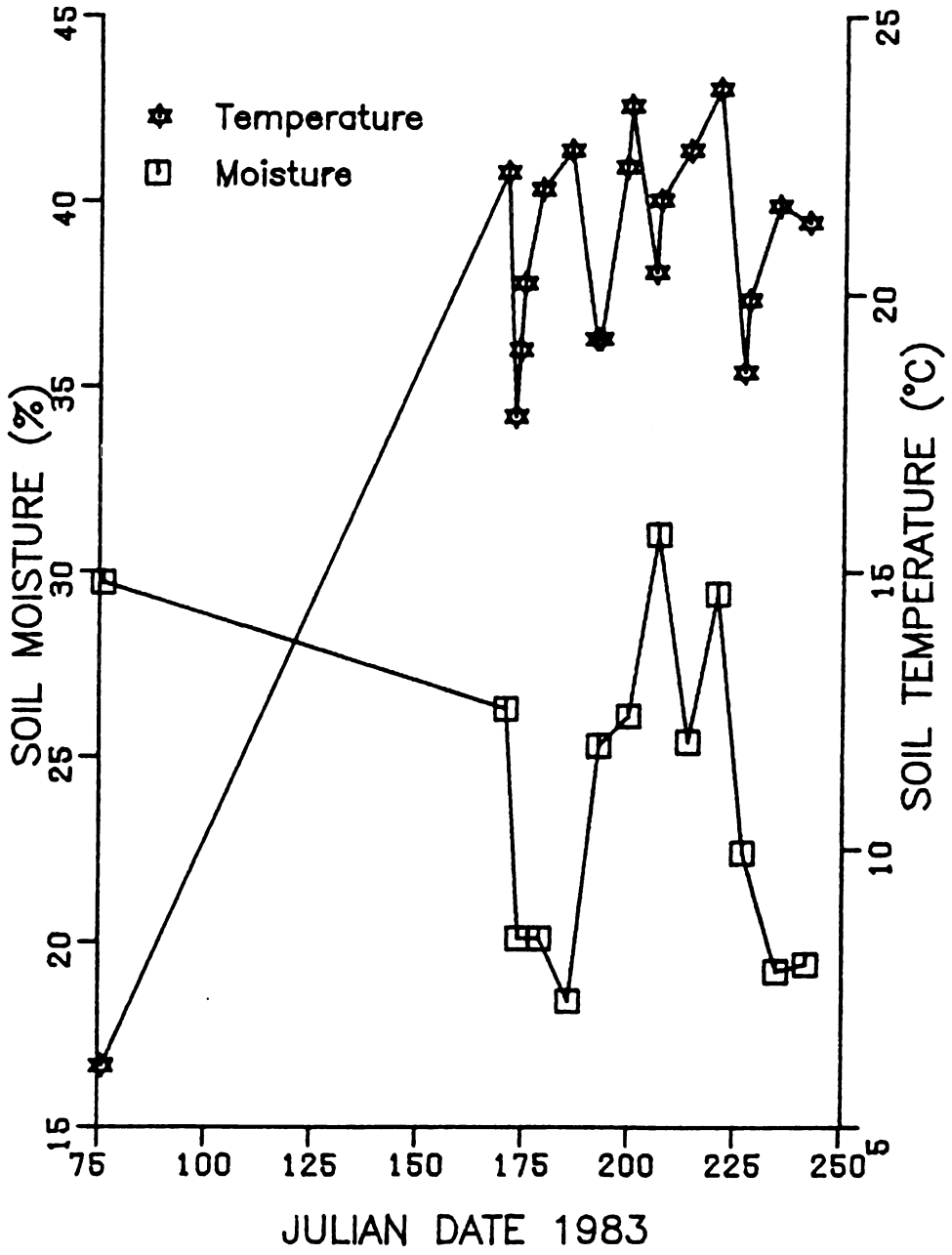


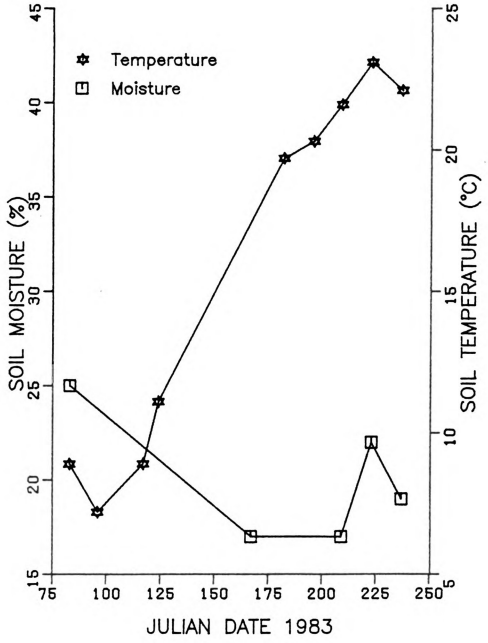
Appendix 4. Minimum and maximum air temperature at the Rodale Research Center, Berks County, Pennsylvania (1982).



