

TECHNOLOGY EVALUATION AND DEVELOPMENT PROGRAM

**EFFECT OF WOODLOT BORDERS  
AND CROP RESIDUE ON THE  
DISTRIBUTION OF INVERTEBRATES  
IN AGROECOSYSTEMS.**

Final draft for  
SWEEP: Soil and Water  
Environmental Enhancement  
Program

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May 20, 1992

## Executive Summary

# **EFFECT OF WOODLOT BORDERS AND CROP RESIDUE ON THE DISTRIBUTION OF INVERTEBRATES IN AGROECOSYSTEMS**

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This study examined the relationships among distance from woodlots in agricultural fields, crop residue, and the abundance and diversity of soil invertebrates. Two sites were used in Southern Ontario. Each site had one field with crop residue over the winter of 1990, and one field without crop residue. Populations of cryptozoic (soil surface) fauna, foliage fauna, and earthworms were measured.

The abundance and richness of cryptozoic invertebrates declined significantly with increasing distance into the fields. The decline in abundance was dependent on date, the greatest decline with increasing distance into the field was in late fall. These declines suggest that cryptozoic invertebrates were present at distances further out into the field, despite their comprising few taxa, and that many of the invertebrates are dependent on the woodlots for winter shelter. Crop residue on the field over winter significantly increased cryptozoic abundance and richness at all distances from the woodlot in some fields, suggesting that crop residue promoted invertebrate persistence in these fields.

The numbers and richness of Carabidae (carabid beetles) increased significantly with increasing distance into the fields in late July and August, particularly in the corn cropping systems. The crop residue appeared to have little effect on carabid distribution.

Evenness of the cryptozoic community increased significantly with increasing distance into the fields. Species dominance, therefore appears greater in the woodlot than in the field. Crop residue cover on some fields significantly decreased evenness at all distances from the woodlot.

Earthworm number and mass increased significantly with increasing distance into the fields, possibly because of increased competition from other macro-decomposers which were more abundant near the woodlot.

## Acknowledgements

This study was funded by the Soil and Water Environmental Enhancement Program of Agriculture Canada. I thank Elias Brubacher and Jim Schneider for the use of their land, and Professor Vernon Thomas and William Matthes for useful discussions. I also thank Corinne Neave for assistance with the field work.

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## **Introduction**

Windbreaks, including shelterbelts, woodlots, fencerows, and hedgerows, tend to increase yields of adjacent field and forage crops through reduced wind erosion, improved microclimate, snow retention, and reduced wind damage (Kort, 1988). Shelterbelts are also attractive to insects and other invertebrates. Small or wingless insects often depend on wind for transport and often settle in protected windbreaks. Insects also accumulate in these areas because of reduced windspeeds which give greater control over flight (Pasek, 1988).

Many invertebrates overwinter in these sheltered sites (Nazzi et al., 1989). Early spring growth in hedgerows and woodlots attracts the invertebrates in May and June before many arable crops are well established (Pollard, 1971). It is therefore conceivable that invertebrate abundance decreases with increasing distance from a woodlot. Shelterbelts and woodlots provide suitable overwintering sites for many invertebrates because the dense vegetation, deep sod layer, and thick litter layer dampen temperature fluctuations and provide insulation against low winter temperatures (D'Hulster and Desender, 1984). Soils are often less dense in non-agricultural areas, providing better aeration for overwintering animals (D'Hulster and Desender, 1982). In addition, invertebrates are not disturbed by agricultural management in these sites, which promotes their persistence. Crop and hay fields are often less suitable for some organisms to overwinter in because of the physical disturbance of yearly plowing and/or a more poorly developed sod layer (D'Hulster and Desender, 1984).

In the spring, some invertebrates move from wooded vegetation into the surrounding fields where prey is abundant. In Western Europe, some carabid species overwinter in shelterbelts and spread into the field as far as the influence of the microclimate of the trees extends. One carabid beetle, Agonum dorsale, leaves its winter quarters in March-April, migrates to the fields in May,



returning to a shelterbelt in August, and moves into its winter habitat again in October (Thiele, 1977).

Other invertebrates stay in hedgerows and woodlots longer in the spring, producing an early generation which feeds on early-growing perennial plants. They then move out into the arable crop after it has become established and feed on insects there. Anthocoris nemorum (Heteroptera) is an example of a common predator in Europe with this type of behaviour (Pollard, 1971).

Other studies indicate that, in general, arthropod diversity drops rapidly as one moves away from the edge of a field (Reichert and Lockley, 1984). The declining diversity indicates that these migrating organisms do not effectively recolonize whole fields, probably only moving until suitable habitat is found.

A study of soybean agroecosystems in Italy (Nazzi et al., 1989) found that hedgerows were important in keeping faunal equilibrium by maintaining non-excessive dominance, greater diversity among the species and greater diversity for carabid beetles. The structure of carabid and spider communities in open fields appeared less balanced in having greater dominance, and less diversity (Nazzi et al., 1989) than that of the fields surrounded by hedgerows. These authors concluded that hedgerows maintained populations of polyphagous predators which help to control numbers of phytophagous organisms (plant herbivores). Other researchers have found similar results. Florida corn fields surrounded by burned pine forest and weedy fields have a more diverse and abundant predator fauna than corn fields surrounded by annual crops (Altieri and Whitcomb, 1980). This is believed to occur because increased habitat diversity provides alternate feeding sites for natural predators and this facilitates dispersal into crop systems (Van Emden, 1965; Altieri and Todd, 1981).

Agricultural practices often reduce populations of soil invertebrates. In root crop and cereal fields of northern great Britain, activity indices of carabids have decreased in some fields by more than 95% due to cultivation (Lys and Nentwig, 1991). Undisturbed areas such as hedges or woodlots facilitate dispersal of carabids back into agricultural fields, and lower the risks of local extinctions of these populations, because these uncultivated areas are important hibernation sites, shelters, and an abundant source of food (Lys and Nentwig, 1991).

Many species of arthropods, however, are restricted to specific habitats, and do not freely range throughout agricultural landscapes. For these arthropods, hedges and woodlots might have limited importance, and a decline in abundance and diversity may not be expected as one moves away from a windbreak. Pollard (1971) found that syrphid fly (Syrphidae) predation on aphids was not affected by the presence of hedgerows surrounding test fields, and concluded that diversity of habitat outside a crop does not add to the stability of crop pest populations. Pollard (1971) indicated that many of the predators found in crops are permanent members of the crop fauna and are not influenced much by hedge or woodlot diversity. These results were in agreement with those of Thiele (1977) who found that most carabid beetles were very habitat specific, rarely moving from one ecosystem to another. Studies on carabids in Sweden (Wallin, 1985) have found that some carabids in agricultural fields are true inhabitants, and are not, or are only slightly dependent on, adjacent uncultivated habitats during parts of their life cycle. These carabids were often found along field edges, however. Agricultural management does benefit some invertebrates, particularly through improved drainage, irrigation, and fertilizer application (Dangerfield, 1990), and these invertebrates probably prefer to live in fields.

Those invertebrates which do not depend on uncultivated areas for overwintering, often overwinter in crop fields. For example, several carabid species dig down to depths of 30-45 cm to overwinter even in hard clay soil (Thiele, 1977). The success of this type of overwintering

depends on the insulative capacity of the soil surface, and therefore might be related to the amount of crop residue on the soil surface. However, this success would vary from species to species. Carabid larvae also overwinter in crop fields, some remaining highly active near the soil surface throughout the winter, while others inhabit deep layers (Thiele, 1977). Absence or presence of litter may have a more profound effect on species which are active near the surface during the winter. Surface litter has been shown to provide increased overwintering habitat for herbivorous insect populations and is assumed for predatory carabid fauna (House and All, 1981).

Earthworms have also been found to be influenced by hedges or woodlots. In a poplar windbreak in Czechoslovakia (Miko et al., 1989), earthworm number was highest on the windward side of the shelterbelt, was low in the windbreak, and rose again as one moved out on the leeward side of the windbreak. Earthworm numbers were found to be correlated with soil humidity, and were low in the windbreak because of high evapotranspiration rates.

Three groups of invertebrates will be examined in the following study with respect to their relationship with woodlots, the cryptozoic invertebrates, the foliage arthropods, and earthworms. The cryptozoic invertebrates live on the surface of the soil and include staphylinid and carabid beetles, spiders, harvestmen, millipedes, slugs, and sowbugs. These invertebrates are important in pest control (eg. ground beetles, spiders), in residue decomposition (eg. millipedes, sowbugs) and subsequent nutrient release (Hendrix et al., 1989).

The foliage arthropods are found on crop and weed plants, and include parasitic wasps of several families, Syrphid flies, Coccinellidae (ladybird beetles), true bugs (Hemiptera) and many plant herbivores (Pollard, 1971). Some of the foliage invertebrates are important in predation and parasitism (Thiele, 1977; Pollard, 1971).

Earthworm activity has a variety of influences within the soil. Briefly, their activity has been found to influence plant yield (Edwards and Lofty, 1980), soil structure (Shaw and Pawluk, 1986), water infiltration rate (Ehlers, 1975; Lal, 1988; Shipitalo and Protz, 1987), residue breakdown (Zachmann and Linden, 1989; MacKay and Kladvko, 1985), and encourage microbial growth (Ghilarov, 1963; Vimmerstedt and Finney, 1973).

### Central Question and Hypothesis

This study addresses two questions. First, does invertebrate abundance and diversity decrease in agricultural fields with increasing distance from woodlots? Second, does crop residue cover on fields have any influence on the distribution of invertebrates with increasing distance from woodlots?

Two null hypotheses will be tested to answer these questions. The first null hypothesis is that increasing distance from a woodlot has no influence on the abundance, richness and evenness of distribution of cryptozoic and foliage fauna communities. This hypothesis will be tested by determining the slope of the faunal-distance relationship (See Figure 1). A significantly non-zero slope would allow the null hypothesis to be rejected. This hypothesis will be tested using all invertebrates that are sampled, not strictly those that overwinter in uncultivated areas, or those that overwinter in agricultural fields. The results will therefore assess whether the woodlot has any influence on the entire invertebrate community. It is already known that woodlots influence some species' distributions (Thiele, 1977; Reichert and Lockley, 1984).

The second null hypothesis to be tested is that the presence of crop residue on a field has no effect on the abundance, richness and evenness of distribution of cryptozoic and foliage fauna

populations. This hypothesis will be tested by comparing abundance and diversity in spring and fall plowed fields, and also in zerotillage fields with and without crop residues. If crop residue influences the invertebrates, the rate of decline (slope) should be lower with increasing distance into the field containing surface residue (See Figure 1). Significantly different slopes would allow this null hypothesis to be rejected. This hypothesis is a test of the influence of crop residue on the entire invertebrate community.

