5-1996

Earthworm population dynamics as influenced by cropping and tillage history

Nathan J. Storck

To the Graduate Council:

I am submitting herewith a thesis written by Nathan J. Storck entitled "Earthworm population dynamics as influenced by cropping and tillage history." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

Donald D. Tyler, Major Professor

We have read this thesis and recommend its acceptance:

Tom Ammons, Michael Mullen, Glenn Wilson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Nathan J. Storck entitled "Earthworm Population Dynamics As Influenced By Cropping And Tillage History". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

Donald D. Tyler

Donald D. Tyler, Major Professor

We have read this thesis and recommend its acceptance:

Mark Mullen

H. Paul Denton

Glenn V Wilson

Accepted for this Council:

C W Minkel

Associate Vice Chancellor
and Dean of The Graduate School

EARTHWORM POPULATION DYNAMICS
AS INFLUENCED BY CROPPING
AND TILLAGE HISTORY

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Nathan J. Storck

May, 1996

DEDICATION

This thesis and the results of all the work that went into researching and producing this document are dedicated to my wife, family, friends, and faculty who supported me throughout this experience. Their cheerful words of encouragement, concern, and honesty are the sole reason this goal was achieved.

ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Don Tyler for putting up with my constant questions. I also wish to thank my graduate committee members, Dr. Tom Ammons, Dr. Michael Mullen, Dr. Glenn Wilson, and Dr. Paul Denton for their help and advice throughout my tenure at the university. Finally, I would also like to thank all the special people who have helped me in so many ways; my wife Marcy, my brother Mark Storck, the greatest secretary in the world Dawn Brown, Janet Gibson, Nancy Austin, Todd Willian, Holly Carter, Bill Halfman, Mark Eisenbies, Barry Kinsall, Dave Walker, and everyone else I may have forgot for without their help, advice, and friendship none of this would have been possible. I cannot thank them all enough.

ABSTRACT

No-tillage farming has become an important practice in many areas of the United States. Because of the loessal soils that exist in West Tennessee and their highly erodible nature, no-till farming is becoming the primary cropping technique with which to reduce erosion and conserve topsoil. Many aspects of no-till farming have been researched in past years; the effects of no-tillage on earthworm population have received little attention in Tennessee agriculture. Earthworms significantly influence the structure and fertility of soils and in turn effect root growth, infiltration of soil water, microbial populations, soil aggregation, and other properties. This research project was conducted to determine and compare the population dynamics of earthworms in cultivated production fields versus no-till production fields. Sites located at the University of Tennessee Milan Experiment Station were chosen for sampling. The sampling was done 4/94, 10/94, and 4/95. Samples for determining the effect of no-till were taken from three no-till and two tilled production fields and from an ongoing experiment containing both no-till and tilled plots. Samples were also taken from a long term no-till cover crop experiment to compare the effects of various covers. Six 30cm X 30cm X 15cm deep volumes of soil were taken from each production field and one sample per plot from the ongoing experiments. Soil samples were taken to determine bulk density, volumetric water content, total carbon, and pH. Surface residue samples were also taken at each no-till sample site.

Earthworms were extracted by hand sorting and preserved in 10% formalin solution for identification. Three seperate species were identified: two native species; *Diplocardia caroliniana* and *Bimastos longicinctus* and one exotic; *Apporectodea trapeszoides* No-till cropping systems had a significant effect on earthworm populations for the 10/94 and 4/95 sampling periods and over the entire period due to the availability of food and limited soil disturbance. Length of time in no-till also had a significant effect on population for the 4/94 and 10/94 sampling periods and over the entire sampling period. Cover crop showed no significant difference for the 10/94 and 4/95 periods, but did for the 4/94 sample period. The results of the analysis performed had a high rate of variability overall.

TABLE OF CONTENTS

LIST OF TABLES

1. INTRODUCTION

Soil conservation has become an important issue in agriculture, especially in West Tennessee where erosion potential is high. The area is composed of loessal type soils and displays a rolling terrain that is an excellent environment for erosion to take place (Fullerton et al., 1977 and Springer and Elder, 1980). Rainfall intensity is high and a large proportion of the area is planted in row crops. In 1977, the Council on Environmental Quality reported erosion rates in Tennessee to be 17 tons per acre (Batie, 1983). Shelton and Bradley (1987) reported that rates in Tennessee were approximately 14.7 tons per acre per year. Because of the erodibility of these soils, no-till usage has become an important practice in western Tennessee. No-till made up 23.5% of the total acreage farmed in Tennessee in 1991. This equated to approximately 421,000 acres (TN Dept. of Ag., 1995). By 1995 no-till had increased to 45.3% of the state total and equaled approximately 1,138,000 acres. Other conservation tillage practices made up 18.5% of the total acreage. In total, 64.9% of the acreage in Tennessee utilizes some form of conservation tillage practice. Recent results from the National Resources Inventory Survey (USDA-SCS, 1992) showed erosion losses in cropland in Tennessee to have dropped to approximately 7.1 tons per acre, a decrease of about 50%.

Research has been done concerning the effects of no-tillage on erosion, soil physical properties, infiltration, and chemical movement through the soil profile. No research has been done in Tennessee on the effects of tillage practices on earthworm populations. The objective of this research was to to determine the effects of no-till versus tillage systems on earthworm populations.

2. EFFECTS OF TILLAGE AND CROPPING SYSTEMS ON EARTHWORM POPULATION DYNAMICS AND SPECIES

Review of Literature

Basic Earthworm Taxonomy

Earthworms are invertebrate animals and belong to the Phylum Annelid (Latin for "rings".), Class Chaetopoda, and Order Oligochaeta. Members of the Order Oligochaeta can be aquatic or terrestrial. The aquatic species are called microdiles. The terrestrial species that are commonly referred to as earthworms are called megadriles (Edwards and Lofty, 1977). Approximately 1,000 species of earthworms have been identified in the world. The most common are in the Family Lumbricidae, which contains over 220 known species. In the northern sections of the United States, most native species did not survive the Quaternary glaciations (Lee, 1985) while those south did. The Lumbricidae family was reintroduced by European settlers approximately 400 years ago.

Earthworms are saprovores, obtaining their energy primarily from ingesting dead plant material (Satchell, 1983). Earthworms are often grouped by their feeding and burrowing habits. Bouche (1977) developed a classification system based on morphological and ecological characteristics as follows: epigees are litter dwelling and feeding and are generally found in decaying plant residue; endocees are shallow dwellers that live in the mineral soil and feed on dead roots; and aneciques live deep in the soil and feed on dead vegetative litter at the surface. Shallow dwelling earthworms are usually located in the upper 12 inches of soil. Deep dwelling species live below this and can be found at depths of approximatley 1.5 to 1.8 meter (Kladivko, 1993).

Basic Earthworm Morphology

The general morphology of earthworms is such that they are streamlined and have no protruding appendages, a perfect structure for burrowing activities. They are externally segmented. These segments, called somites, are on the exterior and are divided along the entire length of the body. They allow for flexibility and are tough muscular structures which also allow the earthworm to push hard packed soil and even push aside stones up to six times their weight. On each segment are bristle-like structures called setae, which are used primarily for movement. They can be extended or retracted by means of muscles that are attached at their base and to the interior of the earthworm. The outer area is called the cuticle which is thin and transparent. Underneath is the epidermis which is made up of a single layer of several types of cells. The epithelial cells give body and strength to the earthworm (Minnich, 1977 and Edwards and Lofty, 1977). Two forms of gland cells are present, mucous and albumen. The mucous cells are responsible for reacting to environmental conditions surrounding the earthworm and secrete coelomic fluid in response to chemical and mechanical irritation or when subjected to extremes of heat, cold, or stress. The coelomic fluid prevents desiccation, promotes respiration, and provides protection from predators (Edwards and Lofty, 1977, Minnich, 1977). The function of the albumen cells is not known. Earthworms are hermaphrodites, possessing both male and female reproductive organs; however they are not self-fertilizing. Reproduction takes place in a swollen sac called the clitellum, which secretes an external cocoon where the eggs or ova are deposited. There they are fertilized and develop (Reynolds, 1977; Edwards and Lofty, 1977; Minnich,1977).

Environmental Effects on Earthworms

Earthworms can be affected by a great number of environmental influences including, pH, soil temperature, soil water content, organic matter availability, soil chemical composition, and soil type. These parameters in turn affect the population, location, and distribution of earthworms within an area.

Earthworms have the ability to sense and detect acids in the soil environment. Soil acidity effects vary from species to species of earthworm, but all species have a pH threshold below which they cannot survive for long. The species *Allolobophora longa* will not burrow into soil below a pH of 4.5

(Laverack, 1961) and *Lumbricus terrestris* below 4.1. Satchell (1955) used soil samples from a pasture that was used for fertilizer experimentation to study pH affects. The soil samples had pH values of 4.0, 4.1, 4.4, 5.0, 5.1, 5.6, 5.8, 6.9, and 7.0. In the most acidic soils the species he utilized showed violent reactions to avoid contact with acid soil and excreted coelomic fluid from their pores to provide protection. After 24 hours, 58 of 60 worms exposed to pH 4.4 or less had died. Edwards and Lofty (1975) studied populations in pH's ranging from 3.7 to 7.5 in the same area as Satchell's (1955) prior research. *Lumbricus terrestris* numbers increased as pH increased, while other species (*A.calignosa, A.rosea, A.nocturna*) had an optimum range of 5.0 to 6.0. This confirmed prior research done by Piearce (1972) in Wales where numbers were higher in soils with a pH of approximately 6.0 and smaller in soils below a pH of 5.0.

Changing soil temperature levels and seasonal climatic factors greatly influence earthworm metabolism, growth, respiration, and reproduction. The optimum temperatures for most earthworm activity range from 10°C to 23°C. This is variable from species to species. Worm breeders report (Minnich, 1977) that deep dwellers (*L.terrestris*) prefer cooler temperatures ranging from 1.7°C to 12.8°C, whereas shallow dwellers (*A.caliginosa*) prefer temperatures ranging from 10°C to 23.3°C (Edwards and Lofty, 1977). Lethal temperatures usually are freezing and upper temperatures are approximately 28°C for *L.terrestris* and 26°C for *A.caliginosa* . Cooler temperatures have been shown to increase the growth period for most species.

Respiration is seriously affected by soil temperature. Pomerat and Zarrow (1936) showed that the respiration rate increased from 25 to 240 mm^3 of air per earthworm per 30 minutes when the temperature was changed from 9°C to 27°C. Several earthworm species produce cocoons year round, however most follow a climatic pattern. Work done by Evans and Guild (1948) showed that Lumbricids produced the fewest cocoons during the winter months when a temperature threshold of approximately 3°C existed. Warmer temperatures allow for quicker cocoon hatching and faster growth. Cocoon production of *A.caliginosa* quadrupled over a range of 6 to 16°C (Evans and Guild, 1948).

