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Native earthworm population dominance after seven years of tillage, burning, and residue level management in a wheat-soybean, double-crop system

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ABSTRACT

Earthworm density is often reduced in low organic matter soils that are intensively managed for row-crop production, but earthworms can serve as a sensitive bioindicator of response to residue management. This study relates earthworm density and community composition to residue management after seven years of consistent management practices in a wheat (*Triticum aestivum* L.)-soybean (*Glycine max* (L.) Merr.), double-crop system in the Lower Mississippi River Valley delta region of eastern Arkansas. Residue management practices included conventional tillage (CT) and no-tillage (NT), N fertilization to produce HIGH and LOW wheat residue levels, and BURN compared to unburned (NO BURN) wheat residue remaining on the soil surface. Total mean earthworm densities ranged from 271 to 508 m^{-2} in the top 20 cm across treatments. Both exotic *Aporrectodea trapezoides* (Dugès) and native *Diplocardia sylvicola* Gates adult earthworms were present with little difference in diversity among sampled communities; however, more than 65% of adults were *D. sylvicola* in all treatments. Native, total, or juvenile earthworm densities in different treatment combinations were correlated to different soil properties, including pH, electrical conductivity, and Mehlich-III-K, Ca Mg, S, Cu, and Mn concentrations. Residue level and burning influenced total, juvenile, and native earthworm densities differently in CT and NT. Tillage presumably influenced earthworm density through effects of residue placement at the surface (NT) or within the soil profile (CT). Earthworm densities were greatest in the BURN-HIGH treatment combination under NT, which contrasted with greatest densities in the NO BURN-HIGH which did not differ from the BURN-LOW treatment under CT. Native earthworms predominated with a common exotic species in a wheat-soybean double-crop system in Arkansas where earthworm densities were dependent on the interaction of tillage with burning and fertilization to influence wheat residue amount. Differences in earthworm abundances may serve as a bioindicator of long-term sustainability of common residue management practices in the highly agriculturally productive delta region in the Lower Mississippi River Valley.

1. Introduction

Understanding the factors affecting earthworm population densities and distributions is important because earthworms are ecological engineers and keystone species (Lavelle et al., 1989). Earthworms play a number of important roles in improving soil quality. Earthworm presence impacts nutrient cycling as well as many soil characteristics, such as soil aggregate structure and stability, litter and microorganism distribution, microbial activity, decomposition rates, and timing and amount of available N (Lavelle et al., 1989). Biotic contributions to nutrient cycling and soil fertility are only going to become more important as sustainability of agroecosystems requires greater productivity to feed a growing world population while maintaining ecosystem functioning under greater variability of weather patterns induced by climate change.

Both native and exotic earthworm species inhabit the southern United States (Kalisz and Wood, 1995). Native and exotic earthworms interact in a number of ways, primarily competing for soil nutrients. Often the introduction of exotic earthworms coincides with increased disturbance and reductions in native earthworm densities, especially in

Abbreviations: CT, conventional tillage; NT, no tillage; HIGH, treatment with large amount of wheat residue produced from fertilization scheme; LOW, treatment with small amount of wheat residue produced from fertilization scheme; BURN, burn treatment; NO BURN, unburned treatment; EC, electrical conductivity; OM, organic matter; TC, total carbon; TN, total nitrogen

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disturbed soils characteristic of urban and rural areas (Kalisz and Wood, 1995; Winsome et al., 2006). Winsome et al. (2006) reported that an exotic species, *Aporrectodea trapezoides* (Dugès), consistently had a greater relative increase in density than a native species, *Argilophilus marmoratus* Eisen, but that differences in densities declined with decreasing habitat quality. Exotic species are generally expected to dominate communities in disturbed systems, albeit at lower densities and decreased diversities compared to undisturbed systems (Hendrix et al., 2006). However, research is not definitive as to whether exotic earthworms will replace native earthworms in managed agroecosystems and to what extent species predominate or co-exist with different residue management strategies in row-crop systems.

During the past several decades, the wheat (*Triticum aestivum* L.)-soybean (*Glycine max* (L.) Merr.), double-crop system has been a common management system in the Lower Mississippi River Valley (LMRV) delta region in the mid-southern and southern US, particularly in Arkansas, with approximately 30% of total soybean production being double-cropped behind wheat (ASPB, 2011). As part of the wheat-soybean double-crop system, wheat residue has frequently been burned to expedite subsequent soybean planting and to remove habitat for pests. However, although the combustion of residual plant material can leave behind non-volatile nutrients in remaining ash left on the soil surface, burning releases carbon dioxide and other greenhouse gases and particulates contributing to atmospheric pollution rather than promoting carbon sequestration and the build-up of soil organic matter (OM) with its associated benefits (Brye, 2012). Given that agronomic soils of the southern US are often low in OM, particularly in the delta region of eastern Arkansas (Brye and Pirani, 2005), soil and environmental quality could be improved with the return of residues to soil for decomposition.

Recognized benefits and technological advances have promoted the adoption of conservation or no-tillage (NT) methods in the south in recent years; however, long-term studies investigating impacts of residue management in the soils and conditions characteristic of southern agricultural systems are rare. Consequently, in fall 2001, Brye et al. (2007) established a field study to investigate the effects of residue managed through differential N fertilization of wheat to produce HIGH versus LOW amounts of wheat residue, residue burning (BURN versus NO BURN), and tillage [conventional tillage (CT) versus NT] in a wheat-soybean, double-crop system on soybean production and soil health and ecology in the LMRV delta region of eastern Arkansas.