## **Materials and Methods**

### 1) Selection of the study sites

Two sites were used in this study, and each had two cropping systems, - one with crop residue on the soil surface during the winter, and one without. The first site was located eight kilometers south of Mount Forest, Ontario (Lat. 45E 54' 48", Long. 80E 43' 30"). The soil at this site was a well drained Harriston loam (pH 7.5; Order Luvisols). In 1990, half of the field was in corn, and the other half was in barley with strips of corn in the center of the field (Figure 2). The corn was cut for silage in the fall of 1990, leaving almost no residue on the soil surface. The barley was also harvested, but most of the straw was left behind. There was no tillage in this field in 1990. This left two distinct areas, one with very little residue, and one with a thick straw residue cover. In 1991, the whole field was lightly harrowed, and planted with corn. The two cropping systems here are: barley-residue corn, and no-residue corn, respectively. Four, 50 m transects were set up in each of the two cropping systems. The entire field at this site was surrounded by a woodlot dominated by Eastern white cedar (*Thuja occidentalis*), Sugar maple (*Acer saccharum*), Choke cherry (*Prunus virginiana*), and Trembling aspen (*Populus tremuloides*). The two cropping systems within this field had identical slope and drainage patterns.

The second site was located eight kilometers southeast of Fergus, Ontario (Lat. 43E 43' 20", Long. 80E 17' 00"). This site comprises two adjacent fields, both of which were planted with soybeans in 1990. The soil type of these fields was an eroded phase Fox sand, and an eroded phase Brady sandy loam; both are in the same catena, the latter is more poorly drained (Order Luvisols). After harvest in 1990, one field (Fox sand) was chisel plowed, burying almost all of the crop residue. The second field (Brady sandy loam) was not plowed, leaving a thick cover of

soybean residue on the surface. The cropping systems here were fall-plowed soybeans, and spring-plowed soybeans, respectively. In the spring of 1990, the field with no crop residue was harrowed with tandem disks, and the field containing crop residue was chisel plowed and harrowed similarly. Five, 50 m transects were run into these two fields from nearby woodlots. These woodlots bordered these fields over 250-300 m, and were dominated by Sugar maple (Acer saccharum), Trembling aspen (Populus tremuloides), and Beech (Fagus grandifolia).

Both study sites therefore have one field which had crop residue on the soil surface during the winter of 1990, and one field without crop residue during this period. There are four tests of the first null hypothesis, and two tests of the second null hypothesis, one for each site.

## 2) Invertebrate sampling procedure

Sampling for invertebrates was done from mid-July until late October. This period was chosen to miss the early season migrations and trap the spatial distribution that is most common at the late summer- early fall peak of invertebrate activity (Neave, 1992; Wallin, 1985).

The following definitions are used in this study:

**Abundance** is the total number of individuals found in a sample. **Richness** is the number of taxa found in a sample, and **Occurrence** is the number of taxa found in all samples. Evenness is the equitability of distribution of abundance among the taxa (Hill, 1973). A community whose abundance is 100, and richness is 4, is more even when each taxa has 25 individuals, than when one taxa has 97 individuals, and the other three taxa have one individual. The latter community is said to have greater dominance.

a) Pitfall traps

Pitfall traps are behavioural traps that capture cryptozoic invertebrates. At each transect, pitfall traps were placed in the soil 7.5 m into the woodlot, at the woodlot edge, and 7.5m, 15m, 30m, and 50m into the field. The pitfall traps were made with 12 cm clear plastic containers, and were partially covered with a lid. Any invertebrates whose path crosses the pitfall traps fall in and are preserved by ethylene glycol. Pitfall traps were emptied weekly, and the invertebrates were then identified and counted.

During the sampling season, some pitfall traps were emptied by raccoons (Procyon lotor). Quinine was added to the ethylene glycol to deter raccoons, but this had no effect. The use of only water in the pitfall traps did not deter racoon interest, either. A number of samples were lost in this way, and the pitfall trap samples over a two week period had to be combined to make a complete set of samples. As a result, only five complete sets of samples were obtained at the Mount Forest and Fergus sites. These pooled sample dates were: August 2nd-9th, August 16-22, August 30-September 6th, September 13-27, and October 8th-16th, and are referred to as sample dates 1 through 5, respectively.

b) Foliage arthropods traps

Foliage arthropods were sampled using two methods. The first method involved taking a large (40 x 80 cm) plastic bag, placing it rapidly over five soybean plants, cutting the stems of the plants at their base, and sealing the bags with the plants inside. This procedure was done in both soybean fields at 0, 20 and 40 m away from the woodlots. These sealed bags were then frozen. After freezing, the plants were beaten within the bags to dislodge any invertebrates, the soybean plants removed, and the contents of the bag were then examined. Samples were also placed in



Tullgren funnels (Southwood, 1987), instead of freezing them, to see if more invertebrates could be obtained. The plastic bag method was used to sample arthropods on soybeans every two weeks.

The second method of sampling foliage arthropods was to use an intercept trap (Southwood, 1978). The corners of a large (50 x 100 cm) yellow plastic bag were tied to adjacent corn plants, and a plastic tray 1m wide was suspended below and filled with ethylene glycol. Flying invertebrates were attracted to the yellow material, flew into it, and subsequently fell into the tray of preservative (Southwood, 1987). These traps were set up along the corn field transects, at 0, 20, and 40 m from the woodlot, and were emptied weekly. Raccoons destroyed most of these traps every week they were set out. Too few samples were obtained to run a statistical analysis.

### c) Earthworms

Earthworms were sampled using a combination of the formalin and hand sorting methods. Earthworm samples were taken at 0, 25, and 50 m at each transect. Formalin (25 mL) was added to 4.5 L of water and sprinkled over 0.45 square meters (Raw, 1959). Any earthworms that came to the surface were collected and, after 30 min., the soil was excavated to a depth of 20 cm, and the rest of the earthworms were found by hand sorting. Sampling for earthworms was done from October 15-18th, 1991, in barley-residue and no-residue corn, and in spring plowed soybeans. Fall-plowed soybeans were not sampled because of lack of access to the site by vehicle.

### 3) Physical measurements

Soil water content was measured gravimetrically over 0-10cm depth at the same distances from the woodlots as the pitfall traps. Water content was measured in both corn, and the spring-

plowed soybean cropping systems. Differences in residue cover between fields was estimated using 0.06 m<sup>2</sup> quadrats on May 28th, 1991.

#### 4) Statistical analyses

Pitfall trap, earthworm, and water content results were run through an analysis of variance factorial model, which considered all interactions between factors. This model was simplified by removing non-significant factors and interactions, and then testing contrasting slopes and intercepts of the distance-abundance/diversity relationship in different cropping systems. Whether slopes were significantly different from zero was tested using a t-test, with an accepted probability of a type I error of 5%. Intercepts and slopes of different cropping systems were contrasted using t-tests.

Results are presented in the form of intercepts and slopes of the invertebrate abundance/diversity - distance relationship. Cryptozoic invertebrate abundance and number of carabids were log(e) transformed, because the abundance data were not normally distributed and could not be used in the factorial model without transformation.

The results presented are from the ANOVA factorial model. If slopes were not significantly different among the different cropping systems (ie. no interaction between distance and cropping system), the model used all data to create a common slope. As a result, cropping systems in some figures demonstrate common, identical slopes. This precludes showing the small variations in slope interest in the untransformed results.

## **Results**

### 1) Analysis of invertebrate distribution

#### a) Invertebrates in pitfall traps

A large number of taxa was captured in the pitfall traps (Table 1). The dominant taxa captured were carabids and crickets for the first two sampling periods, and Anthomyiid flies, harvestmen, and ants were dominant throughout the sampling season. Staphylinid beetles, slugs, and sowbugs were common in the pitfall traps. Occurrence was usually greater when distances were less than 8m from the woodlot for all cropping systems (Tables 1 and 2), particularly at the earliest sample date.

Both slugs and millipedes (Blanilius spp. and Scytonotus spp.) were concentrated near the woodlot (Tables 1 and 2). These animals were found at distances beyond 8m at the last sample date, as a few had moved out to 15m by the end of the growing season. These animals did not advance to 30 and 50m from the woodlot.

There was a general decrease in abundance of cryptozoic invertebrates with increase in distance from the woodlots (Figure 3). The relationship between the abundance of the cryptozoic community and the distance in a field from a woodlot had both linear and quadratic components. There was no significant interaction between distance and cropping system, indicating that the slope of the abundance-distance relationship was not significantly different between cropping systems. The model, therefore, used the data points from all fields to calculate a common slope. There was a significant ( $p < 0.05$ ) distance by date interaction, and the slopes were different for the five sample dates. The slopes revealed a trend towards an increase in the rate of decline of abundance as the season progressed (Figure 3). The slope of this relationship (all cropping

systems) on the first sample date was: Slope = (dist.) X (-0.02925) - (dist.) X 0.000515, and the slope on the fifth sample date was: Slope = (dist.) X (-0.06466) + (dist.) X 0.000515, both being significantly different from zero.

The abundance intercepts were different in each cropping system (Table 3). The spring-plowed soybean cropping system had the largest intercept, which also was significantly higher than the intercept in fall-plowed soybeans (t-test,  $p < 0.0001$ ). The intercepts in barley-residue corn, and no-residue corn were not significantly different.

Carabid beetles were sufficiently abundant in the first two sampling dates to analyze their slope and intercepts. There was no significant interaction between distance and date in the factorial model of carabid abundance or richness, so slope did not change with date. There was, however, a significant ( $p < 0.05$ ) distance and cropping system interaction for both carabid abundance and richness, and the slope was different for each cropping system (Figures 4 and 5).

The rate of increase of number and richness of carabids was greatest in the corn cropping systems (Figure 4 and 5). Slopes were not significantly different when comparing barley residue and no-residue corn systems, or fall and spring-plowed soybeans. All slopes were significantly ( $p < 0.05$ ) different from zero.

Intercepts of carabid abundance and richness were not significantly different when comparing barley residue and no-residue corn, and fall and spring-plowing soybeans (Table 3).

There was a linear decline in richness of the cryptozoic community with increasing distance into the fields (Figure 6). There were no significant interactions between distance and

cropping system, or distance and sample date in the factorial model, so the slope was the same for all cropping systems and dates. The slope of this decline in all cropping systems was: Slope = (dist.) X (-0.03466), and was significantly different from zero.

The richness intercepts were different in each cropping system (Table 3). The intercept of spring-plowed soybeans was significantly higher than the intercept of fall-plowed soybeans (t-test,  $p < 0.004$ ). The intercept of barley residue corn, and no-residue corn was not statistically different.

The general trend of the relationship between evenness and distance from a woodlot was an increase in evenness with increasing distance into the fields (Figure 7). The slope of the relationship between evenness of the cryptozoic community, and the distance from a woodlot had both linear and quadratic components, and is given as: Slope = (dist.) X 0.003244 - (dist.) X 0.000034.

This slope was the same in all four cropping systems and all five sample dates, and was significantly different from zero. The increase in evenness became smaller with increasing distance into the field, and, presumably, reached a maximum, and begin to decline at some point greater than 50m from the woodlot.

The evenness intercepts were different in each cropping system (Table 3). The intercepts of spring-plowed and fall-plowed soybeans were significantly different (t-test,  $p < 0.001$ ), fall-plowed soil having a more even community. There was no significant difference in the intercepts of barley residue, and no-residue corn systems.

b) Foliage arthropods

Too few samples of foliage arthropods were obtained from any of the traps for statistical analysis. The plastic bag method was used four times on soybean plants. No invertebrates were found in the vegetation samples, whether the samples were frozen and examined, or placed in Tullgren funnels.