Moisture content also affects earthworm activities. Sexual activity slows as conditions become drier, obligatory diapause occurs in the Lumbricid species when these conditions arise. This is a condition that may be independent of environmental conditions, but usually occurs in response to adverse conditions. *Allolobophora* species usually enter into a facultative diapause which is in response to existing dry periods (Edwards and Lofty, 1977). Optimum cocoon production has been reported to occur when soil water content is between .28 and .42 by weight (Minnich, 1977). Earthworms are comprised of approximately 85% water by fresh weight. They can lose up to 75% of their body water and still survive. (Edwards and Lofty, 1977; Minnich, 1977).

The kind and amount of organic matter available to earthworms can affect the size of populations and the species present. Work done by Evans and Guild (1948) showed that more cocoons were produced by earthworms eating decaying animal organic matter than those fed plant material and the same occurred with those fed nitrogen-rich diets compared to those with little or no nitrogen present (Evans and Guild, 1948). Guild (1951) stated that all species of earthworms prefer dung or succulent herbage to tree leaves and that pine needles are preferred least of all. Leaf litter is not acceptable to earthworms when it first accumulates on the ground. It usually requires a period of decomposition before being edible.

Mackay and Kladivko (1985) researched the amount of organic matter redistribution by *Lumbricus rubellus* and rates of residue disappearance. Residue disapperance rates increased greatly in both corn and soybean during a 36 day plot experiment. They also reported that earthworms are important in incorporating significant amounts of organic matter into the soil profile. Litter feeding and soil ingesting earthworms can and usually do exist together and can help to redistribute surface crop residue more evenly throughout the soil profile. This would be important in no-till cropping systems.

Earthworms also show a preference for specific soil textures. They are rarely found in very coarse-textured soils, possibly due to physical abrasion of their body surface and the susceptibility of these soils to drought. In research done by Guild (1951), populations were higher in loams. They are also smaller in soils with prolonged saturation because of possible oxygen deficiencies. Generally, as clay content of a soil increases, earthworm populations begin to decrease. However, they can be found in almost any soil that can provide some moisture, protection, and a food supply.

Effects of Agricultural Practices on Earthworms

Organic matter influences earthworm species activity and numbers. Research performed by Hopp (1946) showed that earthworm populations differed greatly in different crops. Numbers were smallest in row crops, and greatest under fields growing winter cereal and summer legumes. The more often row crops were grown the smaller the earthworm populations were. Similar results were obtained by Hopp and Slater (1949). The results from their research showed that the smallest earthworm populations were under continuous corn. Populations were highest under winter cereals. Numbers were as large in fields growing winter cereals followed by legume hay as those in regular pasture land. These results showed that the most important factor affecting the influence of crops on earthworm populations was the amount of plant residue being returned to the soil after harvest. It also showed that earthworms do prefer herbage that is more leafy or succulent compared to the stemmy material produced by crops such as corn. Succulent leaf material often has a low C:N ratio. Corn stalks contain a high percentage of constituents such as cellulose and lignin have a high C:N ratio, and are unpalatable to earthworms (Witkamp, 1966).

Nearly all agricultural lands are treated with some form of fertilizer. The effects of fertilizers can be either direct by changing the soil acidity, or indirect by changing the amount or quality of organic matter available to the resident earthworm populations. Johnstone-Wallace (1937) reported a four-fold weight increase of worms in the soil when an application of superphosphate and lime caused a dense growth of clover to develop. The effects of superphosphate have been disputed and could differ depending on the soil conditions at the time of application (Bachelier, 1963). Doerell (1950) showed superphosphate increased populations. Work done by Escritt and Arthur (1948) reported decreases in populations in grass plots where super-phosphate was utilized.

Indirectly, nitrogen fertilizer has been shown to increase numbers of earthworms due to increased grass production resulting from large additions of nitrogen (Watkin, 1954). Increased numbers were also reported in work done by Jacob and Wiegland (1952), where 128 earthworms/m^2 existed in plots without nitrogen additions compared to 176 earthworms/m^2 in those where various forms of nitrogen were applied. Conflicting results have been reported in work done by Edwards and Lofty (1975) on a long-term experimental field. They were not able to determine a specific trend within their research. Populations decreased after extremely long exposures to a range of nitrigen application rates (48, 94, and 145 kg/ha). Zajonc (1970) reported that increasing rates of nitrogen (100, 200, and 300 kg/ha) decreased earthworm numbers, but that additions of either phosphorus or potassium seemed to alleviate the detrimental effect to some degree. Lower populations have also been observed with ammonium sulfate (Slater, 1954; Richardson, 1938). This is probably due to the acidification of the soil.

Pesticides, including herbicides, fungicides, insecticides, acaracides, and nematicides, have been shown to be either harmless or only slightly toxic to earthworms. Kladivko and Timmenga (1990) found that the placement (broadcast versus banded over the seed row) and timing of a pesticide application could be significant factors affecting the toxicity of pesticides to earthworm populations. Timing is important because earthworms are dispersed throughout the profile at certain times of the year but are more localized at the surface at other times. They suggested that specific placement would affect the proportion of the population exposed to the chemicals. Herbicides are usually not directly harmful to earthworms. Some like atrazine, simazine, and cynazine may have progressive effects on populations if used annually over extended time periods (Edwards and Lofty, 1977). In some instances, indirect positive effects occurred due to the availability of organic matter provided by the action of the herbicide at the soil surface.

Tillage influences earthworm populations by affecting the amount, quality, and location of their food supply. Populations were reported to be higher under pasture (Barley, 1949) and no-till (Kladivko and Timmenga,

1990) than continuously cropped fields. Pasture and no-till systems provide more organic matter and increased insulation because of the vegetative layer that is available. Populations were reported to be lower in colder climates when utilizing conventional tillage practices due to the lack of insulation provided by crop residue on the soil surface. Decreases in population from cultivation were reported to be minimal immediately following tillage operations (Kladivko and Timmenga, 1990). Populations did not begin to markedly decrease until repeated cultivation occurred. Tillage destroys channels formed by the deep burrowing species, which affects the availability of food and forces them to reconstruct channels. Fewer of the shallow species were affected overall; however the loss of the surface insulation decreased populations in the colder climates of the United States (Evans and Guild, 1948). Graff (1953) showed that numbers steadily decreased after pasture land had been plowed. This decrease was by as much as 70% over five years (Evans and Guild, 1948). Mechanical equipment used in these practices had little or no influence on the decrease in numbers as far as death due to machinery usage (Kladivko and Timmenga, 1990). In early work done by Hopp (1947) and Slater and Hopp (1946), deep burrowing earthworms were affected more by tillage than shallow species. Mackay and Kladivko (1985) found higher populations in no-till plots than in moldboard plots of continuous soybeans in their study, but no differences were found with tillage systems in corn. They suggested the wider C:N ratio of corn surface residue as compared to that of soybeans could be the reason for this occurrence. Other reasons listed were the additions of anhydrous ammonia and the use of Terbufos (insecticide) in the corn plots. House and Parmelee (1985) reported higher populations with no-till in a sorghum-soybean rotation as did Lal (1976) in no-till corn and soybeans. Other researchers have found no increase in population, as did De St. Remy and Daynard (1982) in a no-till corn study.

Soil Physical Property Effects

Earthworm activity influences soil structure through 1) ingestion of soil, partial breakdown of organic matter, intimate mixing of these fractions and ejection of the soil through casting and 2) burrowing through the soil and bringing subsoil to the surface (Edwards and Lofty, 1977). Earthworms are responsible for the turnover of large amounts of soil by bringing it from deeper layers of the soil profile to the surface. This varies with habitat and geographic region and ranges from 2 to 250 ton/ha/year. This is equivalent to bringing up layers of soil 1mm to 5cm thick per year. Over the long term, a relatively stone free upper soil layer formed. This occurs particularly in old pasture land (Edwards and Lofty, 1977).

Aggregates are mineral granules joined together that are capable of resisting wetting, erosion and compaction, and will remain loose when the soil is dry or wet (Edwards and Lofty, 1977). Soils that are well-aggregated are usually well aerated and drained (Minnich, 1977; Edwards and Lofty, 1977).

Research has determined that not all earthworm species can produce aggregation with the same efficiency. One theory for formation is that plant material that has passed through the worms helps to hold the soil particles together. Stability of the aggregates can be dependent on the food available and the behavior of the earthworms (Guild, 1951). Research has shown that aggregates formed under grass or forest are more stable than those formed under arable land (Dutt, 1948; Teotia et al., 1950; Mamytov, 1953). Aggregates may also be formed by internal secretions that act as a cementing agent for the soil particles as they pass through the intestines of the earthworm (Bakhtin and Polsky, 1950). There may be more factors involved in this observation due to the large stability differences in castes/aggregates produced in pasture versus that of cultivated land. A second theory is that calcium humate is synthesized internally from organic matter and calcium from the earthworm's calciferous glands are responsible for producing stable casts by cementing soil particles together (Edwards and Lofty, 1977). A bacterium, which can produce stabilizing materials in casts, has been considered as a possible cause for aggregate formation. This is because although organic matter can cause aggregation, it does so only when microorganisms are present (Waksman and Martin, 1939).

Earthworm burrows contribute greatly to the improvement of soil aeration. This is important because soil that does not contain sufficient air space tends to be dense, hard, and compact and is less suitable for plant growth (Minnich, 1977). Soil physical property effects caused by earthworm activity can be explained by changes in pore size distribution. The pores created by the worms can vary in size from large channels created by burrowing (2 - 11mm), or medium in size resulting from casting and turnover of the soil. The large pores influence infiltration, aeration, and root penetration and the medium pores influence water holding capacity (Syers and Springett, 1983). Teotia et al (1950) reported that earthworm activity increased the porosity of two experimental soils from 27.5% to 31.6% and 58.8% to 61.8%, respectively. Stockdill and Cossens (1966) reported similar increases in the infiltration of a pasture where earthworms were introduced. Sharpley et al. (1979) observed a three-fold reduction in infiltration rates when earthworms were removed from a pasture land and a two fold increase in surface runoff. Fields with substantial earthworm populations drain four to five times faster than soils without them (Hopp and Slater, 1949; Teotia et al, 1950; Guild, 1952). In an experiment done by Guild (1951), two fields were compared after a 24 hour time period for free drainage. Both contained similar gravimetric soil water contents; however the field without earthworms was waterlogged, whereas the other was not. Activity of *L. terrestris* in a Wisconsin soil increased cumulative rainfall intake by one half (Peterson and Dixon, 1971). In New Zealand, work done by Stockdill and Cossens (1966) showed an increase of 17% in field capacity in soils that contained earthworms when compared to those without.

Soil water content is another important soil factor affecting earthworms. Rhee (1969) researched earthworm effects on water available to plants. Soil water content was measured at wilting point and field capacity in three plots containing earthworms and three without earthworms. The plots with earthworms had a mean available water content of .373 cm^3 cm^{-3} copmared with .265 cm^3 cm^{-3} in the plots without earthworms. Similar results were obtained by Westeringh (1972).