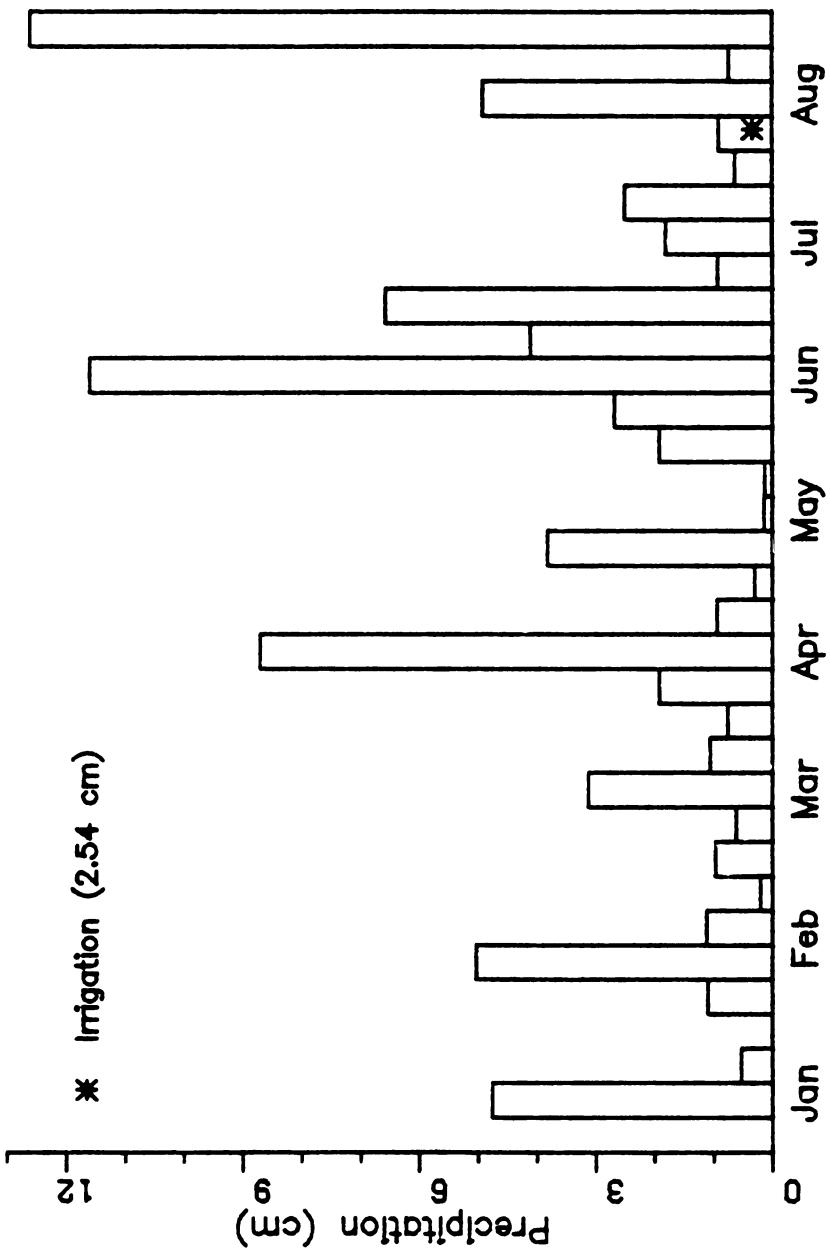
Appendix 5. Minimum and maximum air temperature at the Rodale Research Center, Berks County, Pennsylvania (1983).