The intercept traps set up in the corn cropping systems did capture invertebrates. Occurrence in the barley residue corn system was 20 taxa, in a limited number of samples (Table 4).

c) Earthworms

The number of earthworms increased with increasing distance into the fields (Figure 8). There was no significant distance by cropping system interaction so the slope is the same for all three cropping systems. The slope of the relationship between number of earthworms and distance from woodlots had both linear and quadratic terms: Slope = (dist.) X 0.727 - (dist.) X 0.00916, and was significantly different from zero.

Earthworm number intercepts were different in the three cropping systems, no-residue corn being the highest, and significantly higher than in the barley residue corn system (t-test,  $p < 0.0001$ ; Table 3).

The total mass of earthworms also increased with increasing distance into the fields (Figure 9). As there was no significant interaction between distance and cropping system in the factorial model, the slope was the same for all cropping systems: Slope = (dist.) X 0.3032, and was significantly different from zero.

Earthworm mass intercepts were different for the cropping systems, no-residue corn again having the largest intercept, and was significantly larger than that of the barley residue corn (t-test,  $p < 0.032$ ; Table 1).

## 2) Physical measurements

Water content declined with increasing distance from the woodlot in the no-residue corn soil (t-test,  $p < 0.05$ ; Table 5). There was no significant decline in water content in the barley residue corn system, or in the spring-plowed soybean fields.

Crop residue cover was significantly higher in the barley residue corn field than in the no-residue field ( $43.5 \pm 8.0\%$  and  $16.8 \pm 3.4\%$ , respectively) (t-test,  $p < 0.001$ ). The crop residue cover was significantly higher in the spring-plowed, soybean field than the fall-plowed field ( $62.9 \pm 12.3\%$  and  $7.0 \pm 8.1\%$ , respectively,  $p < 0.001$ ).

## Discussion

### Analysis of invertebrate distribution

#### a) Invertebrates in pitfall traps

Comparison of the occurrence of cryptozoic invertebrates at different distances from the woodlots, and at different times of the year, provides some insight into which invertebrates were migrating, and which appeared to be staying in the fields to overwinter.

On the first sample date, sowbugs, crickets, Staphylinid beetles, Nitidulid beetles, ground beetles, Coccinellid beetles, Anthomyiid flies, ants, Braconid parasitic wasps, wolf spiders, and harvestmen were common, and also present at distances <8m and >8m from the woodlot (Table 1). Slugs, land snails, Blanilius and ground beetles were also common at distances <8m from the woodlot (Table 1).

The above pattern of occurrence changed by the last sample date (Table 2). At this time, ground beetle E was not found at all, ground beetle A and the Coccinellid beetles had left the corn cropping systems, and the Nitidulid beetles and wolf spiders had disappeared from several cropping systems. This change suggests that these taxa had migrated into the woodlots (Thiele, 1977). Crickets, staphylinid beetles, ground beetle B, Anthomyiid flies, ants, Braconid wasps, and harvestmen remained common at all distances from the woodlot at the last sample date. With the exception of the highly mobile Anthomyiid flies, these animals appeared to be staying in the fields, possibly to survive by overwintering.

There was a significant decrease (negative slope) in cryptozoic abundance with increasing distance into the fields. The first null hypothesis (the slope was not significantly different from



zero) can therefore be rejected for cryptozoic abundance. The steepness of this decrease in abundance, depended on the sample date (Figure 3). On the first sample date, there was a decrease in abundance with increasing distance into the field, but the rate of decrease was low, and actually became a rate of increase at 30 m, according to the model. By the last sample date, the rate of decrease in cryptozoic abundance with increasing distance into the fields was much higher. This change in rate of decrease of abundance over time probably reflected invertebrate behaviour. In the summer, the cryptozoic invertebrates appeared to be spread over the entire sampling area as there is little decrease in number with distance. In the fall, when many cryptozoic invertebrates are moving back to the woodlot, the rate of decrease of abundance became much higher as the invertebrates were leaving the field, and migrating into the woodlot and its border.

Crop residue also influenced the distance-abundance relationship. The abundance intercept (Table 3) of spring-plowed soybean fields was significantly higher than that of fall-plowed soybean fields, but the slopes were the same. The second null hypothesis therefore cannot be rejected for invertebrate abundance, but crop residue does have an effect. The rates of decrease are the same for the same date, but the magnitude of the decrease is not, because abundance in the spring-plowed soil is significantly higher than the abundance in fall-plowed soils. There are more invertebrates at every distance from the woodlot in the spring-plowed soil. This difference can be attributed to the presence of crop residue, as it offers protection that is unavailable in plowed soil. There was no significant difference in the intercepts of barley-residue corn and no-residue corn (Table 1). It is not known whether this difference in residue effect between sites is due to the different residue types, or to other differences between sites.

The abundance of cryptozoic invertebrates is often reported to be lower in fields than in unmanaged habitats (Dangerfield, 1990; Mayes and Price, 1978). This trend was also observed in the present study, although the trend was dependent on date.

The abundance results suggest three conclusions. The first is that there appears to be some invertebrates at greater distances into the field for at least part of the year. This conclusion is supported by the gradual decline of abundance with distance in July and August (Figure 3). The second conclusion is that the woodlots appear to be important shelters for the cryptozoic invertebrates. This conclusion is supported by the decrease in invertebrates active at greater distances into the field in late September and October, and no decrease in activity in the woodlot, indicative of migration to the woodlot. The third conclusion is that crop residue promotes the persistence of invertebrates at all distances from the woodlot. More cryptozoic invertebrates were staying in the field later into the season. This conclusion was supported by the significantly greater abundance at all distances and dates in the spring-plowed soybeans, compared to the fall-plowed soybeans. However, this conclusion did not apply in the corn cropping systems.

Both number of carabids, and richness of carabids increased significantly with increasing distance from the woodlot, so the first null hypothesis can be rejected. The presence of crop residue appears to have little effect on carabid numbers and richness, as slopes and intercepts were not significantly different when comparing like cropping systems (Table 3). The second null hypothesis therefore cannot be rejected.

Nazzi et al. (1989) also captured more carabids in an agricultural field than in and near a hedgerow. The present study, and Nazzi's, suggest that carabids are successful in dispersing into

the agro-ecosystem. In the present study, the analysis of carabid distribution was done at the peak of carabid activity (Nazzi et al., 1989; Thiele, 1977), and not later in the season. It is likely that this distribution would change over the season, as it has been found (Nazzi et al., 1989; Thiele, 1977) that many carabids are dependent on woodlots for overwintering.

There was also a significant decrease in richness with increasing distance from a woodlot (Figure 4), so the first null hypothesis can be rejected for richness as well. This significant rate of decrease is unaffected by date, so the lower richness further out in the field would appear to be permanent. The greater abundance at 50 m in the summer, rather than in the fall, would appear to be due to an increase in the numbers of taxa which are already present, and not due to migration of different taxa during the season. This conclusion is supported by species richness remaining low throughout the season. The decrease in richness agrees with the previously noted decrease in occurrence (Tables 1 and 2).

There was no difference in the rates of decrease of richness in the different cropping systems, so the second null hypothesis cannot be rejected. However, the intercept of spring-plowing soybeans was significantly higher than the intercept of fall-plowing soybeans, indicating that residue cover resulted in more invertebrate taxa being present further into the field (Table 3). There was no significant difference between the intercepts of barley-residue corn, and no-residue corn.

Nazzi et al. (1989) found that species diversity and Shannon's diversity index (combined richness and evenness) were lower in the field than in the hedgerow, this agreeing with the present study. Nazzi et al. (1989) attributed this difference to the hedgerows' providing shelter to animals

which are linked with rarer biotopes, such as lowland woods, or to animals which are disrupted by agricultural activities. This is likely also the case in the present study. Richness is greater in the woodlot because some organisms naturally live there and not in the field (refer to discussion of occurrence), and the woodlot also offers shelter to organisms that do live in the field.

The results on richness suggest two conclusions. The first conclusion is that fewer taxa are found at greater distances into the field at all times of the year. This is supported by the strong linear decline in richness in all cropping systems and on all dates. This conclusion suggests that there may be less migration of different taxa into the woodlots than there was of individuals (abundance). Taxa that are found further into the fields may stay there year round, and taxa that are found in woodlots may also be permanent residents (for example slugs and millipedes). The second conclusion is that crop residue on the field over the winter promoted greater richness at all distances into the soybean field. This suggests that crop residue promotes persistence of cryptozoic invertebrates in the field over the winter.

Evenness of the cryptozoic community did not decline with increasing distance from a woodlot, as did cryptozoic abundance and richness. Instead, evenness had a significant rate of increase with increasing distance from the woodlot (Figure 5). This indicates that the equitability of distribution is greater in the field, than in the woodlot and at its edge. This result, combined with the described decrease in richness with increasing distance into the fields, suggests that there is greater dominance in and near the woodlot than in the field. Greater dominance was often observed in the woodlot in individual samples which would be largely composed of ants, harvestmen, slugs, and sowbugs.

The second null hypothesis cannot be rejected for evenness, as the slopes for all cropping systems were the same. However, the fall-plowed soybean intercept was significantly higher than the spring-plowed intercept (Table 3), so the fall-plowed soybean cryptozoic community was more evenly distributed at all distances than the spring-plowed community (Figure 5). This suggests that the crop residue promotes the persistence of several dominant taxa, whose presence significantly lowers the evenness value. There was no significant difference between the intercepts of barley-residue corn and no-residue corn. Nazzi et al. (1989) reported that greater dominance was found in soybean fields than in nearby hedgerows in Italy. This disagrees with the results of my study, possibly because of differences in taxa that are native to the fields and woodlots. There is also a considerable difference between Nazzi's 3-4 m deep hedgerow, and the > 30 m deep woodlots examined in this study. In addition, Nazzi et al. (1989) used a different measure of dominance, which might account for the difference with my study.

Dominance is either a result of competitive exclusion, or a result of a taxa specializing on a resource that is widely distributed and abundant (Krebs, 1985). Intuitively, competition and specialization should be greater in the woodlot where invertebrates are present year round, and where there is not as much change in abundance with time. Animals which specialize on soybeans one year, may find that a different crop has been grown the following year. This specialization on a non-permanent ecosystem component often results in high mortality and has been effectively used to control corn rootworm (Krysan et al., 1986).

Crop residue promoted dominance (lower evenness) in the soybean field. This increase in dominance may be a result of one organism being able to exploit the field habitat in greater

numbers when there was crop residue present. This would result in a general increase in richness which was observed (Figure 4) when crop residue was present on the soybean field.

b) Foliage fauna

The plastic bag method of rapidly covering plants to sample foliage arthropods was not effective in my study, although it has been successful in others (Kevan, 1991)<sup>1</sup>. The lack of invertebrates captured may be a result of very few arthropods being present on the plants, or that those arthropods on the plants may have flown or dropped to the ground while the plants were being covered with the bag.

