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Nematode community profiling as a soil biology monitoring tool in support of sustainable tomato production: A case study from South Africa

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ABSTRACT

Management of the biological component of agricultural soils is a vital aspect of sustainable food production systems. There is a need for soil biology metrics that producers can use as a decision support tool when it comes to managing the soil biological component of agricultural soils. We evaluated the usefulness of nematode community profiling as a soil biology monitoring tool in support of a sustainable commercial-scale tomato production system in South Africa. The objectives were to: (1) study the effects of land use change on nematode communities in the tomato production region, and (2) explore the correlation between tomato crop productivity and the nematode community metrics. The enrichment index was a sensitive indicator of land use change, but the structure index was not. Although the number and proportion of free-living and plant-parasitic nematodes increased and decreased respectively, the selective amplification of specific herbivorous genera was observed. *Helicotylenchus* spp. was sensitive to land use change and might serve as soil health indicator in this tomato production region. Regression analysis indicated a combination of variables associated with soil pH, free-living nematodes (notably the bacterivores) and specific plant-parasitic nematode genera (*Paratrichodorus* spp. and *Rotylenchus* spp.) predicted tomato yield ($R^2 = 0.846$). Despite the useful information gleaned from the nematode community metrics regarding soil food web functioning, the importance of ecologically and economically important nematode genera was re-emphasized. The results of this study highlight an important principle regarding development of soil health metrics for tomato agroecosystems: tomato crop health was not necessarily predicted solely by indicators of soil food web health and functioning.

1. Introduction

Management of the biological component of agricultural soils is a vital aspect of sustainable food production systems. The soil's biological component can provide several ecosystem services to the crop producer; biological nutrient cycling and biological disease suppression attract the most attention from producers and scientists. Producers wish to manage the soil biological component in the same way as they manage fertilizer and pesticide applications based on appropriate laboratory tests or on-site observations (i.e., scouting for insect pests). Not surprisingly, a wide range of soil biology metrics has been described in the literature and several have been commercialized (Pulleman et al., 2012; Riches et al., 2013). Each metric has its theoretical, procedural, and practical shortcomings. The challenge for biologists is to devise a metric that satisfies the basic requirements of scientific excellence, procedural simplicity, and agronomic relevance (Doran and Zeiss, 2000). Nematode Community Profiling (NCP) by means of functional guild analyses and related indices (De Goede and Bongers, 1994; Ferris et al., 2001; Yeates et al., 1993) is a promising soil biology metric that is being used increasingly to describe ecological and land use gradients.

Nematodes are ubiquitous to the soil environment. Vegetable crop producers are well-aware of the negative consequences plant-parasitic nematodes (PPNs) have on crop production. However, few producers are aware that nematode communities contain non-pathogenic nematodes which may provide positive outcomes to crop production. Apart from documenting the PPN community in soil, NCP can provide insights into soil food web stability and ecological functioning. For example, nematodes contribute directly and indirectly to nitrogen cycling in soils (Anderson et al., 1983; Buchan et al., 2013; Ferris et al., 1998) and this information may be

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used by producers for crop nutrient management. Producers may also use the metric to gauge the effect of specific soil or crop management practices on the quality of their soils. For example, nematode genera that are sensitive to disturbance can be used as indicators for assessing the severity of land use change or crop management practices (Zhao and Neher, 2013). To this end, NCP has been used to describe land use change in the vegetable production context by several authors (Bulluck et al., 2002; Li et al., 2014; Reeves et al., 2014; Ruan et al., 2013).

Although crop producers are under increasing pressure to improve the sustainability of their operations, economic considerations dominate the overall sustainability of modern-day crop production enterprises. For this reason, crop producers will always be interested in correlations between soil biology metrics and crop yield. Crop yield is influenced by the complex interactions among an array of biotic and abiotic variables. It remains a challenge to demonstrate consistent correlations between soil biology metrics and crop yield. Aspects of NCP have been correlated with the yield of various crops, including tomatoes (DuPont et al., 2009; Ferris et al., 2004; Wang et al., 2014).

Since 2003, the largest commercial tomato producer in South Africa implemented a 'nature-friendly' open field production system. This particular example of eco-agriculture has been described in literature, albeit superficially (Uphoff and Thies, 2011). Managing the soil microbiological content and diversity by means of compost, manures, compost tea, and Effective Microorganisms® formed an important part of this tomato production system. The objectives of this study were to investigate at a scientific level the following: (i) the impact of land use change, i.e., the conversion of natural vegetation into tomato production units, on the soil nematode communities, and (ii) whether there was a link between tomato crop productivity and NCP metrics.

