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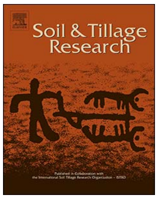

Soil arthropod responses to controlled traffic in vegetable production

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ABSTRACT

In this study, the effects of a controlled traffic (CT) management system on the soil arthropod assemblage in a Red Ferrosol (krasnozem) soil in north-west Tasmania were examined. Individual soil cores were collected at three depths over two seasons (winter and spring, 17 months apart), and soil fauna extracted using Berlese-Tullgren funnels. All arthropods were identified to the level of order and counted. Data were analysed to assess the effects of a controlled traffic system on the overall abundance and ordinal richness of the arthropod assemblage, as well as abundance and species richness in the collembolan assemblage. Multivariate analysis was used to examine the differences in the ordinal composition of the arthropod assemblage. The data were variable between seasons, with significant increases in arthropod and collembolan abundance ($p < 0.01$) at all depths being evident under controlled traffic in spring. Arthropod richness was significantly greater in spring ($p < 0.1$), but a similar effect was not measured for collembolan richness. Overall arthropod abundance was greater under CT in winter ($p < 0.1$), although by depth, differences between treatments were evident only in the deepest samples for arthropod abundance ($p < 0.05$) and arthropod and collembolan richness ($p < 0.1$). While it was not possible to separate the relative impacts of traffic and tillage, it is concluded that the controlled traffic system had positive effects on the abundance and diversity of soil arthropods.

1. Introduction

Agricultural soils retain many of the biological characteristics of natural soil ecosystems, despite the severe disturbance associated with cultivation, modification of vegetation and inputs of various agricultural chemicals. The biota of both agricultural and natural soil ecosystems almost universally include the root systems of higher plants, an abundant microflora of bacteria and fungi, and fauna such as protozoa, nematodes, arthropods and earthworms. To a substantial extent, the living component of agricultural soils has been ignored in agricultural systems, except for the management of a small number of pest and disease organisms (Crossley et al., 1992). Some effort has been made to understand the role of soil organisms in maintaining the physical structure and chemical fertility of soils, and these effects are proving to be overwhelmingly positive (Coleman and Whitman, 2005; Crossley et al., 1992; Lee and Pankhurst, 1992). A key challenge in agriculture is how to manage soils in ways which minimise the negative impacts on soil flora and fauna (Altieri, 1999).

In mechanised crop production, machinery is required for incorporation of crop residues, seed bed preparation, planting, weed control, irrigation, application of fertilizers, herbicides and pesticides and harvesting operations. One consequence of machinery traffic is soil compaction, while another is soil disturbance caused by the need for remedial tillage. The negative effects of soil compaction include reduced water infiltration, increased surface runoff and erosion, reduced soil aeration and gas exchange and reduced crop growth (Batey, 2009; Chamen et al., 1992; Hakansson et al., 1988; Hamza and Anderson, 2005). One of the key reasons for tillage in vegetable production is for the remediation of soil compaction to create soil conditions suitable for subsequent crops (McPhee et al., 2015).

Soil compaction has negative impacts on many soil organisms (Beylich et al., 2010; Brussaard and van Faassen, 1994; Pangnakorn et al., 2003; Whalley et al., 1995), partly as a consequence of the reduced volume and connectivity of soil pores. Many soil organisms (e.g. mites and Collembola, which often number in the tens of thousands per square meter) have no capacity to burrow or dig through the soil, and rely on interconnected soil pores for their physical habitat (Gupta, 1994; Lee and Foster, 1991). Soil compaction represents a loss of habitat for these organisms. For the few soil invertebrates, such as earthworms, ants, beetles and some insect larvae, that are capable of

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Nomenclature

Berlese-Tullgren funnel	an apparatus consisting of a funnel with a gauze insert, overhead light for warmth, and a capture bottle containing ethanol below the funnel. It is used to extract living organisms, particularly arthropods, from samples of soil and is normally arranged in a bank of multiple units
CTF	Controlled Traffic Farming
GNSS	Global Navigation Satellite Systems
Track gauge	the centre to centre distance between tyres across a machine, perpendicular to the direction of travel

actively burrowing, compacted soils may be habitable, but are a less desirable habitat than uncompacted soils (Beylich et al., 2010).