Earthworms require large amounts of water in order to function properly. They obtain it through the food they ingest and directly through their cuticle from surface films or water filled pores. The basic principles that govern plant uptake of soil water also determine the water that earthworms can obtain. Field capacity for any type soil is the optimum water content for earthworms; however this varies from species to species. When a soil reaches wilting point the earthworms are unable to get the water they need much like plants. They must move to an area of higher water conent or go into a resting state until the soil environment returns to field capacity for that soil (Lee, 1985). Numerous studies have been done on the soil physical characteristics of the soils of the southeast. One important area is water retention measurements based on volumetric water content vs. pressure head of water. One study states that the Grenada series typically has values for Θ_v at 15 bars of 0.11, 0.14, and 0.25 cm^3 cm^{-3} (Romkens, et al., 1986). These values are consistent with predicted values for wilting point for a silt loam.

Research concerning earthworms and optimum soil water content has mainly been performed from an ecological view point. Little consideration has been given to the importance of the soil profile parameters mentioned when determining soil water content. Khalaf El-Duweini and Ghabbour (1965) showed that two earthworm species studied in a clay soil preferred gravimetric water contents of .2 to .4 g g^{-1} and .35 to .55 g g^{-1}, respectively. Grant (1955) placed two species of earthworms were placed in a 15cm diameter 60cm deep cylinder that contained a sandy loam soil. The bottom was placed in a jar. The cylinder was saturated and allowed to air dry for two weeks. Water contents were determined based on an oven dry weight at four different levels. The gravimetric water contents ranged from .14 g g^{-1} at the upper 15cm to .3 g g^{-1} at the bottom of the cylinder. The majority of both species of earthworms preferred the gravimetric water content of .3 g g^{-1}. Assuming a bulk density for a representative surface sandy loam of 1.7g/cm^3 (Brady, 1990), the volumetric water content of the lower 60cm of the cylinder would be .36 cm^3 cm^{-3}. This is well above the range of field capacity which would be around 0.10 cm^3 cm^{-3} (Brady, 1990) and right at the porosity of around 0.35 cm^3 cm^{-3} thus suggesting saturated conditions. Madge (1969) reported that earthworms preferred soil that contained a water content between .12 and .17 g g^{-1}. A soil water content of .23 g g^{-1} seemed to be optimum for caste production. There is no single optimum soil water content for any given species of earthworm. The research that has been done indicates that earthworms do prefer wetter soils and that soils at field capacity seem to be an acceptable environment for earthworms.

Population Distribution

Earthworm distribution within an area depends on many different factors. Vertically the distribution varies between species, life cycles, seasonally, and diurnally (Lee, 1985; Baker et al., 1992). This distribution depends on the species (deep vs. shallow dwelling) and the time of the year in conjunction with temperature and soil water content. Guild (1952) stated that earthworms are not randomly distributed in soil. Murchie (1958) reported that the horizontal distribution of earthworms was influenced by the following factors: 1) physiological and chemical, which includes soil temperature, moisture, pH, inorganic salts, texture, and aeration, 2) available food and types, and 3) reproductive potential and dispersive powers of the species. A combination of these factors is responsible for overall distribution.

Schwert (1980) addressed stream drift, mass emergence, and animal transport as possibilities for dispersal of Lumbricids. In his stream drift research 300 cocoons were found in a stream over a five month time period. It was found that 92% of those were viable. Mass emergence is the phenomena where large numbers of earthworms emerge at the surface due to specific soil temperature and moisture parameters. Schwert theorized that this was an evolved behavioral response allowing earthworms to disperse freely and rapidly through loose leaf litter in relative safety. Animal transport was determined to be too difficult to research and of little significance.

Field Population Determination

Determining earthworm populations in the field can be a difficult task. There are several methods that have been utilized and no one method is right for all situations. The methods utilized for sampling can be classified as 1) physical where excavation of the earthworm habitat occurs, 2) behavioral, where they are stimulated to move out of the soil, and 3) indirect, where casts or middens are used to determine numbers (Baker and Lee, 1993). Some of the more utilized methods of enumeration are hand sorting, chemical repellents, electrical methods, and heat extraction (Baker and Lee, 1993; Edwards and Lofty, 1977; Minnich, 1977; and Reynolds, 1977).

Digging and hand sorting is the traditional method for sampling earthworm populations. It is more labor intensive than the others, but is considered the most accurate (Reynolds, 1977; Edwards and Lofty, 1977; Bouche´ and Gardner, 1984). The advantages of this method are that a well defined area can be determined and all active individuals can be collected (Reynolds, 1977). There is no set method in which the soil is removed nor has a specific sample size been determined as best. Reynolds (1977), and Edwards and Lofty (1977) suggested utilizing soil cores of a specific dimension as a viable means to get samples. Hendrix et al. (1992) used a 10cm dia X 15cm deep core and Pilz (1992) used a 625 cm^2 in area X 10 cm deep core. Kladivko et al. (1993) utilized a 45cm X 25cm sampler at a 25cm depth. Zicsi (1958) reported that the number of worms per m^2 decreased with increasing sample size when utilizing the hand sorting method.

The objectives of this study were to determine and compare population dynamics of earthworms in cultivated production fields versus no-till production fields. The effects of time in a no-till cropping system and cover crop on earthworm populations were also considered. The variables of soil bulk density, volumetric water content, total carbon, surface residue, and pH were determined for all fields and given consideration in the research performed.

Materials and Methods

Field Locations and Histories

A total of seven sites were selected on the Milan Experiment Station for this research (Table 1). The station is located in the major physiological province of the Mississippi Valley in West Tennessee. The Mississippi Valley is broken up into three regions, 1) the Mississippi Alluvial Valley, 2) the West Tennessee Plains, and 3) the West Tennessee Uplands. The study sites were located specifically in the West Tennessee Plains physiographic region in the

Table 1. Study site description and field histories

Sample I.D.	Cropping Systems	Landscape Position	Soil Series	Family‡	Field History
NT1	no-till	upland	Grenada silt loam	Fine-silty, mixed, thermic Glossic Fragiudalfs	corn/wheat/soybean rotation ≈ 10 years
NT2	no-till	upland	Grenada silt loam	Fine-silty, mixed, thermic Glossic Fragiudalfs	corn/wheat/soybean rotation ≈ 5 years
NT3	no-till	flood plain	Collins silt loam	Coarse-silty, mixed, acid, thermic Aquic Udifluvent	corn/wheat/soybean rotation ≈ 1 year
NT4	no-till	upland	Grenada silt loam	Fine-silty, mixed, thermic Glossic Fragiudalf	corn/cover crop rotation ≈ 11 years
NT5	no-till	upland	Vicksburg silt loam	Coarse-silty, mixed, acid, thermic Typic Udifluvent	corn rotation ≈ 3 years
T1	tilled	upland	Calloway silt loam	Fine-silty, mixed, thermic Glossaquic Fragiudalf	wheat/soybean rotation ≈ 10 years
T2	tilled	upland	Loring silt loam	Fine-silty, mixed, thermic Typic Fragiudalf	wheat/soybean rotation ≈ 10 years
T3	tilled	floodplain	Vicksburg silt loam	Coarse-silty, mixed, acid, thermic Typic Udifluvent	corn rotation ≈ 3 years

‡Soil Survey of Madison County, Tennessee. April 1978 USDA.SCS

Atwood Quadrangle just inside Gibson County near Milan, Tennessee. In terms of geology, soils in West Tennessee are relatively young compared to the central and eastern sections of Tennessee. At one time, an inland sea completely covered West Tennessee. The eastern shoreline was located basically where the eastern border of the Mississippi River Valley lies today (Fullerton, et al., 1977). The present unconsolidated material that makes up the surface in this area consists of clays, sands, and gravels that were deposited when the waters of the inland sea receded.

The climate is humid mesothermal and the soil temperature regime is thermic. The basic characteristics that exist in the clime are the seasonal changes in the temperature and the lack of extremes in temperature. Temperatures and rainfall together help to determine the climatic patterns that take place in West Tennessee (Fullerton et al., 1977). The average temperatures range from 14 to 17°C. Rainfall is distributed rather evenly; the amount of precipitation received averages between 116 to 140 cm, increasing from the Mississippi Alluvial Plains eastward to the West Tennessee Uplands (Springer and Elder, 1980). Prevailing winds in this region come from the southwest, west, and north. Relative humidity is about 70% higher in the winter months than the rest of the year, and cloud coverage averages between 55 and 60% overall (Springer and Elder, 1980).

The topography of West Tennessee shows the influence that the many tributaries and rivers that exist in this region have had on it. The topography is less rugged in the West Tennessee Plains than the rest of the state; large valleys and swampy areas abound due to the rivers being larger and slower in this region (Fullerton et al., 1977, Springer and Elder, 1980).

The parent material in this region has been largely covered by loess which was deposited during the active glacial periods. Coastal plain materials made up of sediments deposited when the ancient Gulf of Mexico covered the area are also an important parent material. These sediments were eventually exposed and then covered with loess (Springer and Elder, 1980). These soils have distinct layers and can be acidic. Dense fragipans form in the subsoils of the loess soils (Springer and Elder, 1980).

The soils found on the Milan No-till Experiment Station are predominantly silt loams and are formed from loess deposits. The Calloway silt loam (Fine-silty, mixed, thermic Glossaquic Fragiudalf), Collins silt loam (Coarse-silty, mixed, acid, thermic Aquic Udifluvent), Grenada silt loam (Fine-silty, mixed, thermic Glossic Fragiudalf), Loring silt loam (Fine-silty, mixed, thermic Typic Fragiudalf), and Vicksburg silt loam (Coarse-silty, mixed, acid, thermic Typic Udifluvent) series were represented in the study (Madison County SCS Survey, 1978).

In order to determine the effects of tillage on earthworm population dynamics in cropping systems, two tilled fields and three no-till production fields were utilized. The tilled fields were identified as T1 and T2. The fields utilized were identified as NT1, NT2, and NT3. Data collected from the no-till fields NT1, NT2, and NT3 were also utilized to determine effects of time in a no-till cropping system on earthworm populations. The effects of cover crop on population were determined in a no-till corn field identified as NT4. This field was being utilized in a research project examining the effects of several nitrogen application rates and cover crops on corn yield in no-till. The plots with 150 kg ha^{-1} applications of N were chosen for utilization. Three cover crops, crimson clover, winter wheat, and no cover (only previous corn residue), were chosen. A total of twelve plots were utilized from NT4, with four replicates of each cover. Another site was later utilized in which the yields of various corn varieties were being compared in side by side no-till and tilled production fields. Each field conatained four smaller plots in which one sample per plot was removed. The no-till plot was identified as NT5 and the tilled plot as T3.

