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Soil type-driven variable effects on cover- and rotation-crops, nematodes and soil food web in sugar beet fields reveal a roadmap for developing healthy soils

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ABSTRACT

Improving soil health and managing beneficial and harmful nematodes using cover crops such as oilseed radish and mustard integrated with maize and soybean as rotation crops are major priorities in US sugar beet production. Despite extensive research on effects of rotation- and cover-crops on soil health, variable outcomes remain a problem. Using sandy clay loam and loam fields with known SBCN infestation, we tested how two each of oilseed ('Defender' and 'Tillage'), mustard ('Pacific Gold' and 'Ida Gold'), sugar beet ('B-18RR4N' and 'B-10RR34') and soybean ('92Y80' and '92M91'), and a maize ('P9910R') variety affect nematode community and soil food web in the 2013 and 2014 growing seasons. Each treatment (crop) was replicated six times. Maize is a non-host and Defender and Pacific Gold are poor hosts for SBCN. Nematode community composition at intervals during growing seasons and soil physiochemical properties at the end of year 1 were measured. The crops had no effect on nematodes. Nematode abundance and community indices varied by sampling time, growing season and/or soil type. Principal component analysis showed that the crops distinctly separated by soil type and only a few nematode community indices and/or soil physiochemical parameters overlapped with crop. Soil food web analysis showed depleted and degraded conditions in the sandy loam soil and disturbed and approaching enrichment in the loam soil. The study suggests a roadmap to get to agrobiologically suitable soil conditions to meet industry priorities for healthy soils.

1. Introduction

Soil degradation due to intensive cultivation and its impact on maintaining biodiversity and agroecosystem health sustainability are grand challenges in the current conventional crop production systems [1], including sugar beets (*Beta vulgaris* L) in the Great Lakes Region of the USA [2]. Consequently, developing integrated soil health management strategies using agronomic practices such cover crops, crop rotation, conservation tillage, and soil nutrient amendment is a cross-cutting priority [3–6]. Soil health refers to structural, physiochemical, nutritional and water holding integrity of a given soil [1], and it is well established that nematodes, the most abundant metazoan and central players in the soil food web, are an excellent indicator of soil health [7]. Enumerating nematodes into bacterivore, fungivore, herbivore, omnivore and predator trophic groups and colonizer-persister (c-p) groups based on life histories and reproductive strategies can describe the soil food web conditions, nutrient cycling potential, and agroecosystem fitness from worst to best case scenarios [8]. In simple terms, this soil food web model is a tool that leads to accurate decision-making out of complex information that would otherwise be difficult to understand let alone relate to production.

Oilseed radish (*Raphanus* spp.) and mustard (*Sinapis* and *Brassica* spp.) are among the commonly used cover crops [4,9–13]. The rotation systems include cereals (e.g., maize and wheat), legumes (e.g., soybean and dry bean), and/or root or tuber (e.g., carrot, potato, and sugar beet) crops in varying combinations [14]. The use of oilseed radish and mustard as cover-, green manure- and/or trap-crops for managing plant-parasitic nematodes in sugar beet production and other field

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cropping systems [15–23], and use of rotations and sequences are well known. Despite the benefits of cover crops and rotations for improving soil quality and conservation, and pest and disease suppression, however, variable responses within and/or across cropping systems are major challenges yet to be overcome [4,6,24–27]. Soil type is a major factor in variable outcomes of suppression of harmful organisms and/or increase of crop yield using cover crops [4]. Under these circumstances, achieving the cross-cutting priority of developing integrated and sustainable soil health management in cropping systems [2] will be difficult. A clear understanding of the sources of variability and designing suitable management strategies is lacking.

Improved soil structure, physiochemistry, water holding capacity and nutrient cycling, desirable balance between harmful and beneficial soil organisms, and improve biological functioning of the soil [28] are among the ecosystem services that cover cropping and rotation practices generate in field [2,14,18,21], vegetable [24,25,27] under organic and conventional production systems [29]. However, it is rare that these desirable ecosystem services have the same trajectories. Moreover, the heterogeneity of the soil types in the landscape such as the Great Lakes Region sugar beet production system in which the cover cropping and rotation systems are practiced (Table 1) complicate our understanding of variable outcomes and navigating a road to healthy soils from the current degraded conditions. In order to develop integrated and sustainable soil health management practices that fit the Great Lakes Region sugar beet production landscape, therefore, it is necessary to answer an overarching and fundamental question-How does a given cover- and/or a rotation-crop alter soil health and nematode community in a given soil type? Crops and cropping systems are moving targets; whereas, soils are the plates that record the different footprints of the dynamics. Soil type-based assessment will be particularly useful in understanding sources of variability and building biogeographic data base that could lead to establishing benchmarks, more accurate and integrated nematode and soil health management practices across cropping systems. For example, based on the soil food web analysis, the outcomes of the soil conditions could range from worst-case (biologically depleted) to best-case (biological regulated) scenarios [8]. This is important in determining what treatments may be needed to get to healthy soils. For example, the worst-case scenario will likely require treatments (yet to be determined) that boost biological activities while the best-case scenario will mean that ideal conditions have been achieved. Currently, there are no quantitative benchmarks for healthy soils for any crop-soil type combination as well as the timeline that it takes to get to healthy soils from the current conditions with varying degrees of degradations.

