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Endogeic and anecic earthworm abundance in six Midwestern cropping systems

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ABSTRACT

Endogeic and juvenile anecic earthworm abundance was measured in soil samples and anecic populations were studied by counting midden numbers at the sites of two long-term cropping systems trials in South-central Wisconsin. The three grain and three forage systems at each site were designed to reflect a range of Midwestern USA production strategies. The primary objectives of this work were to determine if the abundance of endogeic or anecic earthworms varied among cropping systems or crop phases within a cropping system and were there specific management practices that impacted endogeic or anecic earthworm numbers. The earthworms present in the surface soil were: *Aporrectodea tuberculata* (Eisen), *A. caliginosa* (Savigny), *A. trapezoides* (Dugés); and juvenile *Lumbricus terrestris* (L.). True endogeic abundance was greatest in rotationally grazed pasture [188 m^{-2} at Arlington (ARL) and 299 m^{-2} at Elkhorn (ELK)], and smallest in conventional continuous corn (27 m^{-2} at ARL and 32 m^{-2} at ELK). The only type of anecic earthworm found was *L. terrestris* L. There was an average of 1.2 middens per adult anecic earthworm and the population of anecics was greatest in the no-till cash grain system (28 middens m^{-2} at ARL, 18 m^{-2} at ELK) and smallest in the conventional continuous corn system (3 middens m^{-2} at ARL, 1 m^{-2} at ELK). Earthworm numbers in individual crop phases within a cropping system were too variable from year-to-year to recommend using a single phase to characterize a whole cropping system. Indices for five management factors (tillage, manure inputs, solid stand, pesticide use, and crop diversity) were examined, and manure use and tillage were the most important impacting earthworm numbers across the range of cropping systems. Manure use was the most important management factor affecting endogeic earthworm numbers; but no-tillage was the most important for the juvenile and adult anecic groups and had a significantly positive influence on endogeic earthworm counts as well. The pesticides used, which were among the most commonly applied pesticides in the Midwestern USA, and increasing crop diversity did not have a significant effect on either the endogeic or anecic earthworm groups in this study. Consequently, designing cropping systems that reduce tillage and include manure with less regard to omitting pesticides or increasing crop diversity should enhance earthworm populations and probably improve sustainability.

1. Introduction

Elevated earthworm populations are often recognized by farmers as an indication of a healthy soil (Romig et al., 1996). Indeed, research has confirmed that earthworms have a large impact on the physical, chemical, and biological properties of the soil (Lee, 1985; Edwards and Bohlen, 1996), to the point that some researchers have echoed the farmers claims, and discussed the use of these organisms as biological indicators of soil health (Doran and Safley, 1997; Yeates et al., 1998). In light of their importance to organic matter dynamics and soil structure, ecologists such as Hendrix et al. (1992), Edwards et al. (1995), and Ernst (1995) argue that the long-term sustainability of agricultural soils could be improved by employing cropping systems that promote earthworm numbers.

The species of earthworms present in agricultural fields of the Midwest are primarily peregrine lumbricids that can be broadly classified into two ecological groups: endogeics, or topsoil-dwelling earthworms, and anecics, or deep burrowing, often subsoil-dwelling earthworms (Bouche, 1977). The topsoil-dwelling earthworms are noted for their extensive burrowing activity in the top 25 cm of the soil; for example, Cook and Linden (1996) estimated that the endogeic species, *Aporrectodea tuberculata* (Eisen), produced approximately 1058 km ha^{-1} of new burrows each week. On the other hand, anecic earthworms create one or two burrows that may extend three or more meters into the soil

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profile. Above their burrows these species create structures known as middens, which consist of plant residues pulled partially into their burrows and cemented with cast material. It has been estimated that 0.5 cm of soil (or 2–5 kg soil m^{-2}) is brought to the surface each year by the casting activity of these earthworms (Darwin, 1881).

Agricultural management practices; such as, tillage, crop cover, manuring, and pesticide use; are known to influence both endogeic and anecic abundance (Edwards and Bohlen, 1996). Tillage generally affects both endogeic (Clapperton et al., 1997; Hubbard et al., 1999; Hutcheon et al., 2001) and anecic (Nuutinen, 1992; Wyss and Glasstetter, 1992; Bostrom, 1995; Peigne et al., 2009) earthworm numbers negatively compared to no-tillage. Tillage, however, does not always result in lower abundance of endogeic (Bostrom, 1995; Kladivko et al., 1997; Butt et al., 1999) or anecic earthworms (Edwards and Lofty, 1982; Lofs-Holmin, 1983; Whalen et al., 1998). One reason for this inconsistency is that tillage often occurs in conjunction with the incorporation of crop residues or manure, which are food sources for earthworms. Thus, depending on the quality and quantity of the residues incorporated versus that left on the surface, tillage may inhibit or enhance endogeic or anecic earthworm populations (Siegrist et al., 1998; Carpenter-Boggs et al., 2000; Chan, 2001; Zaller and Kopke, 2004).