The intercept traps were effective in capturing many taxa. This was confirmed through observation and the few samples which were not destroyed by racoons.

c) Earthworms

Both earthworm number and mass were found to increase significantly with increasing distance from a woodlot (Figures 8 and 9). The first null hypothesis can therefore be rejected. The intercept of earthworm number and mass was significantly higher in no-residue corn than in barley-residue corn, indicating that in this case, barley residue did not increase earthworm abundance.

A similar trend was also observed by Miko et al. (1989), who found that earthworm numbers on the leeward side of a windbreak were low, and numbers increased as you moved out from the windbreak. Miko found that earthworm number was negatively influenced by

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<sup>1</sup>Kevan, P.G. Department of Environmental Biology, University of Guelph. Personal communication.

evapotranspiration, close to the windbreak, and correlated with soil humidity. Evapotranspiration and soil humidity do not appear to be factors in my study, as water content was found to be as high in the windbreak as in the field (Table 3). Low earthworm numbers near the windbreak may be a result of competition from other macro-decomposers, such as slugs and millipedes which were more abundant near the windbreak (Figure 3).

## Conclusions

The information obtained for the cryptozoic invertebrates provides some insight into the effect of field size on invertebrate distribution. In mid summer, the factorial model predicts that there should be a good number of cryptozoic invertebrates at distances greater than 50 m from the woodlot, as the model shows very little decline in late July and early August. However, these invertebrates will not be at these distances for long, as many have to return to the woodlot eventually (Figure 3). This shorter presence will lessen the degree to which the cryptozoic invertebrates can perform their functions of predation and decomposition. Crop residue on fields over winter may partially remedy this problem because it increased abundance at all distances on all sample dates.

Richness, however, was never high at the greater distances into the field, as shown by the linear decline of species with increasing distance, at all sample dates. Extrapolating from this trend, one can speculate that eventually, far enough from the woodlot, there would be no taxa present that are dependent on the woodlot. Only taxa that are more strongly linked to the field might be present. The absence of taxa such as millipedes could slow the decomposition process. Crop residue on fields over winter appears to extend the distance at which cryptozoic invertebrates might be found in fields.

The extrapolation of the richness data appears to be supported by the evenness data. Evenness generally increased with increasing distance from the woodlot, but this increase would reach a maximum and begin to decline at some distance greater than 50 m from the woodlot, because of the negative quadratic term in the slope. At larger (than 50 m) distances from the



woodlot, evenness may conceivably become low, indicating greater dominance. The richness and abundance extrapolations also predict greater dominance, with relatively high abundance, and increasingly lower richness with increasing distance from the woodlot.

This study appears to suggest that large fields may have taxa poor centers, with several dominant taxa being present in relatively large numbers for part of the year. This is not an ideal situation, as it probably interferes with the natural predator control of pests, and with decomposition and nutrient cycling. The present study, and others (Nazzi et al., 1989), appears to suggest that smaller fields surrounded by a windbreak, are more likely to take advantage of biotic processes. This would be especially true for lower input agriculture which is more dependent on natural biotic activity.

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Table 1. Occurrence of cryptozoic invertebrates in barley- and no-residue corn fields, and fall- and spring-plowed soybean fields at distances <8 m, and >8 m from a woodlot, on the first sample date.

| Taxon             | Presence (X) or absence (-) |     |                 |     |                      |     |                        |     |
|-------------------|-----------------------------|-----|-----------------|-----|----------------------|-----|------------------------|-----|
|                   | Barley-res. corn            |     | No-residue corn |     | Fall-plowed soybeans |     | Spring-plowed soybeans |     |
|                   | <8m                         | >8m | <8m             | >8m | <8m                  | >8m | <8m                    | >8m |
| slugs             | X                           | -   | X               | -   | X                    | -   | X                      | -   |
| land snail        | X                           | -   | X               | -   | -                    | -   | X                      | -   |
| earthworm         | X                           | X   | -               | -   | X                    | -   | X                      | X   |
| sowbugs           | X                           | X   | X               | X   | X                    | -   | X                      | X   |
| Entomobryinae     | -                           | -   | X               | -   | -                    | -   | -                      | -   |
| Sminturinae       | X                           | -   | -               | -   | -                    | -   | X                      | -   |
| grasshoppers      | X                           | X   | -               | -   | X                    | X   | X                      | X   |
| crickets          | X                           | X   | X               | X   | X                    | X   | X                      | X   |
| leafhopper        | X                           | X   | X               | X   | X                    | X   | -                      | X   |
| damsel bug        | X                           | -   | -               | X   | -                    | -   | -                      | -   |
| aphid             | X                           | X   | X               | X   | -                    | -   | -                      | X   |
| Colleoptera A     | -                           | -   | -               | -   | X                    | X   | X                      | X   |
| beetle larvae     | X                           | X   | X               | -   | X                    | -   | X                      | X   |
| Staphylinidae A   | X                           | X   | X               | -   | X                    | X   | X                      | X   |
| Staphylinidae B   | -                           | -   | X               | -   | X                    | -   | X                      | -   |
| Nitidulidae       | X                           | X   | X               | X   | X                    | X   | X                      | -   |
| ground beetle A   | X                           | X   | X               | X   | X                    | X   | X                      | X   |
| ground beetle B   | X                           | X   | X               | X   | X                    | X   | -                      | X   |
| ground beetle C   | X                           | -   | X               | X   | -                    | X   | -                      | -   |
| ground beetle D   | -                           | -   | X               | X   | X                    | -   | -                      | -   |
| ground beetle E   | X                           | -   | X               | -   | -                    | -   | X                      | -   |
| ground beetle F   | X                           | X   | -               | X   | X                    | X   | X                      | X   |
| ground beetle G   | -                           | -   | -               | -   | X                    | X   | X                      | X   |
| ground beetle H   | -                           | -   | X               | -   | -                    | -   | -                      | -   |
| ground beetle I   | X                           | -   | -               | -   | -                    | -   | -                      | -   |
| ground beetle J   | -                           | -   | -               | -   | X                    | X   | X                      | X   |
| ground beetle K   | -                           | -   | -               | -   | -                    | -   | -                      | X   |
| Coccinellidae     | X                           | X   | X               | X   | X                    | X   | -                      | X   |
| Cantharidae       | X                           | -   | X               | X   | X                    | -   | -                      | -   |
| bombardier beetle | -                           | -   | -               | -   | -                    | X   | -                      | X   |
| Elateridae        | -                           | -   | -               | -   | X                    | -   | X                      | -   |
| weevil            | X                           | -   | X               | -   | X                    | X   | -                      | X   |
| Scarabaeidae      | X                           | X   | X               | -   | -                    | -   | -                      | X   |
| Lepidoptera A     | X                           | -   | -               | -   | -                    | X   | X                      | X   |
| Lepidoptera B     | -                           | -   | X               | -   | -                    | -   | X                      | -   |
| hornworm          | -                           | -   | -               | -   | -                    | -   | X                      | -   |
| Diptera A         | -                           | -   | -               | -   | X                    | -   | -                      | -   |

Table 1 continued

|                    |    |    |    |    |    |    |    |    |
|--------------------|----|----|----|----|----|----|----|----|
| Diptera B          | -  | -  | -  | -  | -  | X  | -  | -  |
| Diptera C          | -  | -  | -  | -  | X  | -  | X  | X  |
| Diptera D          | -  | -  | -  | -  | X  | -  | -  | -  |
| Sciari dae         | -  | X  | -  | X  | X  | -  | X  | -  |
| Ti pul i dae       | X  | -  | -  | -  | -  | X  | -  | X  |
| Phori dae          | X  | X  | X  | -  | X  | -  | -  | X  |
| Syrphi dae         | -  | -  | X  | -  | -  | -  | -  | -  |
| Empi di dae        | X  | -  | -  | -  | -  | -  | X  | -  |
| Call i phori dae   | -  | -  | -  | -  | -  | -  | X  | X  |
| Anthomyi i dae     | X  | X  | X  | X  | X  | X  | X  | X  |
| Drosophi l i dae   | X  | -  | -  | -  | -  | -  | -  | -  |
| Pi pi ncul i dae   | -  | -  | -  | -  | -  | X  | -  | -  |
| ants               | X  | X  | X  | X  | X  | X  | X  | X  |
| Braconi dae        | X  | X  | X  | X  | X  | X  | -  | X  |
| dauber             | -  | -  | -  | -  | -  | -  | X  | -  |
| Api dae            | -  | -  | -  | -  | X  | X  | -  | -  |
| wol f spi der      | X  | X  | X  | -  | X  | X  | X  | X  |
| orb spi der        | X  | X  | -  | -  | -  | -  | -  | -  |
| harvestmen         | X  | X  | X  | X  | X  | X  | X  | X  |
| <u>Blani li us</u> | X  | -  | X  | -  | X  | -  | X  | -  |
| <u>Scytonotus</u>  | X  | -  | -  | -  | -  | -  | X  | -  |
| velvet mite        | -  | -  | -  | -  | -  | -  | X  | -  |
| toad               | -  | -  | -  | -  | X  | -  | X  | -  |
| <hr/>              |    |    |    |    |    |    |    |    |
| Total =            | 36 | 22 | 30 | 18 | 34 | 26 | 34 | 30 |
| <hr/>              |    |    |    |    |    |    |    |    |

Table 2. Occurrence of cryptozoic invertebrates in barley- and no-residue corn fields, and fall- and spring-plowed soybean fields at distances <8m, and >8m from a woodlot, on the fifth sample date.