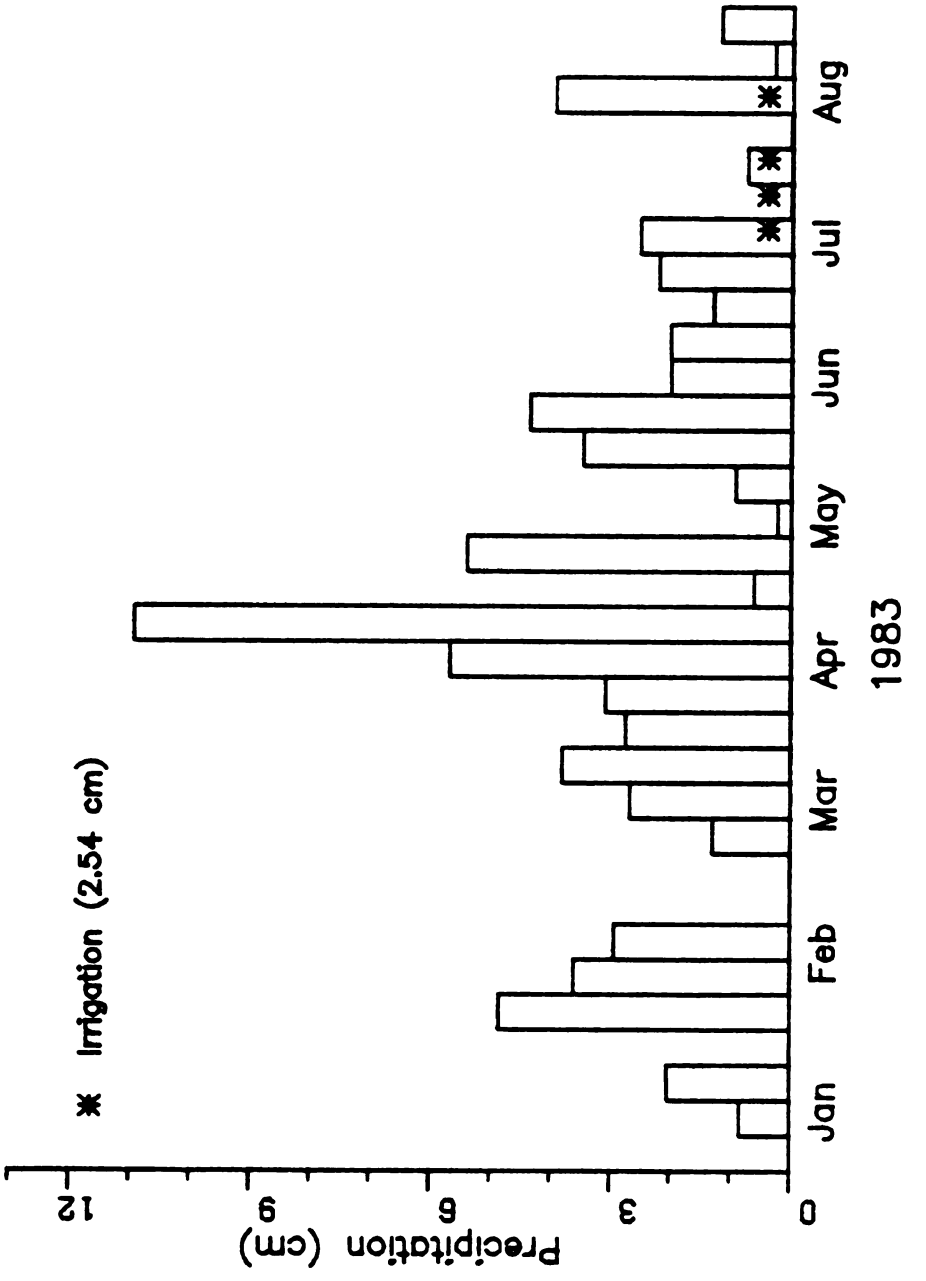
Appendix 6. Soil moisture and temperature in sweet corn at the Rodale Research Center, Berks County, Pennsylvania.