Because of the tillage–food-supply interaction it is difficult to draw broad conclusions about how earthworms will respond to a complex set of management practices (such as tillage, fertilizers, pesticides, and crop rotation) that make up a cropping system. A few studies have undertaken this difficult task and examined earthworm responses to component changes within a cropping system. Lofs-Holmin (1983) and Fonte et al. (2009) studied endogeics numbers as a function of crop residue management, finding that the presence of mulch increased abundance. In the same manner, a number of authors have studied a common rotation under organic, conventional, or biodynamic management (Siegrist et al., 1998; Zaller and Kopke, 2004) or a common rotation with different tillage regimes (Werner and Dindal, 1989; Tomlin et al., 1995; Hubbard et al., 1999; Ernst and Emmerling, 2009). Similarly, with anecics most work has been limited to comparing alternative agronomic techniques on a constant crop rotation, or were conducted on a narrow range of rotations (Werner and Dindal, 1989; Pfiffner and Mader, 1998; Blakemore, 2000).

Recently, a number of authors have investigated the effect on earthworms of adding forage or pasture ley phases to annual crop rotations (Katsvairo et al., 2007; Eekeren et al., 2008; Riley et al., 2008; Nelson et al., 2009). Nelson et al. (2009) found in organic potato rotations in Canada, that although earthworm numbers dropped drastically in the potato and grain phases, it only took 2 years of forage production to return to initial abundance levels. Similarly, Eekeren et al. (2008) studied a 3-year grain and 3-year ley system and found that after 1 year of annual crops, earthworm numbers had dropped and it was not until the third year of temporary grassland that numbers and biomass of endogeics had returned to permanent grassland levels. Anecics, however, did not recover as rapidly. In a comparison of several 4-year rotations with 1–3 years of grass ley in Norway, Riley et al. (2008) concluded that 50% ley in the rotation appeared desirable for maintenance of satisfactory soil structure and earthworm activity. And, in Southeast USA researchers added a single bahiagrass (*Paspalum notatum* Fluegge) phase to a cotton/peanut rotation and with just that year of sod, earthworm abundance and water infiltrations rates increased significantly (Katsvairo et al., 2007).

The Wisconsin Integrated Cropping Systems Trial (WICST) is a long-term study that began in 1990 to examine six cropping systems with production strategies ranging from monocropped corn managed with high inputs, to rotational grazing and organic production with few additional inputs (Posner et al., 1995). Approximately 20 million hectares of crop land in Minnesota, Wisconsin, and Iowa are planted to corn for grain, soybean and alfalfa forage in systems similar to the ones under review in these trials (National Agricultural Statistics Service, 2009). Thus, it provided an excellent opportunity to examine the effect of a range of practical cropping systems that incorporated several management practices known to affect earthworm abundance. Three research questions were examined: (1) did the abundance of endogeic or anecic earthworms vary among cropping systems, (2) did the abundance of endogeic or anecic earthworms vary among crop phases within a cropping system and, if not, could a single phase be sampled to characterize earthworm numbers of the entire cropping system, and (3) were there specific management practices that impacted endogeic or anecic earthworm numbers and, if so, what was the relative importance of these practices?

2. Materials and methods

2.1. WICST study sites

The WICST began in 1990 at two study sites, the Arlington Research Station (43°20′N, 89°21′W) near Arlington (ARL) in south central Wisconsin, and the Lakeland Agricultural Complex (42°40′N, 88°32′W) near Elkhorn (ELK) in southeast Wisconsin, USA. The soil at ARL is a deep and well-drained silt loam, a Typic Argiudoll (USDA soil taxonomy), with an average organic matter content of 4.5% and a pH of 6.6. The soil at the ELK site is a somewhat poorly drained silt loam classified as an Aquic Argiudoll with average organic matter content of 5.4% and average pH of 6.9. Both sites are relatively flat, with a few undulations of less than 2% grade (Posner et al., 1995).

2.2. Cropping systems design

The six cropping systems represent a range of production strategies as seen in Table 1A and the common pesticides used in the conventional production systems are listed in Table 1B. The three cash grain production systems include: (1) a chisel-plowed continuous corn system (*Zea mays* L.) with a high level of external inputs (CS1) including fertilizer, herbicide and a corn rootworm (*Diabrotica virgifera*) insecticidal treatment; (2) a no-till corn and soybean [*Glycine max* (L.) Merr.] system with a moderate level of external inputs (common practice in the Midwestern United States) (CS2); and, an organic corn/soybean/wheat system (*Triticum aestivum* L.) seeded with a red clover (*Trifolium pretense* L.) green manure crop (CS3). Three additional systems apply primarily to the dairy industry and consist of: (1) a high input (herbicides, insecticides) alfalfa [*Medicago sativa* (L)]/corn rotation (CS4) with manuring; (2) an organic forage rotation system with three crops (CS5) plus manuring; and (3) a rotationally grazed pasture system (CS6) with Holstein heifers (*Bos Taurus*) on timothy, (*Phleum pratense* L.), brome grass (*Bromus inermis* L.), orchard grass (*Dactylis glomerata* L.), and red clover. The trial was designed so that all crop phases of the six cropping systems were present each year and there were four blocks (one replication of the 14 phases in each block) at each site. Conventional farm machinery was used to manage the plots that were approximately 0.3 ha each. Additional agronomic details about the WICST have been previously published (Posner et al., 1995; Posner et al., 2008).

2.3. Earthworm sampling and identification

2.3.1. Endogeics

Soil samples were collected to determine topsoil earthworm abundance. In the spring of 1999, two cores per plot were taken