| Taxon          | Presence (X) or absence (-) |     |                 |     |                      |     |                        |     |
|----------------|-----------------------------|-----|-----------------|-----|----------------------|-----|------------------------|-----|
|                | Barley-res. corn            |     | No-residue corn |     | Fall-plowed soybeans |     | Spring-plowed soybeans |     |
|                | <8m                         | >8m | <8m             | >8m | <8m                  | >8m | <8m                    | >8m |
| slugs          | X                           | X   | X               | X   | X                    | X   | X                      | X   |
| land snail     | X                           | -   | X               | -   | -                    | -   | -                      | -   |
| earthworms     | X                           | X   | X               | X   | -                    | X   | -                      | X   |
| sowbugs        | X                           | X   | X               | -   | X                    | -   | X                      | X   |
| grasshopper    | -                           | -   | -               | -   | X                    | X   | X                      | X   |
| cricket        | X                           | X   | X               | -   | X                    | X   | X                      | X   |
| earwig         | X                           | X   | -               | -   | -                    | X   | X                      | X   |
| leafhopper     | X                           | X   | X               | X   | X                    | X   | X                      | X   |
| aphids         | -                           | -   | -               | X   | -                    | -   | -                      | -   |
| Hemiptera A    | -                           | -   | -               | -   | -                    | -   | -                      | X   |
| Nabidae        | X                           | -   | X               | -   | X                    | X   | X                      | -   |
| Coleoptera A   | -                           | -   | X               | -   | -                    | -   | -                      | -   |
| Coleoptera B   | X                           | -   | X               | -   | -                    | -   | -                      | -   |
| beetle larvae  | X                           | -   | -               | -   | -                    | -   | -                      | -   |
| StaphylinidaeA | -                           | X   | X               | X   | X                    | X   | X                      | X   |
| Staphy. B      | X                           | X   | X               | -   | X                    | X   | X                      | X   |
| ground beetleA | -                           | -   | -               | -   | X                    | X   | X                      | X   |
| ground beetleB | X                           | X   | X               | X   | X                    | X   | X                      | X   |
| ground beetleD | X                           | X   | X               | -   | X                    | X   | X                      | -   |
| ground beetleF | X                           | -   | -               | -   | X                    | X   | X                      | X   |
| ground beetleG | X                           | X   | X               | X   | -                    | X   | -                      | -   |
| ground beetleJ | -                           | -   | -               | X   | -                    | X   | -                      | -   |
| Nitidulidae    | -                           | -   | -               | X   | X                    | X   | -                      | -   |
| Coccinellidae  | -                           | -   | X               | -   | X                    | X   | X                      | X   |
| Cantharidae    | -                           | -   | X               | -   | -                    | -   | -                      | -   |
| weevil         | -                           | X   | -               | -   | X                    | X   | X                      | X   |
| Lepidoptera A  | -                           | -   | -               | -   | X                    | -   | -                      | -   |
| Lepidoptera B  | -                           | -   | X               | -   | -                    | -   | -                      | X   |
| Diptera D      | -                           | X   | X               | -   | X                    | X   | -                      | -   |
| Sciaridae      | X                           | X   | X               | X   | -                    | X   | X                      | X   |
| Phoridae       | -                           | X   | X               | X   | -                    | -   | -                      | X   |
| Syrphidae      | -                           | -   | X               | -   | -                    | -   | -                      | -   |
| Empididae      | -                           | -   | -               | -   | -                    | -   | X                      | -   |
| Anthomyiidae   | X                           | X   | X               | X   | X                    | X   | X                      | X   |
| Calliphoridae  | -                           | -   | -               | -   | -                    | -   | X                      | -   |
| robber fly     | -                           | -   | -               | -   | -                    | -   | X                      | -   |
| Drosophilidae  | -                           | -   | -               | -   | X                    | X   | X                      | -   |

Table 2 continued

|                   |   |   |   |   |   |   |   |   |
|-------------------|---|---|---|---|---|---|---|---|
| ants              | X | X | X | X | X | X | X | X |
| Braconidae        | X | - | X | X | X | X | X | X |
| Apiidae           | - | - | - | - | X | X | - | - |
| Lithobiomorpha    | - | - | - | - | X | - | - | - |
| harvestmen        | X | X | X | X | X | X | X | X |
| spider            | - | - | - | X | - | - | - | - |
| wolf spider       | X | - | - | - | - | - | - | - |
| <u>Blaniulus</u>  | X | X | X | X | X | X | X | X |
| <u>Scytonotus</u> | X | - | X | - | - | - | X | - |

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|         |    |    |    |    |    |    |    |    |
|---------|----|----|----|----|----|----|----|----|
| Total = | 23 | 20 | 28 | 17 | 26 | 27 | 25 | 25 |
|---------|----|----|----|----|----|----|----|----|

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Table 3. Intercepts and their standard errors for cryptozoic abundance, richness and evenness, and earthworm number and mass in the four cropping systems.

| Variable             | Intercept in the cropping system |                     |                      |                        |
|----------------------|----------------------------------|---------------------|----------------------|------------------------|
|                      | Barley-residue corn              | No-residue corn     | Fall-plowed soybeans | Spring-plowed soybeans |
| Cryptozoic abundance | 4.652<br>(0.398)                 | 4.809<br>(0.398)    | 4.827<br>(0.375)     | ** 6.431<br>(0.289)    |
| Cryptozoic richness  | 7.011<br>(0.630)                 | 6.423<br>(0.630)    | 6.548<br>(0.594)     | ** 8.274<br>(0.425)    |
| Cryptozoic evenness  | 0.796<br>(0.030)                 | 0.838<br>(0.030)    | 0.812<br>(0.030)     | ** 0.718<br>(0.020)    |
| Number of carabids   | 1.577<br>(0.258)                 | 1.289<br>(0.259)    | 0.972<br>(0.243)     | 0.944<br>(0.173)       |
| Richness of carabids | 1.477<br>(0.236)                 | 1.665<br>(0.237)    | 1.631<br>(0.223)     | 1.431<br>(0.158)       |
| Number of earthworms | 4.586<br>(3.102)                 | ** 23.36<br>(3.102) | -                    | 5.230<br>(2.624)       |
| Mass of earthworms   | 9.676<br>(3.365)                 | ** 18.15<br>(3.365) | -                    | 1.230<br>(2.673)       |

\*\* indicates a significant difference between intercepts

Table 4. List of arthropods captured in intercept traps in the barley-residue corn cropping system, at 0, 20 and 40 m from the woodlot.

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|                          |                       |
|--------------------------|-----------------------|
| Harvestmen               | (Order Phalangida)    |
| Sowbug                   | (Order Isopoda)       |
| Leafhopper               | (Family Cicadellidae) |
| Aphid                    | (F. Aphididae)        |
| Damsel bug               | (F. Nabidae)          |
| Rove beetle              | (F. Staphylinidae)    |
| Ground beetle            | (F. Carabidae)        |
| Soldier beetle           | (F. Cantharidae)      |
| Sap beetle               | (F. Nitidulidae)      |
| Ladybird beetle          | (F. Coccinellidae)    |
| Noctuidae<br>caterpillar | (Order Lepidoptera)   |
| Dark winged fungus gnat  | (F. Sciaridae)        |
| Deer fly                 | (F. Tabanidae)        |
| Anthomyiidae             |                       |
| Blow fly                 | (F. Calliphoridae)    |
| Green bottle fly         | (F. Calliphoridae)    |
| Ant                      | (F. Formicidae)       |
| Parasitic wasp           | (F. Braconidae)       |
| bee                      | (F. Apidae)           |

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Table 5. Water content (%) at different distances from a woodlot in the different cropping systems, on October 15-18.

| Cropping system        | Distance from woodlot |      |      |      |      |
|------------------------|-----------------------|------|------|------|------|
|                        | 0m                    | 7.5m | 15m  | 30m  | 50m  |
| Barley-res. corn       | 22.1                  | 25.3 | 26.3 | 28.3 | 24.2 |
| No-residue corn        | 34.1                  | 31.3 | 31.2 | 28.5 | 27.9 |
| Spring-plowed soybeans | 22.1                  | 25.3 | 26.3 | 28.3 | 24.2 |

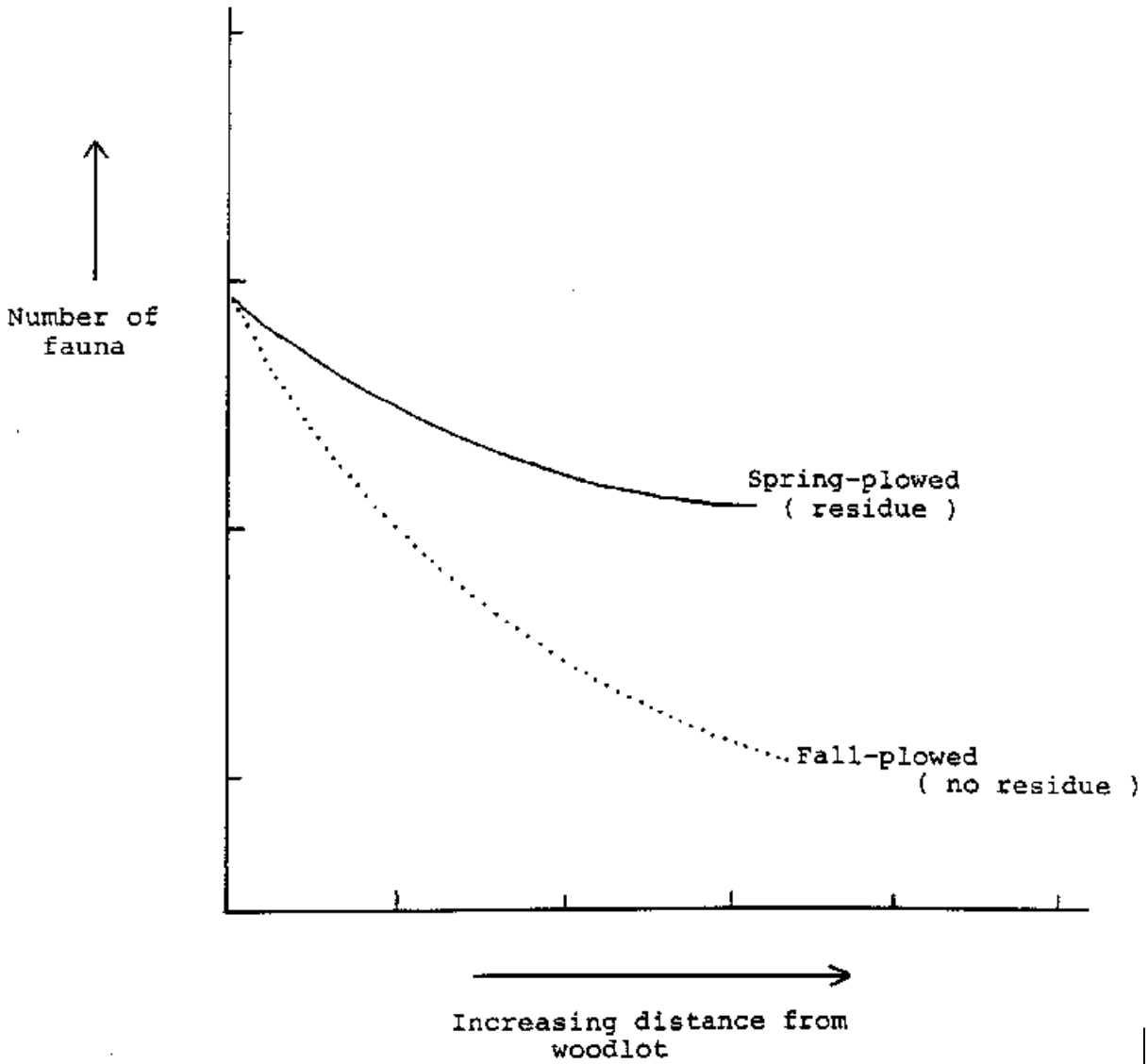


Figure 1. Hypothetical number of fauna found in soils with, and soils without crop residue, at different distances from a woodlot. Rate of decrease (slope) is less in the soil with crop residue.