Conventional agricultural row-crop management, by using practices such as CT that decrease surface residue, largely affect invertebrate community composition in the southern US, reducing diversity and resulting in communities comprised mostly of a few, often exotic species (Callaham et al., 2006). In contrast, residue management practices that increase crop residue amounts can increase organic carbon in the soil, providing earthworms with more organic resources for growth and proliferation (Eriksen-Hamel et al., 2009). However, these authors also showed that, although endogeic earthworms may benefit from residues tilled into soil, earthworm movement might be physically restricted due to barriers created as a result of repeated CT, such as tillage or hard pans. Overall, practices that reduce soil disruption and return more crop residues to the soil tend to increase earthworm population densities.

Brye et al. (2007) showed that several soil properties could be improved when NT was used compared to CT and when wheat residues were left on the soil surface unburned rather than when residues were burned after harvest. Specifically, soil organic matter (OM), total nitrogen and carbon and extractable Zn in the surface 10 cm of soil increased more under NT than CT over a two-year study period (Brye et al., 2007). Though no earthworms were observed in 2001 prior to initiating the field study of Brye et al. (2007), visual observations during routine annual soil sampling indicated increasing earthworm densities throughout the study area four to five years after initial establishment. However, burning is a practice that may interact with N fertilization to alter residue amount and nutrient availability, and tillage management alters residue placement and soil properties that impact earthworm success (Callaham et al., 2003; Mele and Carter, 1999a). Burning has been shown to impact earthworm populations both positively and negatively, depending on species present (Callaham et al., 2003; Mele and Carter, 1999a). Native earthworm species in the mid-southern and southern US may have greater temperature tolerances than exotic species (Callaham et al., 2003; James, 1988; Millican and Lutterschmidt, 2007), and may be adept at acquiring resources from terrestrial systems subjected to periodic burning (Callaham et al., 2003).

No known agronomic field studies have investigated potential effects of multiple years (i.e., > 5 years) of consistent residue management practices on earthworm communities in the LMRV delta region of eastern Arkansas. Therefore, the objective of this field study was to evaluate seven years of consistent residue management practices [i.e., HIGH versus LOW wheat-residue level, burning (BURN) versus not burning (NO BURN) residue, and CT versus NT] on earthworm species diversity and density in the surface 20 cm in a wheat-soybean, double-crop production system. It was hypothesized that residue quality (affected by burning) and level (affected by N fertilization) would interact with effects of residue placement and disturbance (tillage) to impact earthworm species diversity and density differently among treatment combinations.

2. Materials and methods

The wheat-soybean, double-crop system field study (Brye et al., 2007; Cordell et al., 2007) was established at the Lon Mann Cotton Research Station (N 34°, 44′, 2.26” and W 90°, 45′, 51.56”) in Marianna, AR in fall 2001. The 30-yr (1981–2010) mean annual air temperature in the region is 16.6 °C and mean annual precipitation is 1284 mm (NOAA, 2017). Prior to the establishment of the site, soybean was grown in a non-double-cropped system under CT management. Land was prepared by disking twice followed by field cultivation and broadcast application of 20 kg N ha^{-1}, 22.5 kg P ha^{-1}, 56 kg K ha^{-1} and 1120 kg ha^{-1} of pelletized limestone to adjust soil pH levels prior to planting of the first wheat crop in the fall 2001 (Cordell et al., 2007).

This study is part of an ongoing, larger study. The experiment was designed as a split–split plot in which the whole plot portion of the design was a randomized complete block with three blocks and tillage as the main treatment factor. The split plot factor was the burn treatment and the split–split plot factor was residue level. The plots sampled for this study include 24 (3 × 6 m^2) plots on Calloway silt-loam soil (fine-silty, mixed, active, thermic, Aquic Fraglossudalf; NRCS-USDA, 2014). All plots were furrow irrigated as needed throughout the season for the first three years (2002–2004), after which the 24 plots sampled in this study have not been irrigated.

All plots received 101 kg N ha^{-1} as urea in early March beginning in 2002, while the HIGH plots were fertilized with an additional 101 kg N ha^{-1} broadcast application of urea in late March for the first three years (2002–2004). After 2004, LOW plots received 0 kg N ha^{-1} and HIGH plots received 101 kg N ha^{-1}. Nitrogen was applied to the wheat crop at rates where all N was expected to be taken up by the plants with no carry-over N left to differentially affect the subsequent soybean crop (Cordell et al., 2007). Since carry-over N was not expected to affect the subsequent soybean crop, the actual treatment imposed on the subsequent soybean crop was the differential wheat residue levels.

Wheat was harvested in early to mid-June each year, with the aboveground wheat residue mowed to the soil surface after harvest. Based on residue samples collected from a 0.25-m^2 metal frame each year in all plots following harvest and mowing, in the years between 2002 and 2007, aboveground wheat residue levels ranged from 2.1 to 6.5 and from 3.2 to 11.0 Mg ha^{-1} and averaged 4.7 and 6.8 Mg ha^{-1} in the LOW and HIGH residue treatments, respectively (Amuri et al., 2008). The residue level in the HIGH treatment was numerically greater