Appendix 7. Soil moisture and temperature in clover at the Rodale Research Center, Berks County, Pennsylvania.



Appendix 8. Weekly precipitation at the Rodale Research Center, Berks County, Pennsylvania (1982).



Appendix 9. Weekly precipitation at the Rodale Research Center, Berks County, Pennsylvania (1983).

Appendix 10. Pre-plant and post-harvest soil nutrient analysis in organic and conventional treatments (1982).

Treatment	pH	P[a]	K[b]	Mg[b]	Ca[b]	CEC[b]
Organic system						
All treatments[c]	6.9	296	0.59	1.98	7.6	10.8
Bloodmeal[d]	6.9	400	0.56	2.40	8.4	11.9
Compost[d]	6.9	384	0.62	2.30	8.3	11.5
Conventional system						
All treatments[c]	6.8	206	0.65	2.23	9.10	13.2
NH_4NO_3[d]	7.0	390	0.58	2.40	8.00	11.2
Compost[d]	7.1	421	0.61	2.60	9.5	11.8

[a] Kg/hectare

[b] Milliequivalent/100 g (cation exchange capacity)

[c] April 23, 1982

[d] October 27, 1982

Appendix 11. Seasonal prominence values and relative prominence values of soil Collembola in clover, and clover-oats, to a soil depth of 15.24 cm (1983).

	Sampling date (Julian date)							
	(83) March 24[3]		(97) April 7[3]		(116) April 16[3]		(133) May 12[3]	
Taxon	PV[1]	RPV[2]	PV	RPV	PV	RPV	PV	RPV
P. violenta	0.23	0.83	0	0	0.10	1.18	0.29	1.18
E. unostrigata	0	0	0	0	0	0	0	0
I. notabilis	7.20	26.04	1.18	12.88	0.30	3.53	5.00	20.27
P. minuta	0.36	1.30	0.07	0.76	0	0	0.58	2.35
F. americanus	0.23	0.83	0.51	5.57	0.04	0.47	0.75	3.04
I. viridis	0.12	0.43	0.04	0.44	0	0	0	0
I. minor	1.65	5.97	0.04	0.44	2.94	34.63	0.52	2.11
I. palustroides	0.04	0.14	0	0	0.15	1.77	11.42	46.29
I. tricolor	0.02	0.07	0	0	0	0	0	0
T. vosiii	17.80	64.38	7.22	78.82	4.92	57.95	6.11	24.77
Sminthuridae	0	0	0.10	1.09	0.04	0.47	0	0

continued

Appendix II, continued

Taxon	Sampling date (Julian date) (152) 3 June 1 PV	RPV	(167) 4 June 16 PV	RPV	(182) 4 July 1 PV	RPV	(196) 4 July 15 PV	RPV
P. violenta	0.04	0.26	0	0	0	0	0	0
E. unostrigata	0.04	0.26	0	0	0.21	4.99	0.70	37.63
I. notabilis	5.87	38.07	0.19	6.99	0.37	8.79	0.07	3.76
P. minuta	0.29	1.88	0	0	0	0	0	0
E. americanus	0.30	1.95	0	0	0	0	0	0
I. viridis	0.39	2.53	0.04	1.47	0.07	1.66	0	0
I. minor	5.68	36.84	0	0	0.04	0.95	0	0
I. palustroides	0.10	0.65	2.03	74.63	1.00	23.75	0.04	2.15
I. tricolor	0	0	0.10	3.68	0.52	12.35	0	0
T. vosiii	2.55	16.54	0.32	11.76	1.96	46.56	1.05	56.45
Sminthuridae	0.16	1.04	0.04	1.47	0.04	0.95	0	0

continued

Appendix 11, continued

Taxon	Sampling date (Julian date)					
	(209)[4] June 1		(223)[4] June 16		(237)[4] July 1	
	PV	RPV	PV	RPV	PV	RPV
P. violenta	0.04	1.26	0	0	0	0
E. unostrigata	1.65	51.89	1.95	83.33	5.44	97.32
I. notabilis	0.50	15.72	0.19	8.12	0.04	0.72
P. minuta	0.04	1.26	0	0	0	0
F. americanus	0	0	0	0	0	0
I. viridis	0	0	0	0	0	0
I. minor	0.04	1.26	0	0	0.04	0.72
I. palustroides	0	0	0	0	0	0
I. tricolor	0.16	5.03	0.16	6.84	0	0
T. vosiii	0.75	23.58	0.04	1.71	0.07	1.25
Sminthuridae	0	0	0	0	0	0

[1]Prominence value = AD x $\sqrt{AF}$ (see text).