Field Sampling Methods

A sampling technique based on a design used by Kladivko (1993) was designed and utilized. Samples were obtained from 30 cm X 30 cm sample areas to a depth of 15 cm. An area within fields NT1, NT2, NT3, T1, and T2 was selected for sampling. Each area was approximately 0.5 hectare in size. The sample sites were located 14.5m from the edge of each field utilized and separated by a distance of 30m from each other, and marked with flags. Six samples per site were removed for population determination and specimen collection (Figure 1). The soil within the 30 cm X 30 cm X 15cm volume was removed by the use of a spade or shovel. One randomly located sample per cover crop was taken from the twelve plots utilized where the effect of cover crop on population dynamics was investigated (Figure 2). Each soil sample was placed on a plastic sheet approximately $1m^2$ then hand sorted in order to collect specimens within the soil block. Each specimen was placed into a 120 mL widemouth plastic bottle containing 10% formalin solution for storage purposes and species identification. Earthworms that were damaged or cut in half were counted as one earthworm. The containers were marked with the date, location in which the specimens were procured, and total number collected.

Prior to the removal of the soil block, plant residues within each 30 cm X 30 cm sample area were completely removed, placed into plastic bags, and marked with the location and date of sampling. Additional soil samples were taken from each site to 15 cm in order to determine pH and total carbon. Soil surface temperature was determined by the use of a thermometer to a depth of approximately 2 cm prior to sampling. Undisturbed bulk density samples were taken using a hammer driven core sampler (Blake and Hartge, 1982). Soil water content was determined by taking soil samples with a bucket auger to a depth of approximately 15 cm. The sampling was performed in the spring of 1994, fall of 1994, and the spring of 1995. Samples were taken only from the no-till fields NT1, NT2, NT3, and NT4 in the spring of 1994. In the

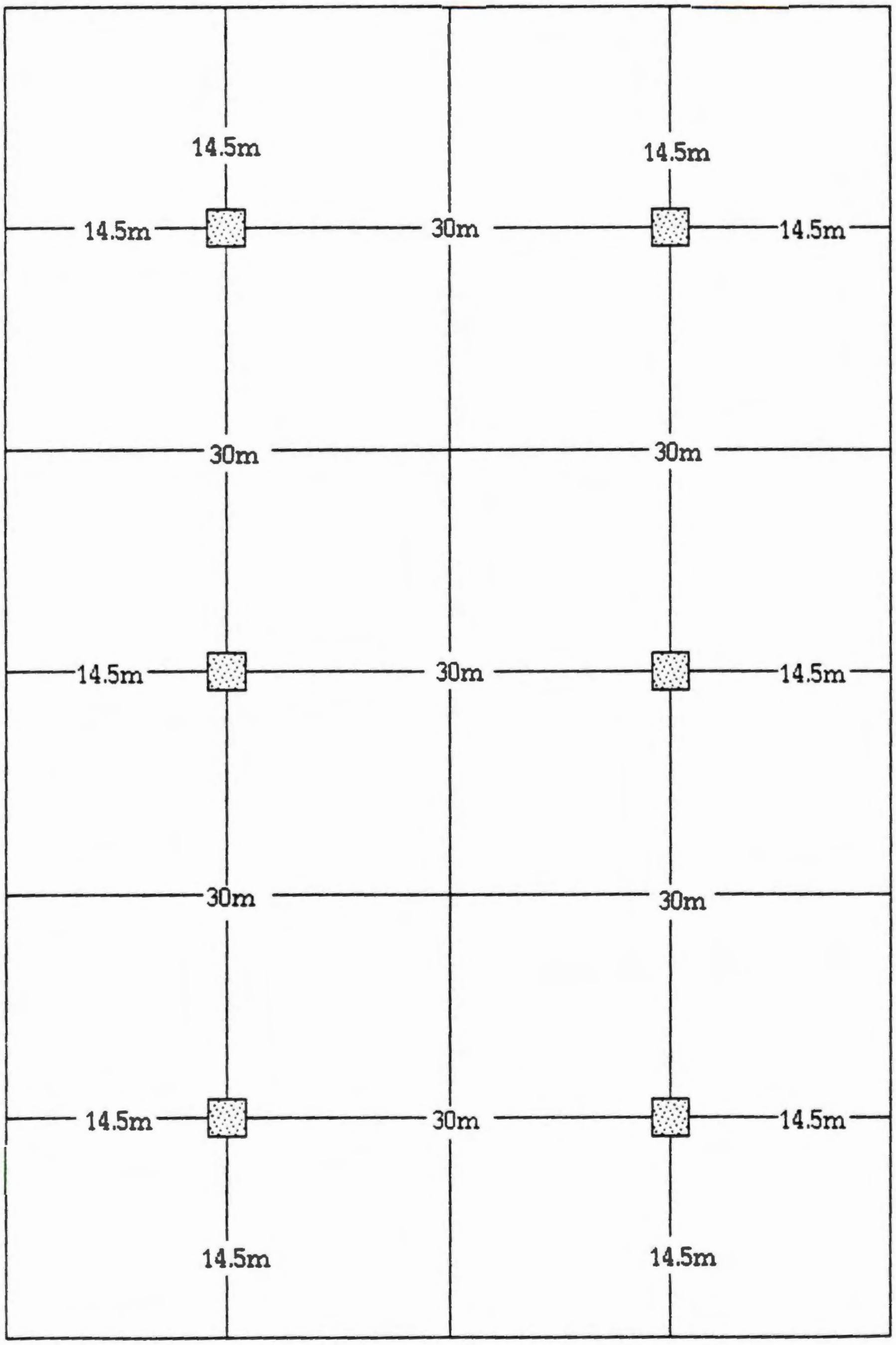

Figure 1. Sampling plan for fields NT1, NT2, NT3, T1, and T2.

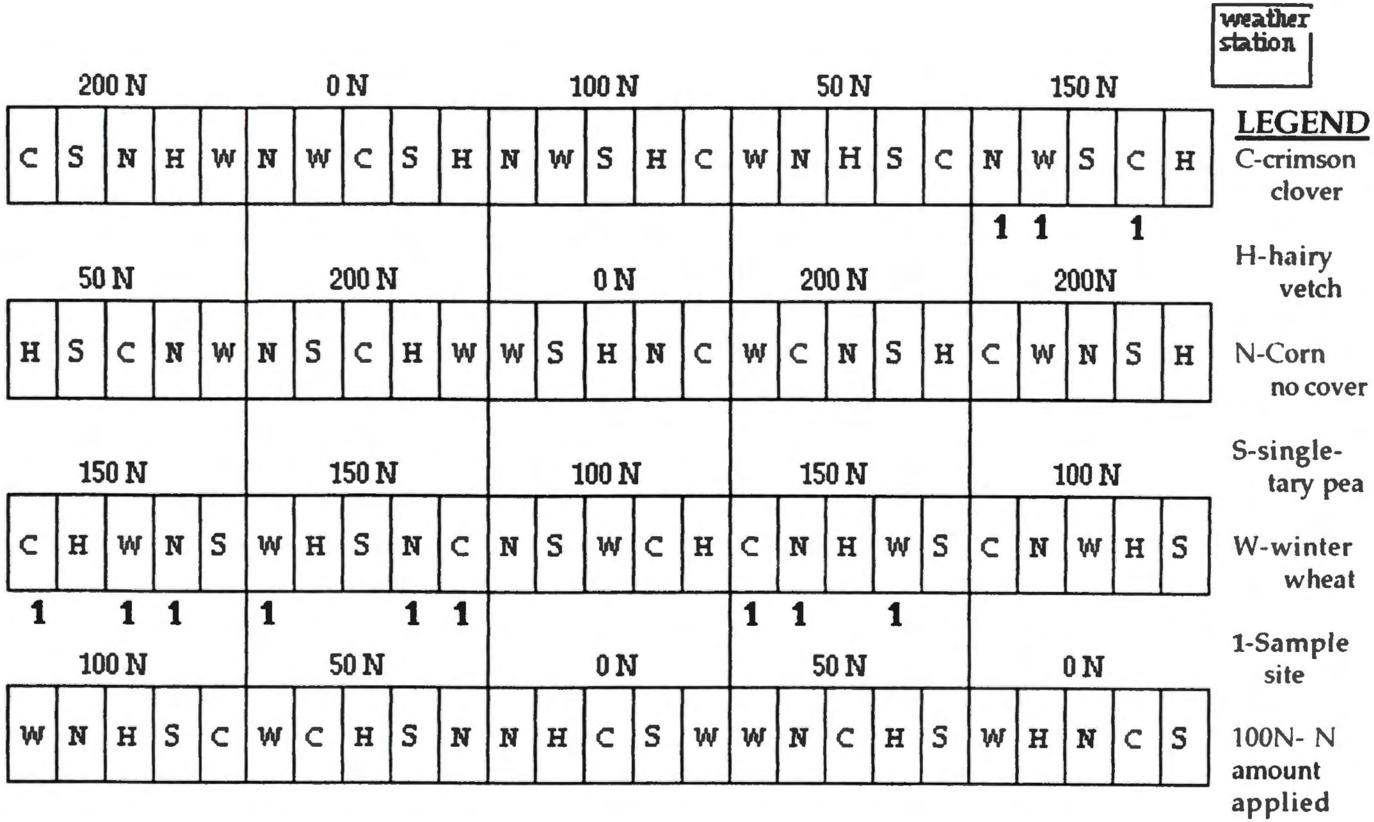

Figure 2. Plot diagram for field NT4.

Fall of 1994 samples were removed from tilled fields T1, T2, and T3 and no-till fields NT1, NT2, NT3, NT4, and NT5. In the Spring of 1995 sampling was done on the same fields as in the fall except fields NT5 and T3 .

Laboratory Methods

Soil samples were air dried for approximately three days. The air dried samples were crushed and passed through a 2mm sieve then ground to pass through a 60 mesh sieve. Soil pH was determined on a 1:1 vol/wt (water/soil) and 2:1 vol/wt. (water - $CaCl_2$/soil) (McLean, 1982). Total carbon was determined by the dry combustion method through the use of a high temperature furnace (Nelson and Sommers, 1982).

Bulk density and soil water content samples were oven dried for approximately 24 hours at 37 °C. The samples and the tins were weighed prior to drying and the data was recorded. Gravimetric water content was determined and converted to volumetric water content using bulk density. Residue samples taken from the no-till fields were air dried for four days and then weighed. The earthworm specimens were removed from the 10% formalin solution and placed into plastic receptacles containing 70% ethanol for shipping to the University of Georgia Institute of Ecology where they were identified utilizing the Soil Biology Guide (Dindal, 1980).

The SAS statistical program (Schlotzhauer and Littell, 1991) was utilized for data analysis. Comparisons of tillage effects, time in no-till and cover crop were made utilizing Analysis of variance (ANOVA) and Duncan's Multiple Range test at a 95% confidence interval by each sample date and across all three sampling dates. Correlations between time in no-till and the various soil properties determined were determined.