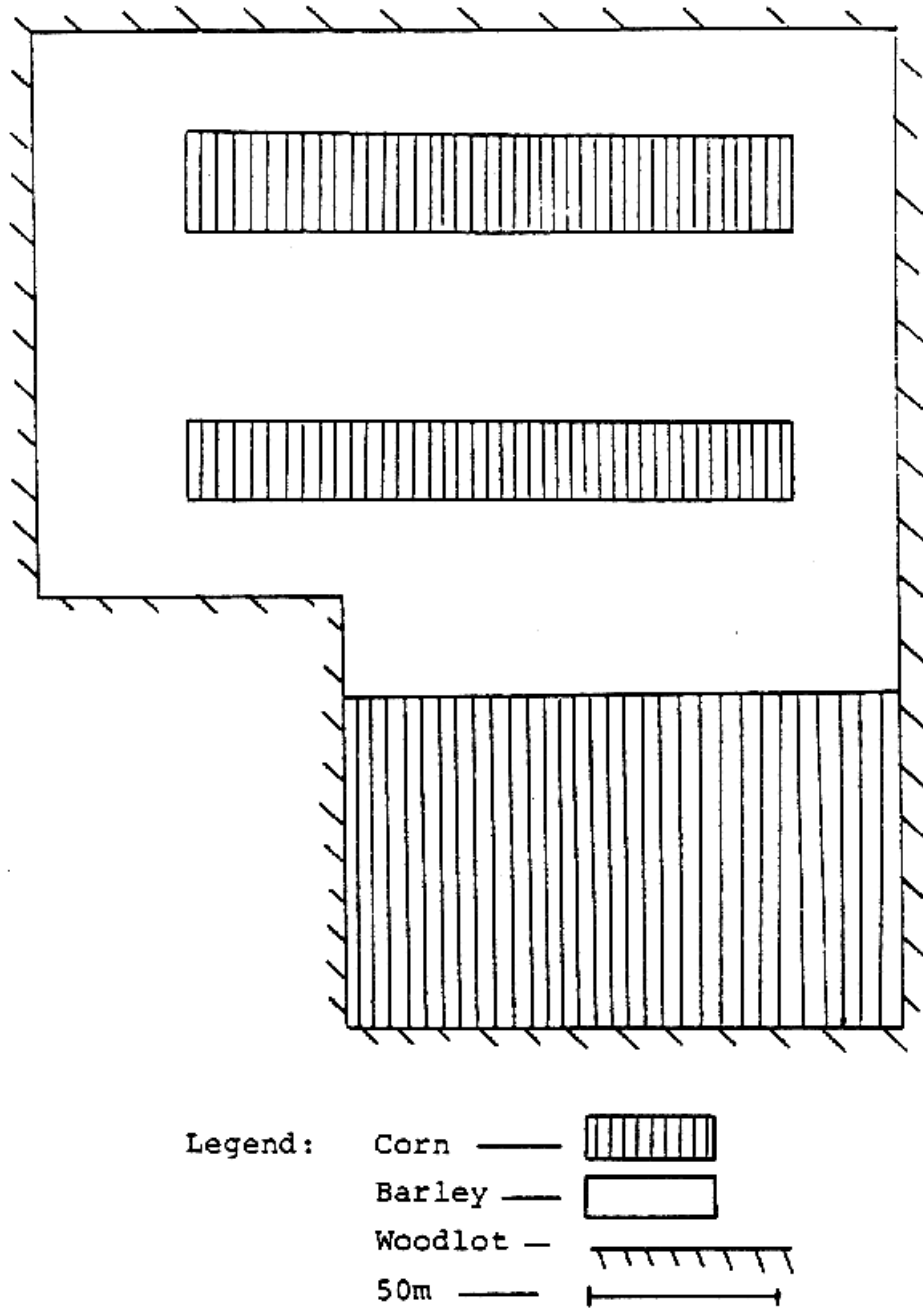


Figure 2. Pattern of crops grown in a zerotillage field south of Mount Forest, Ontario, in 1990.

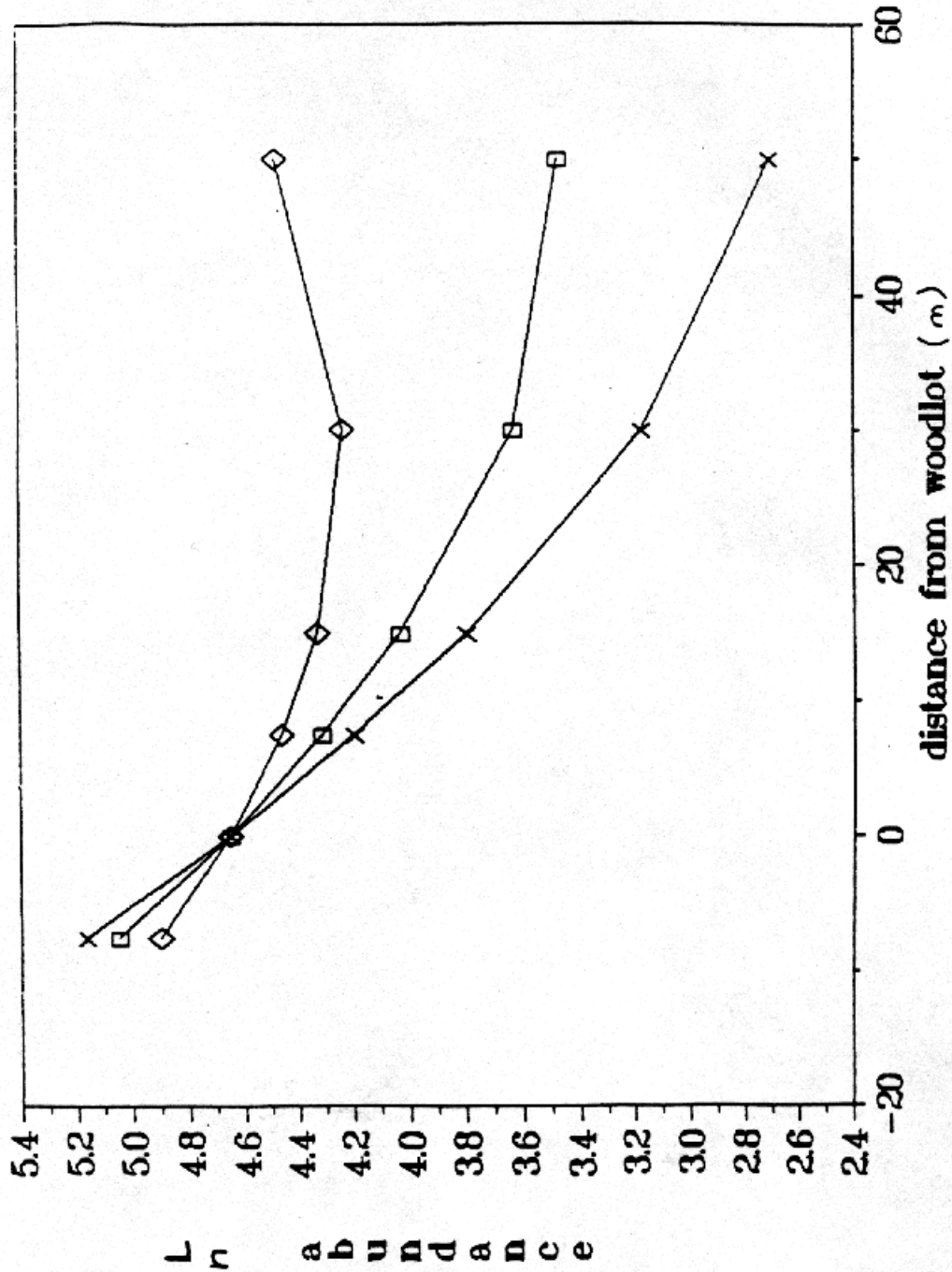


Figure 3. Decrease in cryptozoic abundance in the barley-residue corn cropping system at three sample dates, with increasing distance into the field. Distance 0 represents the edge of the field, negative values are within the woodlot, and positive values are within the field. This applies to all successive figures.

Legend: ● August 2-9, ~ August 30 - September 6, × October 8-16.

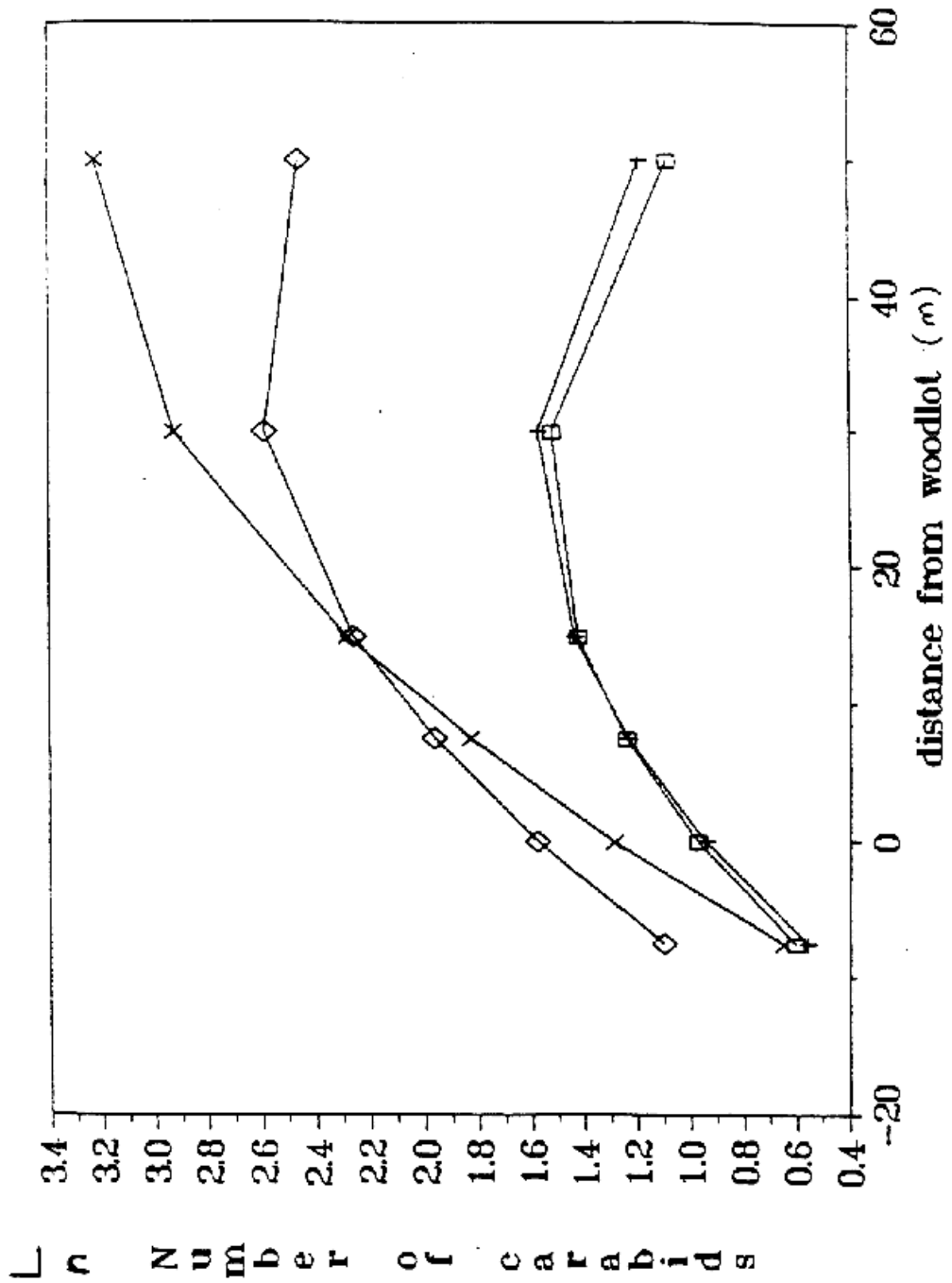


Figure 4. Increase in number of carabids with increasing distance into the field, for the four cropping systems.

