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# Influence of long-term corn–soybean crop sequences on soil ecology as indicated by the nematode community

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ABSTRACT

In the Midwestern United States, corn–soybean rotation is an essential agricultural practice, but relatively little is known about the impact of different corn–soybean cropping sequences on soil ecology. A long-term research site in Waseca, Minnesota was established in 1982 to study corn–soybean rotation. At the site, various corn–soybean crop sequences can be compared each year including corn and soybean in 1 to 5 years of monoculture and continuous monoculture of each crop. Additionally, granular nematicides (terbufos or aldicarb) have been applied to half of each plot since 2010 to minimize nematode populations, particularly plant-parasitic nematodes, across crop sequences. The nematode community, a sensitive indicator of changes in soil ecology, was assessed at this site to determine the impact of corn–soybean crop sequences and nematicide application on the soil ecosystem. Nematicide application was effective against target nematodes, herbivores, but also impacted non-target nematodes and thus soil ecology. Nematicide application decreased fungivore and bacterivore populations, diversity, and maturity; but significantly increased enrichment compared to no nematicide application. The nematode community and thus soil ecology was significantly different in corn compared to soybean cropping systems and changed most during initial years after switching crops. Cropping systems in corn supported significantly greater fungivore populations, fungal decomposition pathways, more diversity, and a more mature ecosystem compared to soybean systems. Soybean systems supported significantly greater bacterivore populations and a more disturbed, enriched ecosystem. These differences between corn and soybean systems demonstrate that each crop has a distinct impact on the soil ecosystem.

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## 1. Introduction

Crop rotation is a common practice in agricultural systems to maintain crop productivity particularly for corn (*Zea mays* L.) and soybean (*Glycine max* L. Merr.). In the United States, corn–soybean rotation is among the most important agronomic systems and is a major feature of the landscape. In 2014, 37 and 34.3 million hectares of corn and soybean respectively were planted in the United States which is 53.5% of total area planted to principal crops (NASS-USDA, 2014) or 4% of total land area (Nickerson et al., December 2011). Most research on corn–soybean rotation has focused on agronomic factors such as crop yield (Crookston et al., 1991; Crookston and Kurle, 1989; Howard et al., 1998; Porter et al., 1997; Wilhelm and Wortmann, 2004), soil nutrients (Meese et al., 1991; Omay et al., 1998; Peterson and Varvel, 1989), pathogen populations (Howard et al., 1998; Porter et al., 2001; Whiting and Crookston, 1993), other soil properties (Copeland et al., 1993; Meese et al., 1991), or plant physiology (Copeland and Crookston, 1992; Nickel et al., 1995; Pikul et al., 2012).

Less is known about the impact of different cropping systems on soil biology and ecology. Since corn–soybean systems are so common, a better understanding of this system would provide a better understanding of our landscape. Additionally, a better understanding of soil ecology under different cropping systems may give insight into mechanisms behind agronomic benefits of crop rotation and help determine optimal practices for maintaining productive soil. The nematode community is a dynamic indicator of soil ecology because it spans a wide range of trophic groups and ecological niches, and is sensitive to changes in the environment (Bongers, 1990; Ferris et al., 2001; Fiscus and Neher, 2002).

The nematode community has been used as a tool for assessing various management practices in agricultural systems including tillage (Okada and Harada, 2007; Sanchez-Moreno et al., 2006; Villenave et al., 2009), fertilizer application (Hu and Cao, 2008; Leroy et al., 2009; Liang et al., 2009; Villenave et al., 2010), and organic management practices (Dong et al., 2008; Overstreet et al.,

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2010). Some studies have examined the influence of different cropping systems on the nematode community (Briar et al., 2012; Carter et al., 2009; Djigal et al., 2012; Govaerts et al., 2006; Osler et al., 2000; Rahman et al., 2007), but none have focused on corn–soybean rotations in a temperate climate.

Examining distinct cropping sequences over an extended time period may reveal trends that are not apparent over a shorter time period and reflects the long time periods that agricultural fields remain in production. In 1982, a long-term field study involving various corn and soybean crop sequences was initiated in Waseca, Minnesota to examine agronomic aspects of corn–soybean rotation when soil nutrients are not limiting. This site is a unique opportunity to examine the influence of corn–soybean crop rotations on soil ecology and the nematode community.

To help determine the role of nematodes in agronomic aspects of crop rotation, crop sequences with and without nematicide application have been maintained at the site since 2010. In particular, soybean cyst nematode (SCN, *Heterodera glycines*) is the major pathogen of soybean in this area, causing yield losses of 30% or more in some cases (Chen et al., 2001). However, environmental impacts of pesticide application are increasingly under scrutiny with many nematicides no longer approved for use (Rich et al., 2004). Additionally, nematicides can impact both target nematodes that damage plants and non-target nematodes (Chelinho et al., 2011; De Bruin and Pedersen, 2008; Sanchez-Moreno et al., 2010) that provide beneficial services in the soil ecosystem (Ferris et al., 2012) making it important to understand the full impact of these applications. Nematicide can also be a tool to understand the role of nematodes in the impacts of crop rotation on other agronomic factors. The objective of this study was to assess impact of nematicide application and long-term crop rotations on soil ecology based on the nematode community.