Results

Total earthworm populations collected for all plots in each sampling period are presented on a number per meter squared basis (Table 2). A majority of the specimens were able to be identified; however many were juveniles or subadult Lumbricidae and it was not possible to positively identify them. Species identified from the collection were *Bimastos longicinctus* and *Aporrectodea trapezoides*,both of the family Lumbricidae, and *Diplocardia caroliniana* of the family Megascolecidae. Lumbricids are widely dispersed over the United States. They can occur in a variety of habitats including grasslands, open pasture, dense forest, acid bogs, and alkaline upland soils (Dindal, 1980). Lumbricids require an adequate amount of moisture and will not be found in dry or arid regions. *Bimastos longicinctus* is one of only two native terrestrial species of Lumbricidae that exist in the Unites States (Dindal, 1980). Lumbricidae castings have been shown to make soil minerals more available and are higher in microorganisms than most soil. Lumbricids can enhance soil fertility by

Table 2. Total earthworm populations (no. m^{-2}) collected for all sample periods

Sample I.D.	Population (no. m^{-2}) by sampling date		
	4/94	10/94	4/95
NT1	105	86	37
NT2	72	66	42
NT3	11	25	2
NT4			
-crimson clover	36	152	69
-winter wheat	180	227	105
-no cover	78	175	77
NT5	ND	111	ND
T1	ND	2	0
T2	ND	0	0
T3	ND	5	ND

ND No data

increasing exchangeable calcium, magnesium, and potassium and the availability of molybdenum (Edwards and Lofty, 1977). They are also very active in the spring and fall and winter in southern regions. They also have remarkable dispersal abilities (Schwert, 1980). Classification is performed based on external and internal features and color. Lumbricids are fairly easy to identify (Dindal, 1980). *Aporrectodea trapezoides* species is one of the many European exotics that were introduced by early European settlers.

Members of the Megascolecidae family, as represented by *D. caroliniana,* are native to the United States, mainly the southern and midwestern sections. Most did not survive the Wisconsinan glacial period that occurred. Their temperature tolerance is higher than most earthworm species. They cannot be identified by external characteristics and are somewhat more difficult to identify than Lumbricidae.

These results were similar to most like it that have been taken from agricultural plots in this region in that it contained three species of earthworms (Lee, 1985). The two native species identified usually do not survive well in the disturbed soils of an agricultural environment. Their presence is one indicator of the positive effects no-tillage practices can have on soil ecology.

Natives *D. caroliniana* and *B. longicinctus* made up approximately 48% and 3% respectively of the specimens collected over all sampling periods, while *A. trapezoides* made up approximately 12%. Unidentifiable juveniles made up about 27% of the collection; however there is a very good chance that these were of the *D. caroliniana* species. The final 8% of the collection were unidentifiable subadult Lumbricidae, these were most likely of the *A.trapezoides* species. The species that dominated the soil environment of the no-till fields researched were the native *D. caroliniana* species, which prefer an undisturbed habitat. The makeup of the entire collection for each site and sample date are given (Tables 3, 4, and 5). No numbers are given for the tilled fields due to the small numbers of specimens found in them.

Earthworm populations were analyzed in two ways. First, numbers were compared within each separate sampling period for each parameter studied. The population numbers were pooled for the entire data set in the second analysis with the same parameters considered. Analysis of variance (ANOVA) and Duncan's multiple range test were performed for each analysis ($P \leq 0.05$, unless otherwise noted).

Specimens were collected in the no-till and tilled fields on 10/94 and 4/95 for tillage comparison. Populations were significantly higher (ANOVA, $P \leq 0.05$; Duncan's multiple range test, $P \leq 0.05$) in the no-till fields for both sampling periods. The no-till and tilled data given represent all the populations found in NT1, NT2, NT3, T1, and T2 (Tables 6 and 7). Data was gathered on 4/94, 10/94, and 4/95 for analysis of the effect of time in no-till on earthworm populations. Periods of 10 years, 5 years, and 1 year were utilized

Table 3. Species makeup for 4/94 collection

Sample I.D.	Species				
	A. trapezoides	*B. longicinctus*	*D. caroliniana*	Subadult L.	Juveniles
	-------------	-------------	%	-------------	-------------
NT1	39	0	7	46	9
NT2	2	38	46	0	13
NT3	17	0	17	50	17
NT4					
-crimson clover	15	0	38	7	38
-winter wheat	6	0	35	7	51
-no cover	21	0	32	14	32

Table 4. Species makeup for 10/94 collection

Sample I.D.	Species				
	A. trapezoides	*B. longicinctus*	*D. caroliniana*	Subadult L.	Juveniles
	%				
NT1	0	2	36	15	47
NT2	8	0	53	5	33
NT3	7	57	14	0	21
NT4					
-crimson clover	5	0	56	5	32
-winter wheat	6	1	48	6	39
-no cover	5	1	44	6	43
NT5	8	1	65	3	15
T1	100	0	0	0	0
T2	0	0	0	0	0
T3	50	0	50	0	0

Table 5. Species makeup for 4/95 collection

Sample I.D.	Species				
	A. trapezoides	*B. longicinctus*	*D. caroliniana*	Subadult L.	Juveniles
	---	---	%	---	---
NT1	25	0	65	5	5
NT2	4	0	95	0	0
NT3	0	100	0	0	0
NT4					
-crimson clover	16	0	72	0	12
-winter wheat	21	0	73	0	5
-no cover	17	0	75	0	7
T1	0	0	0	0	0
T2	0	0	0	0	0

Table 6. ANOVA Table - No-till and tilled cropping system results by sample date

Date	Source	df	Sum of squares	Mean square	F Value	Pr>F	C.V.(%)
10/94	Tillage system	1	194.3	194.3	13.19	.0011	120
	Error	28	412.5	14.7			
	Total	29	606.8				
4/95	Tillage system	1	45.0	45.0	8.84	.006	150
	Error	28	142.5	5.09			
	Total	29	187.5				

Table 7. Mean earthworm population (no. m^{-2}) for no-till and tilled comparison by sample date

Cropping System	--------Mean populations (no. m^{-2})-------- by sampling date	
	10/94	4/95
No-till	58.6 A	27.7 A†
Tilled	.9 B	0.0 B
No-till (NT5)	111.1 A	ND
Tilled (T3)	5.5 B	ND

†Means within column followed by the same letter are not significantly different according to Duncan's Multiple Range Test ($P \leq 0.05$)

ND No data

in the time in no-till comparison. Time was shown to be significant (ANOVA, $P \leq 0.05$) in Table 8 for the 4/94 and 4/95 sampling periods, but not during the 10/94 time frame. Using Duncan's multiple range test ($P \leq 0.05$), populations were not significantly different between 10 years and 5 years in 4/94 and 4/95. Populations of both periods were significantly different than those in 1 year of no-till during the same 4/94 and 4/95 time periods. No difference was found in populations for the 10/94 sampling period (Table 9). Cover crop resulted in no significant difference in populations for each sampling period except for the 4/94 sampling periods (Tables 10 and 11). On the 4/94 sampling date Duncan's multiple range test ($P \leq 0.05$) showed a difference between populations in crimson clover and winter wheat and no difference between either and no cover (Table 11).

When data from all sample dates were pooled, time in no-till significantly effected earthworm populations (Table 12). Duncan's multiple range test ($P \leq 0.05$) showed a significantly lower number of earthworms were found in fields in no-till for only 1 year compared to those in 5 and 10 years of no-till (Table 13). Populations found in no-till fields were significantly higher than in tilled fields (Tables 12 and 13). The side by side comparison also showed significantly higher populations in no-till than tilled systems (Tables 12 and 13). Although the overall effect of cover crop was not significant in the ANOVA (Table12), Duncan's multiple range test ($P \leq 0.05$) showed a difference between winter wheat and crimson clover (Table 13).

Table 8. ANOVA Table - Time in no-till results by sample date

Date	Source	df	Sum of squares	Mean square	F Value	Pr>F	C.V.(%)
4/94	Time in no-till	2	233.0	111.5	5.83	.013	77
	Error	15	287.0	19.1			
	Total	17	510.0				
10/94	Time in no-till	2	94.1	47.1	2.20	.14	86
	Error	15	320.2	21.3			
	Total	17	414.3				
4/95	Time in no-till	21	47.4	23.7	3.75	.048	103
	Error	15	95.0	6.3			
	Total	17	142.4				

Table 9. Mean earthworm population (no. m^{-2}) for time in no-till comparison

Sample I.D.	Time in no-till	---Mean populations (no. m^{-2})--- by sample date		
		4/94	10/94	4/95
NT1	10 years	105.5 A	87.0 A	36.6 A†
NT2	5 years	72.2 A	66.6 A	42.5 A
NT 3	1 year	11.1 B	25.8 A	1.8 B

†Means within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test ($P \leq 0.05$)

Table 10. ANOVA Table - Cover crop results by sample date

Date	Source	df	Sum of squares	Mean square	F Value	Pr>F	C.V.(%)
4/94	Cover crop	2	358.1	179.1	3.03	.098	87
	Error	9	531.5	59.1			
	Total	11	889.6				
10/94	Cover crop	2	96.1	48.1	0.53	.60	57
	Error	9	810.5	90.1			
	Total	11	906.6				
4/95	Cover crop	2	23.2	11.6	0.24	.79	91
	Error	9	431.8	48.0			
	Total	11	454.9				

Table 11. Mean earthworm population (no. m^{-2}) for cover crop comparison

No-till cover crop	Mean populations (no. m^{-2}) by sample date		
	4/94	10/94	4/95
Crimson clover	36.1 A†	152.7	69.4
Winter wheat	180.3 B	227.7	105.5
No cover	77.7 AB	175.0	77.7

†Means within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test ($P \leq 0.05$)

Table 12. Analysis of variants for all data from all three dates pooled.

Source	df	Sum of squares	Mean square	F Value	Pr>F	C.V.(%)
Years in no-till	2	318.8	159.4	9.42	.00033	91
Error	51	862.7	16.9			
Total	53	1181.5				
Tillage system†	1	213.1	213.1	19.79	4.E-05	140
Error	58	624.5	10.8			
Total	59	837.7				
Cover crop	2	374.9	187.4	2.52	.09	78
Error	33	2458.1	74.5			
Total	35	2832.9				
Tillage system††	1	180.5	180.5	72.29	.00015	30
Error	6	15.0	2.5			
Total	7	195.5				

†Comparison of fields (NT1, NT2, NT3, T1, and T2)
††Side by side (NT5 and T3)

Table 13. Mean earthworm population (no. m^{-2}) pooled over all dates for all comparisons

Comparison	Factors	Mean population (no. m^{-2})
Time in no-till	10 years	76.5 A†
cropping system	5 years	60.4 A
	1 year	13.0 B
No-till (NT) vs Tilled (T)	NT	43.2 A
cropping system	T	0.46 B
No-till (NT) vs. Tilled (T)	NT	111.0 A
side by side comparison	T	5.5 B
Cover crop effects	winter wheat	171.1
in no-tillage system	no cover	110.1
	crimson clover	86.0

†Means followed by same letter are not significant according to Duncan's Multiple Range Test ($P \leq 0.05$)

Correlation analysis was run considering time in no-till only. There was a positive correlation with time in no-till and earthworm populations ($P \leq 0.001$). A positive correlation also existed between earthworm population and volumetric water content, surface residue, and total carbon ($P \leq 0.05$) (Table 14). Mean soil data recorded during the research is given in Table 15.