Therefore, the primary objective of this study was to determine how selected oilseed radish and mustard as cover crops grown over 45–50 days, and maize, soybean and sugar beet as rotation crops grown full season affect nematode community and soil health in selected soil types with known plant-parasitic nematode problems. The duration of 45–50 days represents the time that these cover crops are grown before they are incorporated into the soil or killed with herbicide before they seed and become weeds. The working hypothesis was that the effects of cover and rotation crops on soil health and nematode community will vary by soil type. Knowing if and how each cover crop and/or rotation crop affects nematodes, soil health at a given time and space is critical to designing best soil health management practices on a one-size-fits-all across soils types or on a location-specific basis by soil type.

Table 1
Diversity of soil types, texture composition and pH, and presence of *Heterodera* cysts/100 cc of soil found during the 2010 survey of six sugar beet fields within approximately 30 km radius in Saginaw and Bay Counties of Michigan.

Field codes	Soil properties[†]					Cysts/100 cc soil[‡]
	Type[‡‡]	Texture (%)			pH	
		Sand	Silt	Clay		
1	Sandy clay loam	48.8	18.4	32.9	7.4	5.0 a
2	Sandy clay loam	47.8	23.4	28.9	7.0	4.4 a
3	Sandy clay loam	49.9	23.7	26.9	7.6	3.0 a
4	Silt clay loam	11.5	47.6	40.9	7.4	1.5 a
5	Clay loam	42.8	24.4	32.9	7.2	5.4 a
6	Clay	16.8	32.4	50.9	7.6	2.0 a

[†]Soil properties are composite data from each field.
[‡]Cyst data are means of four samples per field.
[‡‡]These fields are within the proximity of the current study area and cover cropping and rations using the same crops described herein are common practices.

2. Materials and methods

2.1. Characterizing broad field conditions and experimental site selection

As part of establishing experimental soil types that represent the sugar beet production system in the Saginaw Valley, the heartland of Michigan field crops production, a preliminary survey was conducted during November 2010. Six sugar beet production fields with known sugar beet cyst nematode (SBCN, *Heterodera schachtii* Schmidt) problem, primary nematode for the industry, were randomly selected within approximately 30 km radius in Bay and Saginaw Counties. In each field, four soil samples, each approximately 800 cc and a composite of five to six random cores within about 50 m^2 area, were collected [30]. Cysts (*Heterodera* spp.) were extracted from a sub-sample of 100 cc soil from each sample [31] and soil pH and percent sand, silt and clay texture were analyzed from a composite sample per field as described in Ref. [32]. The fields had an average of 1.5–5.4 cysts per 100 cc of soil (Table 1). Albeit at low infestations, this established broad presence of cysts which is one of the reasons for cover- and rotation-crop use practices. Soil pH ranged 7.0 to 7.6 across fields (Table 1). Three of the fields were classified as sandy clay loam type and the other three were either silt clay loam, clay loam or clay soil (Table 1). Cover cropping and rotations that included varieties in the current study are common practices in these fields with no regard for soil type.

Based on the survey and grower collaborations within the Saginaw Valley, one field with sandy clay loam soil in Saginaw County and one with a loam soil in Huron County were selected for this study during the 2013 and 2014 growing seasons. While logistical and resource limitations did not allow experimenting on multiple sites for each soil type, the study was repeated on the same fields over two growing seasons. The fields are about 80 km apart, within the proximity of the survey area described in Table 1, and good representation of diversity of soil types in the region. The sandy clay loam field had a 3% OM, pH 7.6 and 53.7% sand, 25.6% silt and 20.7% clay texture. The loam field had 3.4% OM, pH 7.1 and 47.4% sand, 29.0% silt, and 23.7% clay. For ease of reference, the fields will be referred to by soil types throughout the text.

2.2. Experimental design and treatments

The treatments were two oilseed radish (*Raphanus sativus* L) cultivars, a yellow mustard (*Sinapis alba* L), an oriental mustard (*Brassica juncea* L), two sugar beet (*Beta vulgaris* L) cultivars, and a soybean cyst nematode (SCN, *Heterodera glycines*, Ichinohe) resistant '92Y80' and susceptible '92M91' soybean (*Glycine max* Mill), and a maize (*Zea mays* L) cultivar 'P9910R'. The oilseed radish and mustard represent cover crops, sugar beet the main crop, and soybean and maize, rotation crops. The sugar beet cultivars were SBCN-tolerant 'BTS18RR4N' and –susceptible 'BTS10RR34'. Tolerant cultivars are as suitable as susceptible cultivars for nematode infection and reproduction, but they do not suffer as much yield loss from nematode infection [33,34]. The oilseed radish cultivars were 'Defender' and "Tillage', the oriental mustard was 'Pacific Gold' and the yellow mustard was 'Ida Gold'. Defender and Pacific Gold are poor hosts while Tillage, Ida Gold are suitable hosts for