Legend: ● Barley residue corn field, × No-residue corn field, ∩ Fall plowed soybean field, + Spring plowed soybean field.

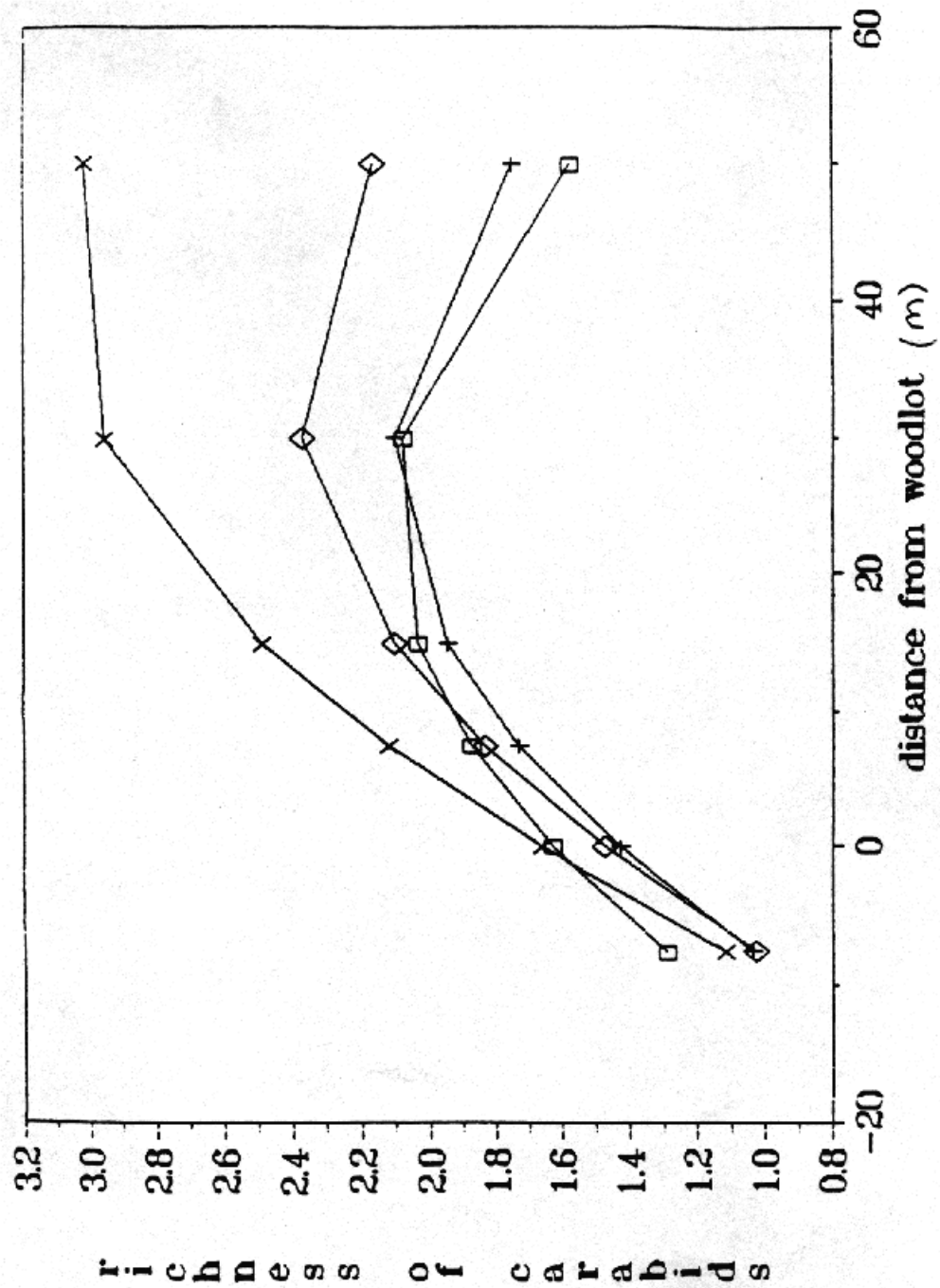


Figure 5. Increase in carabid richness with increasing distance into the field, for the four cropping systems.

Legend: ● Barley residue corn field, × No residue corn field, □ Fall plowed soybean field, + Spring plowed soybean field.



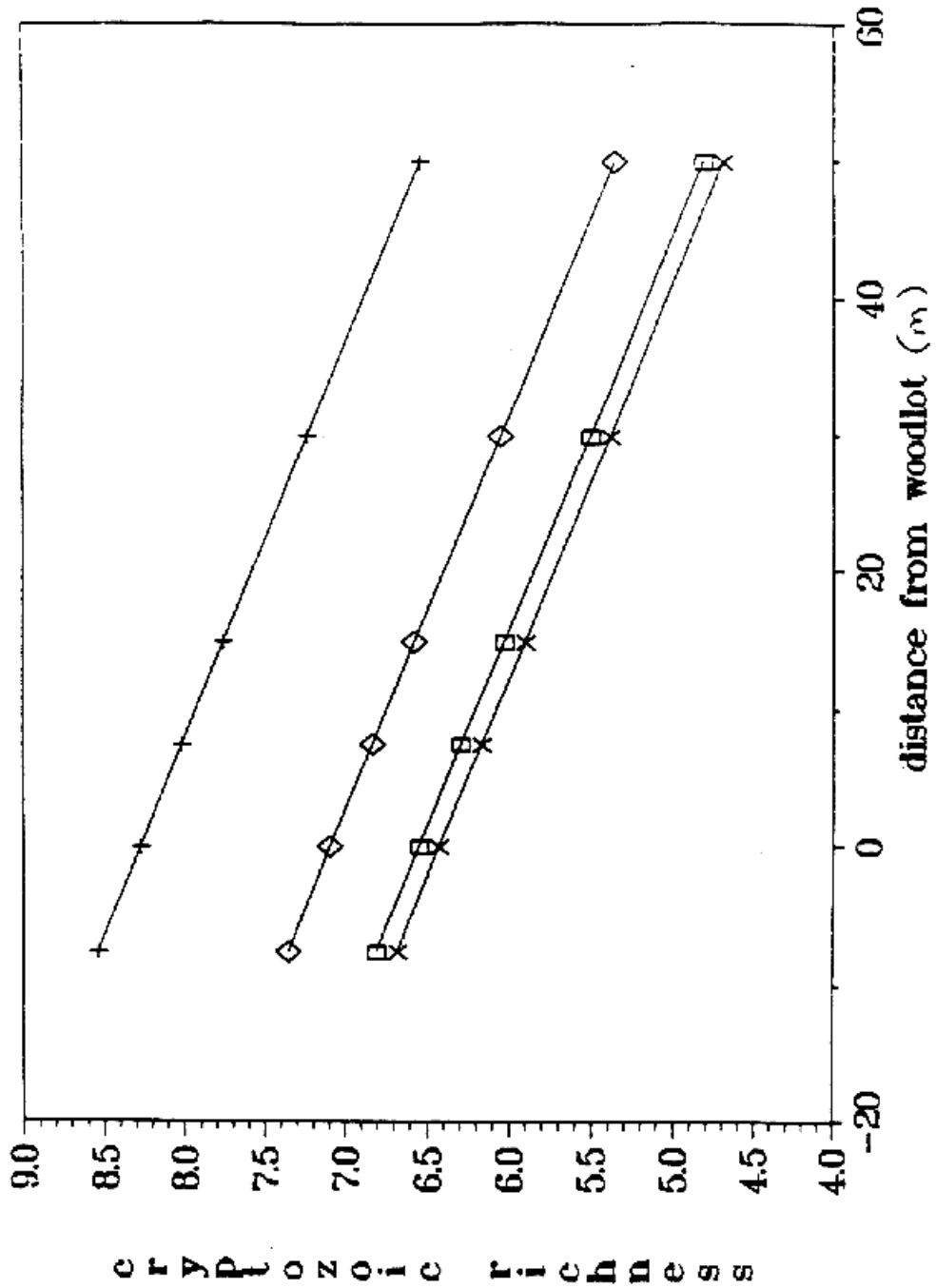


Figure 6. Decrease in cryptozoic richness in the four cropping systems with increasing distance into the field.

Legend: • Barley residue corn field, × No residue corn field, ~ Fall plowed soybean field, + Spring plowed soybean field.

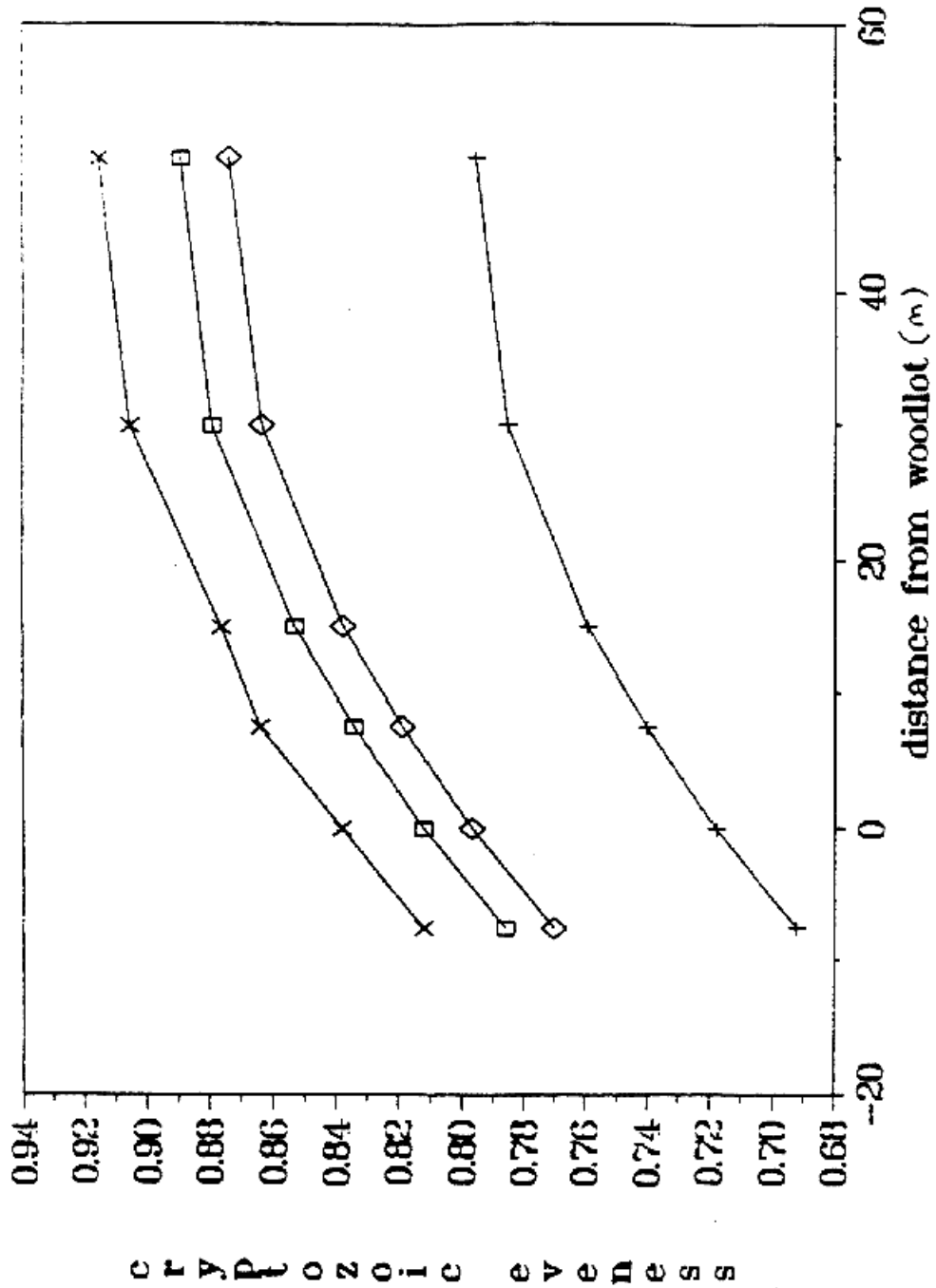


Figure 7. Increase in the evenness of the cryptozoic community in the four cropping systems with increasing distance into the field.