[2]Relative prominence value = prominence value/$\sum_i$ (see text).

[3]Weedy clover site (Figure 2).

[4]Clover-oats site (Figure 2).

Appendix 12. Seasonal prominence values and relative prominence values of Collembola in clover and sudex, at 5.08 cm soil depths, to a total depth of 15.24 cm (1983).

	Sampling date (Julian date)											
	March 24 (83)[3]						June 22 (173)[4]					
	Soil depth (cm)											
	0 - 5.08		5.08 - 10.16		10.16 - 15.24		0 - 5.08		5.08 - 10.16		10.16 - 15.24	
Taxon	PV[1]	RPV[2]	PV	RPV	PV	RPV	PV	PRV	PV	RPV	PV	RPV
P. violenta	0.10	0.76	0.26	1.84	0	0	0	0	0	0	0	0
E. unostrigata	0	0	0	0	0	0	0	0	0	0	0	0
I. notabilis	3.36	25.40	0.26	1.84	0	0	7.00	31.93	1.06	45.89	11.88	69.33
P. minuta	0.44	3.33	0	0	0.04	0.49	0	0	0	0	0.38	2.22
F. americanus	0.07	0.53	0.45	3.18	0.10	1.23	1.50	6.84	0	0	0	0
I. viridis	0.04	0.30	0.04	0.28	0	0	0	0	0	0	0	0
I. minor	0.32	2.42	0.82	5.79	1.67	20.62	3.89	17.75	0.38	16.45	0.75	4.38
I. palustroides	0	0	0	0	0	0	1.00	4.56	0	0	0	0
I. tricolor	0	0	0	0	0	0	0.53	2.42	0	0	0	0
O. encarpatus	0	0	0	0	0	0	0	0	0	0	0	0
T. yosii	8.90	67.27	12.33	87.08	6.29	77.65	8.00	36.50	0.87	37.66	4.00	23.34
Sminthuridae	0	0	0	0	0	0	0	0	0	0	0.13	0.73

Continued

Appendix 12, continued

	Sampling date (Julian date)											
	July 26 (206)[4]						September 1 (243)[4]					
	Soil depth (cm)											
	0 - 5.08		5.08 - 10.16		10.16 - 15.24		0 - 5.08		5.08 - 10.16		10.16 - 15.24	
Taxon	PV	RPV	PV	RPV	PV	RPV	PV	PRV	PV	RPV	PV	RPV
P. violenta	0	0	0.35	7.06	0.44	13.25	0.35	3.93	0	0	0	0
E. unostrigata	0	0	0	0	0	0	0.25	2.81	0	0	0	0
I. notabilis	0.86	9.58	1.73	34.88	0.88	26.51	0.35	3.93	0	0	0	0
P. minuta	1.73	19.27	0	0	0	0	0	0	0	0	0	0
F. americanus	1.75	19.49	0.13	2.62	0	0	7.00	78.65	2.12	100	0	0
I. viridis	0	0	0	0	0	0	0	0	0	0	0	0
I. minor	1.41	15.70	0.53	10.69	0.70	21.08	0	0	0	0	0	0
I. palustroides	0.25	2.78	0	0	0	0	0.35	3.93	0	0	0	0
I. tricolor	0.25	2.78	0	0	0	0	0.35	3.93	0	0	0	0
O. encarpatus	1.73	19.27	0.63	12.70	0	0	0	0	0	0	0	0
T. yosii	0.65	7.24	1.59	32.06	1.30	39.16	0.25	2.81	0	0	0	0
Smithuridae	0.35	3.90	0	0	0	0	0	0	0	0	0	0

[1]Prominence value = AD x $\sqrt{AF}$ (see text).

[2]Relative prominence value = prominence value/$\sum f_i$.

[3]Weedy clover site (Figure 2).

[4]Sudax site (Figure 2).