## 2. Materials and methods

### 2.1. Experimental design

The study was conducted in a Nicollet clay loam (fine-loamy, mixed, mesic Aquic Hapludoll; pH 6.5; 5.5% organic matter) at the Southern Research and Outreach Center in Waseca, Minnesota (44°04′N, 93°33′W) at a field site where plots of various corn–soybean crop sequence treatments have been maintained continuously since 1982. The three sequence types including 14 crop sequence treatments (Table 1) were: (i) five years corn followed by 5 years soybean with each phase grown each year such that both crops have treatments in years 1, 2, 3, 4, and 5 of monoculture every year; (ii) continuous monoculture of each crop; (iii) annual rotation between two cultivars – but crop monoculture – of each crop. Since 1995, sequence type (iii) has been single-cultivar monoculture of corn or soybean. Beginning in 2010, treatments in sequences (i) and (ii) were corn cultivars with *Bacillus thuringiensis* trait (Bt) or SCN-susceptible soybean cultivars while sequence (iii) was corn cultivars without Bt trait or SCN-resistant soybean. From 2010 onward, half of each plot was treated with in-furrow, granular nematicide to create a split-plot experiment arrangement with subplots 4.57 m wide by 7.62 m containing 6 crop rows.

In 2010 and 2011, terbufos nematicide (Counter 20G, AMVAC Chemical Corporation) was applied in-furrow at planting at 2.44 kg a.i. ha$^{-1}$. In 2012–2014, aldicarb nematicide (Bolster 15G, AMVAC Chemical Corporation) was applied in-furrow at planting at 2.94 kg a.i. ha$^{-1}$. For both nematicides, these rates, which were approximately double the label rate, were used to achieve maximum nematode control for completing the research objectives. Both crop sequence and nematicide factors were randomized complete block designs with 4 replicates within the split-plot arrangement.

### 2.2. Soil sampling and nematode assessment

Soil samples for nematode community analysis were collected in 2013 and 2014 at three times during each year: Spring (within 2 days before planting), midseason (47–64 days after planting [DAP]), and fall (at harvest) from all subplots. From each subplot, 20 soil cores were taken in the two central rows (within 10 cm of plant rows) to a depth of 20 cm. Soil samples were homogenized by passing through a metal screen with 4 mm apertures before further processing. In 2013, soil samples were collected on 3 June (day of planting, but before seeds were planted), 6 August (64 DAP), and 8 October (127 DAP). In 2014, soil samples were collected on 19 May (2 days before planting), 7 July (47 DAP), and 9 October (139 DAP). 128 soil samples were analyzed each season for a total of 768 soil samples analyzed during the study.

**Table 1**
Corn (C) and soybean (S) cropping sequence treatments[a] in Waseca, MN.

| Treatments | Crop sequence by year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
| 10-year rotation | | | | | | | | | | |
| 1. | C4 | C5 | S1 | S2 | S3 | S4 | S5 | C1 | C2 | C3 |
| 2. | C3 | C4 | C5 | S1 | S2 | S3 | S4 | S5 | C1 | C2 |
| 3. | C2 | C3 | C4 | C5 | S1 | S2 | S3 | S4 | S5 | C1 |
| 4. | C1 | C2 | C3 | C4 | C5 | S1 | S2 | S3 | S4 | S5 |
| 5. | S5 | C1 | C2 | C3 | C4 | C5 | S1 | S2 | S3 | S4 |
| 6. | S4 | S5 | C1 | C2 | C3 | C4 | C5 | S1 | S2 | S3 |
| 7. | S3 | S4 | S5 | C1 | C2 | C3 | C4 | C5 | S1 | S2 |
| 8. | S2 | S3 | S4 | S5 | C1 | C2 | C3 | C4 | C5 | S1 |
| 9. | S1 | S2 | S3 | S4 | S5 | C1 | C2 | C3 | C4 | C5 |
| 10. | C5 | S1 | S2 | S3 | S4 | S5 | C1 | C2 | C3 | C4 |
| Continuous Monoculture | | | | | | | | | | |
| 11. | Cc | Cc | Cc | Cc | Cc | Cc | Cc | Cc | Cc | Cc |
| 12. | Ss | Ss | Ss | Ss | Ss | Ss | Ss | Ss | Ss | Ss |
| Continuous; non-*Bt* corn and SCN-resistance soybean post-2010, alternating cultivars pre-1995 | | | | | | | | | | |
| 13. | Cc | Cc | Cc | Cc | Cc | Cn | Cn | Cn | Cn | Cn |
| 14. | Ss | Ss | Ss | Ss | Ss | Sr | Sr | Sr | Sr | Sr |

[a] Cc and Cn are continuous corn with non-Bt and Bt cultivars since 2010 respectively; C1 through C5 are 1st- to 5th-year corn after 5 years of soybean; S1 through S5 are 1st-to 5th-year soybean following 5 years of corn; Ss and Sr are continuous soybean with SCN-susceptible and resistant cultivars respectively since 2010. All soybeans, except Sr, were susceptible to SCN.

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