Discussion

When comparing the earthworm populations in the no-till fields (NT1, NT2, and NT3) to those found in the tilled fields (T1 and T2) it is clear that tillage had a distinct effect. Both the no-till and tilled field's soil temperatures, pHs, water contents, and total carbon amounts were similar, however, the tilled fields did not have a readily available food source (organic matter) to sustain a substantial earthworm population. This is evident by the number of specimens found (two) in all the tilled fields. The no-till fields provided an environment better suited for the propagation of earthworms. The most obvious and important advantage is the availability of a consistent food source for the earthworms. The environment within the no-till fields also remained very stable due to the lack of soil disturbance. The results of the analysis do show a high variability. The side by side comparison done between no-till (NT5) and tilled (T3) plots further showed the benefits of a no-till environment. The close proximity of the no-till plots to the tilled plots

Table 14. Correlation results for time in no-till analysis.

	E Pop[a]	ρ_b[b]	θ_v[c]	Residue	Total C	pH (1:1)	pH (2:1)
Timein no-till	.48***	- 0.11	0.16	0.54***	0.74***	- 0.23	-0.39**
E Pop		0.03	0.32*	0.31*	0.30*	0.02	-0.14
ρ_b			0.31**	0.06	-0.33**	-0.10	-0.11
θ_v				0.16	-0.11	-0.33**	-0.37***
Residue					0.48***	0.01	-0.09
Total C						-0.003**	-0.09
pH (1:1)							0.88***

[a]E Pop, Earthworm Population
[b] ρ_b, Bulk density
[c] θ_v, Volumetric water content
* Indicates significance @ .05 level
** Indicates significance @ .01 level
*** Indicates significance @ .001 level

Table 15. Mean soil data recorded for each sample date at 0-15 cm depth

	4/94		10/94		4/95	
	no-till	tilled	no-till	tilled	no-till	tilled
Soil temperature (°C)	19.7	ND	14.7	13.9	14.4	14.7
pH (1:1) -H_20:soil	5.70	ND	5.8	5.8	5.9	6.1
pH (2:1) -.01 M $CaCl_2$:soil	5.30	ND	5.4	5.2	5.5	5.6
Total carbon (%)	.90	ND	.95	.95	.91	.97
Volumetric water content (Θ_v)	.34	ND	.35	.26	.22	.11
Bulk density (σ_b)	1.53	ND	1.57	1.41	1.50	1.26

ND No data

and the fact that earthworm populations were twenty times that of the tilled plots substantiates the benefits of no-till to earthworm numbers. There was a small amount of residue left on the surface of the tilled plots which could account for twice the amount of earthworms found in tilled plot T3 compared to both tilled fields T1 and T2. The variation in this case was also much lower even with a smaller number of samples taken.

The populations that were collected in no-till fields NT1, NT2, and NT3 where time in this cropping system followed a trend found in research that has been done by Edwards and Lofty (1975). In their study it took approximately three to four years for noticeable population increases to occur in fields returned to pasture. This increase was based on an increase of organic matter with an increase in time. Increases continued until the population reached a plateau (Edwards and Lofty, 1975). The no-till fields utilized to evaluate the time effect were all in similar crop rotations and all three were on silt loam soils. NT3 has been in a no-till system for only one year when it was first sampled. The populations were much smaller than those in NT1 and NT2 which had been in no-till 10 and 5 years respectively.

The ANOVA did not show a significant difference in the initial sampling or over the entire sample period in the cover crop comparison. No difference was shown the last two sample periods. Earthworms have shown a preference for more leafy material and any organic matter that is in the latter stages of decomposition. All cover situations had been in a no-till system for over 11 years and provided an ample food supply.

The data gathered on the various soil parameters in the no-till fields fell within the limits of toleration for most earthworm species. Mean soil temperature, pH, total carbon, volumetric water content, and bulk density were determined for each sampling period and are given in Table 15. Soil temperature ranged from a high of 19.7°C during the first sampling to a low of 14.4°C in the last. The pH of the no-till fields ranged from 5.7 to 5.9 (1:1, water: soil) and 5.3 to 5.5 (2:1, .01 M $CaCl_2$: soil) which is at a tolerable level to earthworms. Total carbon ranged from 0.904 in 4/94 to 0.981% in 4/95. Bulk densities for the no-till fields were very close for all three sample periods and averaged 1.53 g/cm^3 while the tilled fields averaged 1.34 g/cm^3. The volumetric water content followed a seemingly normal trend. Water content was 0.336 cm^3cm^{-3} during the 4/94 sample period and became higher during the 10/94 period with the normal wetter fall months. It dropped dramatically in the spring during the final period to 0.218 $cm^3\ cm^{-3}$. All the fields themselves were much drier overall than any of the other sample periods. Field capacity for a silt loam is normally close to .3 $cm^3\ cm^{-3}$ (Romkens et al., 1986). The no-till fields as a whole were well above this typical value. Wilting point is around .11 $cm^3\ cm^{-3}$ and although the fields were above that point at the 4/95 field sampling date they were much drier than any other period before.

Populations varied a great deal in every no-till field. During the 4/95 sampling period the area was under dry conditions and this could have led to higher variability in populations that occurred. Most earthworms will enter into a resting state in response to drought or low water availability. They move deep into the soil profile and go into a motionless state and will not feed. This is called diapause. Researchers do not agree on whether they leave this state after a specific period of time or once the soil environment returns to more suitable conditions (Lee, 1985).

The correlations that existed between earthworm population and soil environmental properties are good indicators that there is a need for further research in specific areas. Soil water content, bulk density, total carbon, pH, and palatable organic matter are all topics that need further investigation.

Dindal (1980) mentions the need for further research on the interaction of Lumbricidae (one native and one introduced species) with Megascolecidae (native species), which is the exact scenario that exists in the no-till fields researched. Early research showed that introduced species tended to crowd out the native ones due to better ability to adapt to a different environment and eventually they dominate the area. Dindal (1980) observed that both species were able to coexist without negative impacts on either species.

The earthworm population differences that were seen when comparing the number of years a field was in no-till cropping system were determined to be significant except for the 10/94 sampling. Edwards and Lofty's (1975) work concluded that once an area has been in a system such as pasture, populations begin to plateau after a period of time. Once a field is in a no-till system the same scenario occurs. The population changes that could occur are not necessarily due to the time period in which it has been maintained, but to other exterior environmental conditions that could be occurring at the time of sampling. Volumetric water content, residue, and total carbon were three factors that correlated with earthworm population. No-till populations were much higher than those found in the tilled fields. The lack of organic matter that could be used as a food source was most likely the cause for the very small populations found. Populations in the cover crop comparison showed no significant difference for the 4/94 and 4/95 sampling periods and did in the 10/94 period. Earthworms have been shown to have a preference for specific organic material, such as leafy, succulent material over more stalky or woody organic matter. So long as either was in some stage of decay, earthworms will eat any type of food that is available to them. Because of the high variability of the data gathered it is important that more sampling over a longer period of time is done in order to substantiate or discount the initial findings.

No-till populations were significantly higher than tilled due to the availability of residue. Populations in the 10 and 5 year no-till fields were also higher than the 1 year field due to the buildup of residue and lack of recent soil disturbance. No significant difference existed in cover crop populations because all the residue was highly decomposed and palatable.

LIST OF REFERENCES

Bachelier, G. 1963. La Vie Animale daus les Sols. Orston, Paris. 279 pp.

Baker, G.H., V.J. Barrett, R. Grey-Gardner, and J.C. Buckerfield. 1992. The life history and abundance of the introduced earthworms *Aporretodea trapezoides* and *A. caliginosa* (Annelid: Lumbricidae) in pasture soils in the Mount Lofty Ranges, South Australia. Aust. J. Ecol. 17: 177-188.

Baker, G.H. and K.E. Lee. 1993. Earthworms. p. 359-371. *In* M.R. Carter (ed.) Soil Sampling and Methods of Analysis. Canadian Society of Soil Science. Lewis Publ., Chelsea, MI.

Bakhtin, P.U. and M.N. Polsky. 1950. The role of earthworms in structure formations of sod-podsolized soils. Pochvovedenic. 487-491.

Barley, K.P. 1949. The influence of earthworms on soil fertility. I. Earthworm populations found on agricultural land near Anelaide. Austral. J. Agri. Res. 10: 171-178.

Batie, S.S. 1983. Soil erosion: crisis in America's cropland. Conservation Foundation. p. 136.

Blake, G.R. and K.H. Hartge. 1982. Bulk density. p. 363-375. *In* A. Klute (ed.) Methods of soil analysis, Part 1, Second Edition. ASA/SSSA Publisher, Madison, WI.

Bouche´, M.B. 1977. Strategies lombriciennes. In Soil organisms as components of ecosystems, ed. U. Lohm and T. Persson. Biology Bulletin (Stockholm) 25: 122-132.

Bouche´, M.B. and R.H. Gardner. 1984. Earthworm functions VIII. Population estimation techniques. *Revue d'Ecologie et de Biologie du Sol* 21, 37-63.

Brady, N.C. 1990. The nature and property of soils. Macmillian Publ. Co. New York, New York.

De St. Remy, E.A. and T.B. Daynard. 1982. Effects of some tillage methods on earthworm populations in monoculture corn. Can. J. Soil Sci. 62: 699-703.

Dindal, D. 1980. Soil biology guide. Wiley Publ., New York, New York.

Doerell, E.C. 1950. How do earthworms react to the application of minerals. Deutche Landwirtschaff. Presse, 4: 10.

Dutt, A.K. 1948. Earthworms and soil aggregation. J. Am. Soc. Agron. 40: 407.

Edwards, C.A. and J.R. Lofty. 1975. The invertebrate fauna of the Park Grass plots. Rep. Rothamstad Exp. Stn. for 1974, Pt. 2. pp. 133-154.

Edwards, C.A. and J.R. Lofty. 1977. Biology of earthworms. Chapman and Hall Publ., London.

Escritt, J.R. and J.H. Arthur. 1948. Earthworm control-a resume of methods available. J. Bd. Greenkeep. Res. 7(23): 49.

Evans, A.C. and W.J. McL. Guild. 1948. Studies on the relationships between earthworms and soil fertility. V. Field populations. Annals of Applied Biology. 35: 485-493.

Fullerton, Ralph O., Horace G. McDowel, Ovid M. McMillian, Jewell Phelps, John B. Ray, and R. Paul Terrel. 1977. Tennessee-Geographic Patterns and Regions, Kendall Hunt Publishing Company, Dubuque. IA.

Graff, O. 1953. Investigations in soil zoology with special reference to the terricole Oligochaeta. Z. PflErnahr. Dung. 61: 72-77.

Grant, W.C. 1955. Studies on moisture relationships in earthworms. Ecology, 36: 400-407.

Guild, W.J.Mc.L. 1951. The distribution and population density of earthworms (Lumbricidae) in Scottish fields. J. Anim. Ecol. 20, 1: 88-97.

Guild, W.J.Mc.L. 1952. Variation in earthworm numbers within field populations. J. Anim. Ecol. 21: 169.