Legend: ● Barley residue corn field, × No residue corn field, ◻ Fall plowed soybean field, + Spring plowed soybean field.

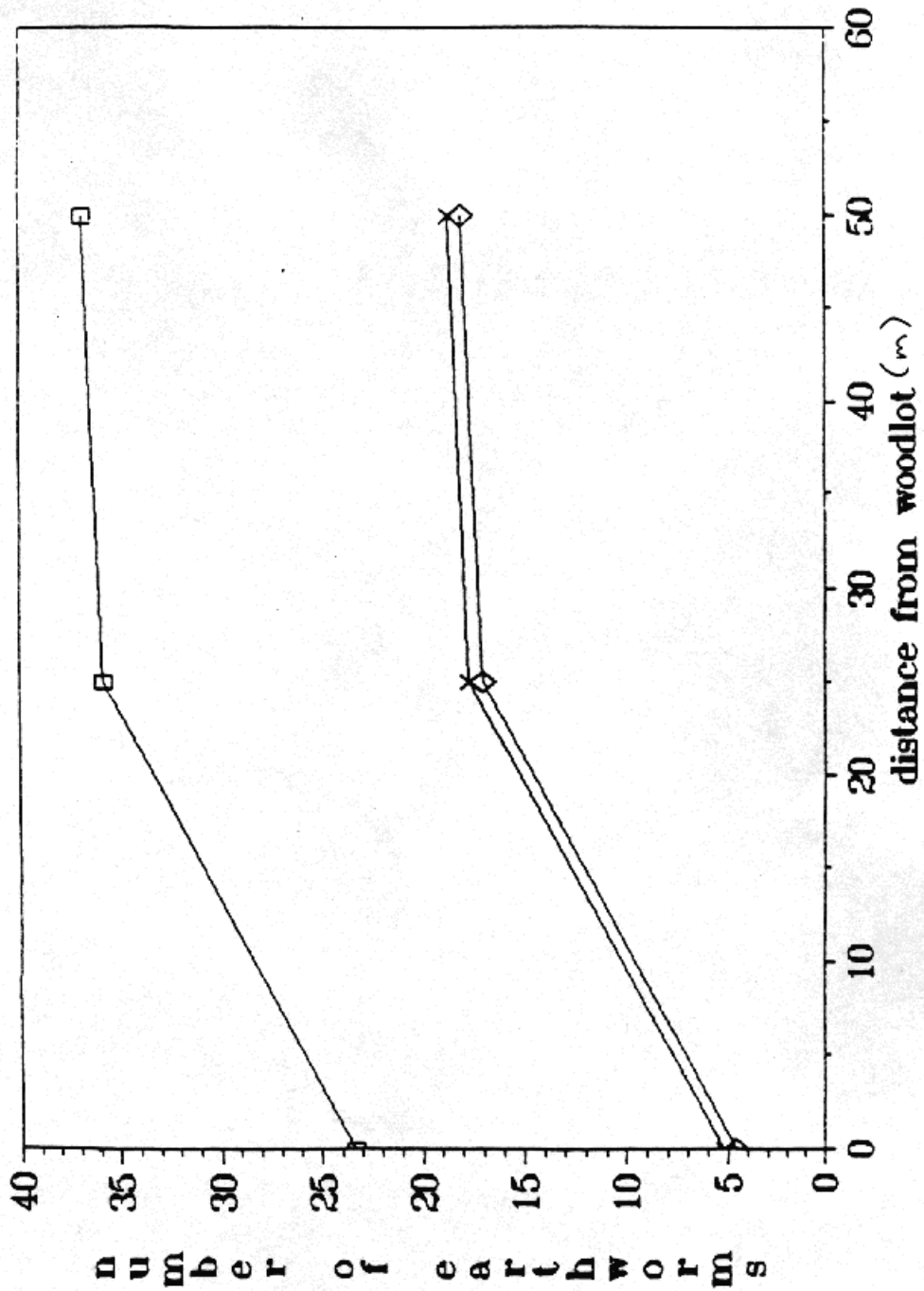


Figure 8. Increase in the number of earthworms in three cropping systems with increasing distance into the field.

Legend: ● Barley residue corn field, ~ No residue corn field, × Spring plowed soybean field.

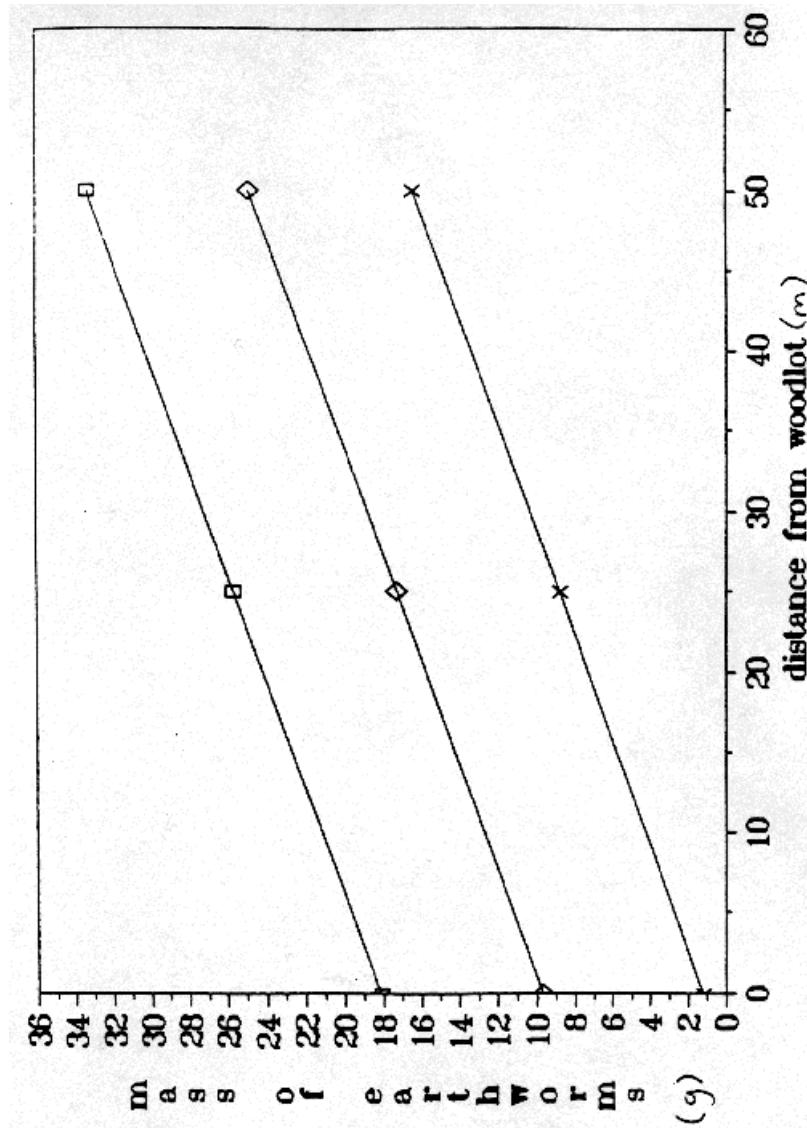


Figure 9. Increase in the mass of earthworms in three cropping systems with increasing distance into the field.

Legend: ● Barley residue corn field, ~ No residue corn field, × Spring plowed soybean field.

**Appendix** Systematic list of animals considered in this study, to the lowest level of identification.

The Phylum and Class level of classification was taken from Villee, Solomon and Davis (1985?). The Philomycidae classification is from Burch (1962), and the Lumbricidae and Sparganophilidae classification is from Reynolds (1977). Diplopoda classification is from Shelley (1988), and all other orders, suborders, and families were from the classification of Borror and Delong (1964).

Kingdom Animalia

Phylum Mollusca

Class Gastropoda

Family Philomycidae - slugs

Phylum Annelida

Class Oligochaeta

Family Lumbricidae - earthworms

Family Sparganophilidae - earthworms

Phylum Arthropoda

Subphylum Chelicerata

Class Arachnida

Order Phalangida - harvestmen

Order Acarina - mites

- velvet mite

Order Araneida - spiders

Subphylum Crustacea

Class Crustacea

Order Isopoda - sowbugs

Subphylum Urinamia

Class Chilopoda - centipedes

Order Lithobiomorpha

Class Diplopoda - millipedes

Order Polydesmida - Scytonotus granulatus

Order Julida - Archiborioiulus pallidus

Class Insecta

Subclass Apterygota

Order Collembola - springtails

Family Sminthuridae

Family Entomobryinae

Subclass Pterygota

Order Orthoptera

Family Acrididae - grasshoppers

Family Gryllidae - crickets

Order Dermaptera - earwigs

Order Hemiptera

Family Nabidae - damsel bugs

Order Homoptera

Family Cicadellidae - leafhoppers  
Family Aphididae - aphids  
Order Coleoptera  
Family Staphylinidae - rove beetles  
Family Carabidae - carabid beetles  
Family Cantharidae - soldier beetles  
Family Elateridae - click beetles  
Family Nitidulidae - sap beetles  
Family Coccinellidae - ladybird beetles  
Family Meloidae - bombardier beetles  
Family Curculionidae - snout beetles  
Family Scarabaeidae - scarab beetles  
Order Lepidoptera - butterflies and moths  
Family Sphingidae - hornworms  
Family Noctuidae  
Order Diptera  
Family Tipulidae - crane flies  
Family Mycetophilidae - fungus gnats  
Family Sciaridae - dark winged fungus gnats  
Family Empididae - dance flies  
Family Phoridae - humpbacked flies  
Family Syrphidae - bee flies  
Family Tabanidae - deer flies  
Family Asilidae - robber flies  
Family Calliphoridae - blow flies  
Family Anthomyiidae  
Family Drosophilidae  
Family Pipunculidae  
Order Hymenoptera  
Family Braconidae - parasitic wasps  
Family Larrinae - mud dauber  
Family Formicidae - ants  
Family Apidae - bees