2. Materials and methods

2.1. Site description

The study concentrated on commercial open-field tomato operations in the lowveld biome centered on the town of Mooketsi (23°36′5.95″S; 30°5′37.02″E), Limpopo Province, South Africa. The area is dominated by a single vegetation type, the Tzaneen Sour Bushveld, and is located 631–832 m above sea-level (Mucina and Rutherford, 2006). The mean annual precipitation (781 mm), mean annual temperature (19.7 °C), mean annual frost-free days (364 days) and mean annual potential evaporation (2097 mm) enables year-round tomato production.

2.2. Tomato production system

Fields intended for tomato cultivation were cleared, ploughed and ridged 12 weeks before planting date. Soil conditioners (such as compost or manures) were incorporated into ridges. Six-weeks old indeterminate tomato seedlings (cv. Nemo-Netta) were transplanted into the ridges and fertigated via drip irrigation as necessary. A stake-and-trellising production system was used. The mean planting density was 11500 plants ha^{-1}; plants were pruned so that the final planting density was 23,000 fruit bearing stems ha^{-1}. Pest and disease control were performed in accordance with growers' integrated pest management programs. First harvest started 10–12 weeks after planting and continued until week 25 after planting. Plant growth was terminated after 30 weeks and fields were abandoned to naturally recover for periods of one to seven years before the next cultivation event. No dedicated task-specific crop rotations were practiced, although cattle occasionally grazed the abandoned fields.

2.3. Sampling strategy

Soils in various stages of the tomato production cycle were surveyed from 2009 to 2013. Samples were taken once from the various tomato production sites within the same bioregion. Soil samples were taken from three-hectare open field tomato production units because the producers recorded tomato yield data at that scale. Twenty composite soil samples were taken at 15 cm depth from the production units. Soil samples reached the laboratory within 24 h. Samples were taken when field clearing and ridging activities commenced (referred to as pre-plant soil) (56 samples, 45%) and during the first ten weeks after planting (referred to as cultivated soil) (28 samples; 23%). Finally, samples were taken from undisturbed sites (referred to as natural soil) in the same bioregion (39 samples, 32%), giving a total of 123 samples. The different groups of samples represented a soil management gradient which described a change in plant communities from natural grasslands, to bare soil and then to a homogeneous population of a non-indigenous cultivated plant, the tomato (Table 1).

2.4. Analyses

Soil physical properties were analysed according to standard methods (The Non-Affiliated Soil Analyses Work Committee, 1990) by a commercial soil testing laboratory (Bemlab, Somerset-West, South Africa). Sand, silt, and clay content were determined with the hydrometer method on samples taken at 15 cm depth. Soil was air dried, sieved through a 2 mm sieve for determination of the stone fraction (weight/weight basis) and analysed for pH (1.0 M KCl).

Nematode community analyses were performed by a commercial nematode testing laboratory (Nemconsult, Upington, South Africa). Free-living nematodes (FLN) as well as PPNs were extracted according to the decanting sugar flotation procedure (Pofu and Mashela, 2013) and counted/identified by means of a compound microscope at 1000× magnification. Nematodes were identified to genus level only. Nematodes were assigned to trophic groups according to Yeates et al. (1993). Free-living nematodes included all the non-plant-parasitic nematode trophic groups, whereas

Table 1
Description of sample sites according to disturbance levels and soil quality variables in the lowveld tomato production region of the Limpopo Province of South Africa (mean ± standard error).

Site	Description	N	pH	Stone (%)	Clay (%)	Silt (%)	Sand (%)
Natural (N)	Undisturbed soils covered by natural vegetation	39	5.51 ± 0.1	10.7 ± 2.5	9.9 ± 1.8	5.9 ± 0.5	84.2 ± 2.1
Pre-plant (P)	Disturbed soils (freshly tilled, bare soil)	56	5.82 ± 0.08	10.5 ± 1.5	10.8 ± 0.8	6.0 ± 0.3	83.2 ± 1.0
Cultivated (C)	Disturbed soils (synthetic and organic fertilization, synthetic pesticides, monoculture of non-indigenous plant)	28	6.12 ± 0.16	12.2 ± 2.5	5.6 ± 1.2	4.8 ± 0.6	89.6 ± 1.7