Hendrix, P.F., B.R. Mueller, R.R. Bruce, G.W. Langdale, and R.W. Parmelee. 1992. Abundance and distribution of earthworms in relation to landscape factors on the Georgia Piedmont, U.S.A. Soil Biol. Biochem. 24: 1357-1361.

Hopp, H. 1946. Earthworms fight erosion too. Soil Conserv. 2: 252-254.

Hopp, H. 1947. The ecology of earthworms in cropland. Soil Sci. Soc. Am. J. 12: 503-507.

Hopp, H. and C.S. Slater. 1949. The effect of earthworms on the productivity of agricultural soils. J. Agric. Res. 78: 325-339.

House, G.L. and R.W. Parmelee. 1985. Comparison of soil arthropods and earthworms from conventional tillage and no-tillage agroecosystems. Soil and Tillage Research. 5: 351-360.

Jacob, A. and K. Wiegland. 1952. Transformation of the mineral nitrogen of fertilizers in soil. Z. PflEnrahr, Dung, 59: 48-60.

Jefferson, P. 1955. Studies on the earthworms of turf. A. The earthworms of experimental turf plots. J. Sports Turf Res. Lust. 9(31): 6-27.

Johnstone-Wallace, D.B. 1937. The influence of wild white clover on the seasonal production and chemical composition of pasture herbage and upon soil temperature, soil moisture, and erosion control. 4th INt. Grassl. Congr. Rep. p. 188-196.

Khalaf El-Duweini A. and Ghabbour, S.I. 1965. Population density and biomass of earthworms in different types of Egyptian soils. J. Appl. Ecol. 2: 271-287.

Kladivko, E.J. 1993. Earthworms and crop management. Agronomy Guide. Purdue University Cooperative Extension Service. Bulletin: AY-279, 10/93.

Kladivko, E.J. and H.J. Timmenga. 1990. Earthworms and agricultural management. p. 192-216. *In* J.E. Box. Jr., and L.C. Hammond (ed.) Rhizosphere dynamics. AAAs Selected Symposium.

Kladivko, E.J., N.M. Akhouri, and Glenn Weesies. 1993. Earthworm populations and species distributions under no-till and conventional tillage in Indiana. Draft publication.

Lal, R. 1976. No-tillage effects on soil properties under different crops in western Nigeria. Soil Sci. Soc. Am. J. 40: 762-768.

Laverack, M.S. 1961. Tactile and chemical perception in earthworms. II. Responses to acid pH solutions. Comp. Biochem. Physiol. 2(I): 22-34.

Lee, K.E. 1985. Earthworms: Their ecology and relationships with soils and land use. Academic Press, Sydney, Australia.

Mackay, A.D. and E.J. Kladivko. 1985. Earthworm and rate of breakdown of soybean and maize residues in soil. Soil Biol. Biochem. 17: 851-857.

Madge, D.S. 1969. Field and laboratory studies on the activities of two species of tropical earthworms. Pedologica, 9: 188-214.

Mamytov, A. 1953. The effect of earthworms on the water stability of mountain-valley serozem soils. Pochvovedrie, 8: 58-60.

Minnich, J. 1977. The earthworm book: How to raise and use earthworms for your farm and garden. Rondale Press, Emmaus PA.

Murchie, W.R. 1958. Biology of the oligochaete *Eisenia rosea* (Savigny) in an upland forest soil of Southern Michigan. Am. Midl. Nat. 66: 113-131.

McLean, E.O. 1982. Soil pH and lime requirements. p. 199-224. *In* A. Klute (ed.) Methods of soil analysis, Part 2, Second Edition. ASA/SSSA Publisher, Madison, WI.

Nelson, D.W. and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. p. 539-560. *In* A. Klute (ed.) Methods of soil analysis, Part 2, Second Edition. ASA/SSSA Publisher, Madison, WI.

Peterson, A.E. and R.M. Dixon. 1971. Water movement in large soil pores: validity and utility of the channel system concept. Coll. Agr. Life Sci. Univ. Wis. Res. Rep. 75.

Piearce, T.C. 1972. The calcium relations of selected *Lumbricidae* . J. Anim. Ecol. 41: 167-188.

Pilz, V. 1992. Succession of earthworm populations in abandoned fields. Soil Biol. Biochem. 24: 1623-1628.

Pomerat, G.M. and M.T. Zarrow. 1936. The effect of temperature on the respiration of the earthworm. Proc. Natn. Acad. Sci. USA. 22: 270-272.

Reynolds, J.W. 1977. The earthworms (*Lumbricidae and Sparganophilidae*) of Ontario. Life Sciences Miscellaneous Publications, Royal Ontario Museum.

Rhee, J.A. van. 1969. Inoculation of earthworms in newly drained polder. Pedobiologia 9, 118-132.

Richardson, H.C. 1938. The nitrogen cycle in grassland soils: with special reference to the Rothamstad Park grass experiment. J.Agric. Sci., Camb. 28: 73-121.

Römkens, M.J.M., S.K. Scott, H.M. Selim, R.E. Phillips, and F.D. Whisler. Physical characteristics of soils in the southeastern region. Captina, Gigger, Grenada, Loring, Olivier, and Sharkey Series. 1986. Regional Bulletin 264. Publ. by Mississippi Agricultural and Forestry Experiment Station, Mississippi State, Mississippi.

Satchell, J.E. 1955. Some aspects of earthworm ecology. pp. 180-201. *In* Soil Zoology, D.K. Mc E. Kevan (ed.). Butterworths, London,

Satchell, J.E. 1983. Earthworm microbiology. p. 341-364. *In* Earthworm ecology, ed. J.E. Satchell, London, Chapman and Hall.

Schwert, D.P. 1980. Active and passive dispersal of lumbricid earthworms. *In* "Soil Biology as Related to Land Use Practices" (D.L. Dindal, ed.). pp. 182-189. Proc. 7th Intl. Colloq. Soil Zool., Syracuse, 1979. Environmental Protection Agency, Washington, D.C.

Schlotzhauer, S.D. and R.C. Littell. 1991. SAS system for elementary statistical analysis. 3rd ed. SAS Institute Inc., Cary, NC.

Sharpley, A.N., S.K. Sayers, and J.A. Springlett. 1979. Effect of surface casting earthworms on the transport of phosphorus and nitrogen on surface runoff from pastures. Soil Biol. Biochem. 2: 459-462.

Shelton C.H. and J.F. Bradley. 1987. Controlling erosion and sustaining production with no-till systems. Tennessee Farm and Home Science. Winter 1987. Issue 141. Publ. University of Tennessee Agricultural Experiment Station. Knoxville, TN.

Slater, C.S. and H. Hopp. 1946. Relations of fall protection to earthworm populations and soil physical conditions. Soil Sci. Soc. Am. Proc. 12: 508-511.

Slater, C.S. 1954. Earthworms in relation to agriculture. U.S.D.A. A.R.C. Circ.

Springer, M.E. and J.A. Elder. 1980. Soils of Tennessee, The University of Tennessee Agricultural Experiment Station, Knoxville, TN.

Stockdill, S.M.J. and G.G. Cossens. 1966. The role of earthworms in pasture production and moisture conservation. Proc. N. Z. Grassl. Assoc. p. 168-183.

Syers, S.K. and J. A. Springett. 1983. Earthworm ecology in grassland soils. *In* Earthworm ecology: From Darwin to vermiculture. pp. 67-83. J.E. Satchell (ed.). Chapman and Hall, London.

Tennessee Department of Agriculture. 1995. Tennessee Farm Facts. Tennessee Agricultural Statistics Service, Fact finding for agriculture. USPS 368-470, vol. 95 no. 06. Nashville, TN.

Teotia, S.P., F.L. Duley, and T.M. McCalla. 1950. Effect of stubble mulching on number and activity of earthworms. Neb. agric. Exp. Sta. Res. Bull. 165, 20.

U.S. Department of Agriculture. 1978. Soil survey of Madison County, Tennessee. Soil Conservation Service.

U.S. Department of Agriculture. 1992. Soil erosion and land use in Tennessee. Natural resources inventory. USDA-SCS Report.

Waksman, S.A. and J.P. Martin. 1939. The conservation of the soil. Science 90: 304-305.

Watkin, B.R. 1954. The animal factor and levels of nitrogen. J. Br. Grassld. Soc. 9: 35-46.

Westeringh, W. van de. 1972. Determination of soil structure in worm free orchards. Pedobiologia 12, 6-15.

Witkamp, M. 1966. Decomposition of leaf litter in relation to environment, microflora, and microbial respiration. Trop. Agric. 52, 97-104.

Zajonc, I. 1970. Earthworm synusiae of meadow stratocenoses and choriocenoses. Acta. Zooltech. Univ. Agr. Nitra. 21: 203-211.

Zicsi, A. 1958. Einfluss der Trockenheit und der Bodenarbeitung auf das Leben der Regenwurmer in Ackerboden. Acta. Agron. 7: 67-74.

APPENDICES

Appendix A

Sample Data

No-till Fields

Sample I.D.	Bulk density (g/cm^3)		
	4/94	10/94	4/95
NT1-1	1.50	1.59	1.50
2	1.55	1.55	1.70
3	1.53	1.53	1.51
4	1.51	1.53	1.51
5	1.50	1.52	1.44
6	1.55	1.57	1.50
NT2-1	1.55	1.53	1.43
2	1.47	1.62	1.08
3	1.55	1.54	1.53
4	1.57	1.61	1.38
5	1.61	1.57	1.34
6	1.43	1.57	1.54
NT3-1	1.42	1.45	1.56
2	1.63	1.68	1.39
3	1.44	1.60	1.73
4	1.60	1.54	1.57
5	1.49	1.66	1.68
6	1.60	1.62	1.49

Tilled Fields

Sample I.D.	Bulk density (g/cm^3)		
	4/94	10/94	4/95
T1-1	ND	1.31	1.10
2		1.23	1.40
3		1.47	1.18
4		1.42	1.33
5		1.47	1.30
6		1.48	1.07
T2-1	ND	1.26	1.21
2		1.52	1.43
3		1.37	1.26
4		1.51	1.20
5		1.45	1.38
6		1.38	1.27

ND No data

Cover Crop Field

Sample I.D.		Bulk Density (g/cm_3)		
		4/94	10/94	4/95
NT4				
(Crimson Clover)	1	1.64	1.54	1.68
	2	1.59	1.57	1.00
	3	1.60	1.62	1.15
	4	1.50	1.64	1.67
NT4				
(Winter Wheat)	1	1.59	1.62	1.73
	2	1.52	1.56	1.60
	3	1.57	1.57	1.29
	4	1.57	1.51	1.50
NT4				
(No cover)	1	1.57	1.53	1.88
	2	1.59	1.54	1.07
	3	1.53	1.59	1.18
	4	1.49	1.54	1.50

Corn Variety Field

Sample I.D.		Bulk Density (g/cm_3)		
		4/94	10/94	4/95
NT5	1	ND	1.54	ND
	2		1.58	
	3		1.44	
	4		1.48	
T3	1	ND	1.38	ND
	2		1.39	
	3		1.44	
	4		1.44	

ND No data

No-till Fields

Sample I.D.	Volumetric water content Θv (cm³/cm³)		
	4/94	10/94	4/95
NT1-1	.315	.355	.233
2	.308	.380	.310
3	.337	.352	.267
4	.303	.321	.294
5	.315	.340	.241
6	.321	.382	.256
NT2-1	.348	.369	.232
2	.344	.401	.150
3	.361	.343	.202
4	.353	.357	.261
5	.388	.392	.261
6	.336	.369	.258
NT3-1	.322	.388	.201
2	.391	.348	.156
3	.323	.301	.172
4	.364	.306	.181
5	.346	.303	.180
6	.364	.311	.119

Tilled Fields

Sample I.D.	Volumetric water content Θv (cm³/cm³)		
	4/94	10/94	4/95
T1-1	ND	.237	.082
2		.272	.166
3		.308	.090
4		.304	.066
5		.289	.084
6		.257	.065
T2-1	ND	.223	.128
2		.308	.120
3		.301	.108
4		.314	.112
5		.262	.121
6		.261	.111

ND No data

Cover Crop Field

Sample I.D.		Volumetric water content θv (cm³/cm³) 4/94	10/94	4/95
NT4				
(Crimson Clover)	1	.347	.371	.196
	2	.195	.327	.154
	3	.328	.405	.164
	4	.320	.385	.225
NT4				
(Winter Wheat)	1	.302	.387	.223
	2	.279	.335	.244
	3	.335	.403	.222
	4	.354	.435	.234
NT4				
(No cover)	1	.319	.343	.263
	2	.313	.327	.143
	3	.320	.377	.191
	4	.325	.386	.255

Corn Variety Field

Sample I.D.		Volumetric water content θv (cm³/cm³) 4/94	10/94	4/95
NT5	1	ND	.330	ND
	2		.291	
	3		.299	
	4		.174	
T3	1	ND	.278	ND
	2		.469	
	3		.104	
	4		.272	

ND No data

No-till Fields

Sample I.D.	Total carbon (%)		
	4/94	10/94	4/95
NT1-1	1.118	1.257	1.338
2	1.285	.936	.974
3	1.076	1.251	1.524
4	1.000	1.341	.862
5	1.381	.908	1.058
6	1.338	.769	1.285
NT2-1	.899	.889	.982
2	.862	.760	1.186
3	.761	.830	.916
4	1.035	.842	1.109
5	.966	.979	1.532
6	.873	.887	.956
NT3-1	.702	.730	.838
2	.700	.742	.739
3	.670	.729	.830
4	.563	.579	.752
5	.643	.579	.705
6	.675	.568	.664

Tilled Fields

Sample I.D.	Total carbon (%)		
	4/94	10/94	4/95
T1-1	ND	1.480	1.051
2		1.054	1.072
3		.988	1.254
4		.979	1.309
5		1.015	1.242
6		1.113	1.179
T2-1	ND	.834	.853
2		.876	1.020
3		1.073	.870
4		.687	.808
5		.854	.861
6		1.011	.685

ND No data

Cover Crop Field

Sample I.D.		Total carbon (%)		
		4/94	10/94	4/95
NT4				
(Crimson Clover)	1	.922	.943	.848
	2	.967	1.142	1.070
	3	.823	1.238	1.399
	4	.901	1.200	1.264
NT4				
(Winter Wheat)	1	.828	.960	.939
	2	.919	1.091	.924
	3	.817	.925	.849
	4	.820	1.068	1.013
NT4				
(No cover)	1	.882	.802	.743
	2	.905	.931	.978
	3	.798	.931	.729
	4	.713	.709	.817

Corn Variety Field

Sample I.D.		Total carbon (%)		
		4/94	10/94	4/95
NT5	1	ND	1.072	ND
	2		.725	
	3		.925	
	4		.727	
T3	1	ND	.936	ND
	2		.942	
	3		.971	
	4		.986	

ND No data

No-till Fields

Sample I.D.	pH					
	4/94		10/94		4/95	
	1:1†	2:1	1:1	2:1	1:1	2:1
NT1-1	6.10	5.65	5.30	5.05	5.95	5.85
2	6.50	5.50	5.40	4.95	5.50	5.15
3	6.00	5.50	6.30	5.85	5.35	5.25
4	6.10	5.40	6.20	5.70	4.90	4.85
5	6.40	5.65	6.40	5.71	6.00	5.65
6	6.10	5.90	6.19	5.50	5.05	4.98
NT2-1	4.85	4.80	5.00	4.60	6.37	6.00
2	5.60	5.40	5.50	5.20	6.40	6.00
3	5.00	4.90	5.70	5.30	5.90	5.60
4	5.30	5.20	5.40	5.40	6.10	5.70
5	5.60	5.40	6.00	5.60	6.60	6.12
6	5.70	5.40	6.20	5.80	6.60	6.05
NT3-1	4.95	5.65	6.45	6.20	6.50	6.02
2	5.80	5.50	6.35	5.95	6.05	5.56
3	5.80	5.50	6.00	5.70	6.50	5.90
4	5.80	5.40	6.05	5.80	6.30	5.85
5	6.00	5.65	6.45	5.99	6.25	5.90
6	6.20	5.90	6.60	6.15	6.45	6.00

†1:1 water: soil and 2:1 .01 M $CaCl_2$:soil

Tilled Fields

Sample I.D.	pH					
	4/94		10/94		4/95	
	1:1	2:1	1:1	2:1	1:1	2:1
T1-1	ND	ND	6.40	5.80	5.40	5.08
2			6.00	5.45	6.20	5.80
3			6.60	6.00	6.75	6.32
4			5.75	5.28	6.70	6.25
5			6.45	5.90	6.40	5.85
6			6.65	6.10	6.40	5.80
T2-1	ND	ND	5.61	5.20	5.95	5.45
2			4.65	4.20	5.10	4.65
3			5.85	4.90	6.10	5.50
4			5.31	4.70	5.65	5.18
5			5.50	4.75	6.35	5.89
6			5.15	4.55	5.60	5.00

ND No data

Cover Crop Field

Sample I.D.		pH					
		4/94		10/94		4/95	
		1:1†	2:1	1:1	2:1	1:1	2:1
NT4							
(Crimson Clover)	1	5.80	5.30	4.85	4.50	5.30	5.00
	2	4.70	4.20	4.40	4.00	5.05	4.85
	3	4.90	4.40	4.75	4.45	5.75	5.30
	4	4.80	4.20	5.55	5.29	4.80	4.30
NT4							
(Winter Wheat)	1	5.40	4.80	4.80	4.45	5.70	5.05
	2	5.30	4.60	5.60	5.20	5.90	5.65
	3	4.70	4.00	4.25	3.90	5.60	5.12
	4	5.70	5.00	5.45	5.10	5.50	4.99
NT4							
(No cover)	1	5.00	4.40	4.80	4.40	5.80	5.00
	2	5.60	5.00	5.90	5.50	6.00	5.40
	3	5.90	5.20	5.80	5.50	6.10	5.50
	4	5.40	4.90	5.45	5.10	5.75	4.70

†1:1 water: soil and 2:1 .01 M $CaCl_2$:soil

Corn Variety Field

Sample I.D.		pH					
		4/94		10/94		4/95	
		1:1	2:1	1:1	2:1	1:1	2:1
NT5	1	ND	ND	5.70	5.05	ND	ND
	2			6.00	5.10		
	3			5.60	4.90		
	4			5.50	4.85		
T3	1	ND	ND	6.10	5.50	ND	ND
	2			6.00	5.40		
	3			6.10	5.39		
	4			6.15	5.60		

ND No data

Residue data for NT fields - 4/94

Sample I.D.	Residue (Mg/ha) 4/94	10/94	4/95a
NT1	8.75	20.98	16.42
NT2	7.46	9.35	7.75
NT3	4.14	10.54	5.32
NT4 (3 cover crops)			
-crimson clover	11.52	14.71	6.60
-winter wheat	7.07	13.54	9.58
-no cover	10.37	13.65	8.26
NT5	ND	14.52	ND

ND No data

Appendix B

Earthworm Species Data

4/94 Species Identification and Population

Sample I.D.	Species					Total
	A. trapezoides	*B. longicinctus*	*D. caroliniana*	Subadult L.	Juveniles	
NT1	22	0	4	26	5	57
NT2	1	15	18	0	5	39
NT3	1	0	1	2	1	5
NT4						
-crimson clover	2	0	5	1	5	13
-winter wheat	4	0	18	3	21	46
-no cover	6	0	15	6	21	48

10/94 Species Identification and Population

Sample I.D.			Species			Total
	A. trapezoides	*B. longicinctus*	*D. caroliniana*	Subadult L.	Juveniles	
NT1	0	1	17	7	22	47
NT2	3	0	19	2	12	36
NT3	1	8	2	0	3	14
NT4						
-crimson clover	3	0	32	3	18	56
-winter wheat	5	1	39	4	32	81
-no cover	3	1	28	4	27	63
NT5	3	4	26	1	8	42
T1	1	0	0	0	0	1
T2	0	0	0	0	0	0
T3	1	0	1	0	0	2

4/95 Species Identification and Population

Sample I.D.			Species			Total
	A. trapezoides	*B. longicinctus*	*D. caroliniana*	Subadult L.	Juveniles	
NT1	5	0	13	1	1	20
NT2	1	0	22	0	0	23
NT3	0	1	0	0	0	1
NT4						
-crimson clover	4	0	18	0	3	25
-winter wheat	8	0	28	0	2	38
-no cover	5	0	21	0	2	28
T1	0	0	0	0	0	0
T2	0	0	0	0	0	0

VITA

Nathan J. Storck was born in Monroe, Wisconsin on December 4, 1964 to Donald and Jeanette Storck. He was raised in Centralia, Illinois where he graduated from high school in 1983. He attended and graduated from Southern Illinois University in Carbondale, Illinois in 1987 and received a Bachelor's of Science degree in Agronomy in the Plant and Soil Science Department. He was also commissioned a 2nd Lieutenant in the United States Army in May 1987. He attended and graduated from the Infantry Officer Basic Course at Fort Benning Georgia in 1988. He served with the 2nd Infantry Division in the Republic of Korea and the 101st Airborne (Air Assault) Division and participated in combat operations during Operation Desert Storm. He is currently serving in the United States Army Reserve and holds the rank of Captain. His awards include the Bronze Star Medal, Meritorious Service Medal, Army Commendation Medal (2 awards), Army Achievement Medal, Southwest Asia Theater Medal, Liberation of Kuwait Medal (Kingdom of Saudi Arabia and Republic of Kuwait), National Defense Medal, Army Service Ribbon, Overseas Ribbon, Combat Infantryman Badge, Ranger tab, Parachutist badge, and Air Assault badge. He is married to the former Marcy Lyn Watkins. After receiving his Master of Science degree in Soil Conservation from the University of Tennessee Knoxville Plant and Soil Science Department he plans to work with the Natural Resources Conservation Service as a soil scientist.

221
mg