Many modifications to agricultural management practices have been demonstrated as strategies for reducing soil compaction. These include modifications to implements so that multiple operations (e.g. tillage, sowing, application of fertilisers and pre-emergent herbicides) can be achieved in a single pass, thereby reducing the number of passes required. Minimum tillage, no-till farming and low ground pressure tyres may also reduce the extent of compaction. The most effective strategy for managing compaction in cropping soils is controlled traffic farming (CTF) (Chamen et al., 2003; Chamen, 2015; McPhee et al., 2015; Tullberg, 2010; Vermeulen et al., 2010). CTF relies on all machines having the same track gauge and compatible working widths, and then constraining their movement in the field to permanently defined and located wheel-tracks (Baker et al., 2007). This results in a large area of the field having no traffic, and hence no soil compaction, while a much smaller area becomes permanent wheel-tracks, which may or may not grow crop, depending on the circumstances. Achieving the degree of precision required to maintain this pattern of machinery movement has been greatly aided by the development of GNSS guidance and auto-steering technologies, although dimensionally incompatible machinery designs are a major hurdle to adoption in some industries (McPhee and Aird, 2013).

When assessing the status of soil biology, it is generally impractical to collect data for all organisms present. The soil biota is comprised of such a wide range of different taxonomic groups that such a comprehensive study would require a diverse range of expertise and research methodologies. This problem is overcome by selecting a subset of 'indicator taxa' for study on the assumption that they will provide some insight into the status of the remaining biota (King and Hutchinson, 2007; Pankhurst et al., 1995; Paoletti et al., 2007a,b). In this study, soil arthropods identified to the level of Order, and the Collembola, identified to species level, were used as indicators. Soil arthropods include groups such as the collembolan and oribatid mites, which are primarily grazers of the microorganisms found in decomposing organic materials, and predators such as micro-spiders, centipedes and mesostigmatid mites, which prey upon a range of organisms including nematodes, protozoa and other arthropods. The merits of arthropods as indicators of biological properties in agricultural soils are discussed extensively by King and Hutchinson (2007); Pankhurst et al. (1995); Paoletti et al. (2007a,b), and the usefulness of Collembola as indicators by Greenslade (2007).

In this study, the effects of a controlled traffic management system on soil biological properties were assessed. The benefits of controlled traffic farming for reducing soil compaction and improving soil structure have been widely reported over many years (Bakker and Barker, 1998; Chamen and Longstaff, 1995; Gerik et al., 1987; McHugh et al., 2009; McPhee et al., 2015; Tisdall and Adem, 1988). This study was undertaken to determine if changes in traffic and tillage management under controlled traffic led to responses in soil arthropod abundance and richness. The null hypothesis was that there would be no impact on the relative composition and abundance of soil arthropods, when measured by depth and season, as the result of controlled traffic management.

2. Materials and methods

2.1. Site description

The experimental site was located in a 1.6 ha field on the Tasmanian Institute of Agriculture Vegetable Research Facility, approximately 9 km west-south-west of Devonport, Tasmania, Australia (41°12′20″ S, 146°15′50″ E). The site has deep, friable, Red Ferrosol soils (Isbell, 2002), representative of prime vegetable production areas in Tasmania. Characteristics of the soil at the site are described in McPhee et al. (2015). The farm has an elevation of 90–150 m and an undulating topography ranging from 2–16% slope. The site used in this study had an average slope of 6%, ranging from 2.5–9%. Rainfall is winter dominant, with a long term average of 980 mm/y. Irrigated summer cropping is the main enterprise of the region, although rain-fed winter crops are also grown.

2.2. Experimental design

The experiment site was established as two replications of two treatments – controlled traffic (CT), with all wheel traffic confined to permanent wheel tracks on a track gauge of 2 m, and conventional practices using random traffic (RT). Each treatment plot was transected by three equally spaced sampling areas, as described in McPhee et al. (2015). All soil fauna samples were taken from within these sampling areas. This approach was taken to allow for spatial variation, given that the degree of replication was limited by field layout and the logistics of machinery operation, particularly at harvest.

2.3. Site management during the study period

Details of site establishment and management are outlined in McPhee et al. (2015). A number of vegetable and cover crops was grown on the site during the study. Twice the number of tillage operations were used on the RT treatment over the full course of the work. This difference in tillage management was a direct consequence of the isolation of machinery traffic from the cropping bed in the CT treatments.

2.4. Soil arthropod sampling

Soil cores for arthropod extraction were collected during the growth of the broccoli (*Brassica oleracea* var. *italic*) and carrot (*Daucus carota* subsp. *sativus*) crops (winter and late spring, respectively), 17 months apart. The cores were 160 mm diameter and 50 mm deep, and were taken from 0–50 mm, 70–120 mm and 140–190 mm depths. In both winter and spring, one sampling point was selected within each of the sampling areas in each of the treatment plots (i.e. six sample points within each of the RT and CT treatments). Samples were taken near the centre-line of beds to avoid any influence of the wheel tracks at the bed margins. Soil samples were kept cool during the field sampling process, and transferred to the laboratory within a few hours. Arthropods were extracted from the soil using Berlese-Tullgren funnels over a period of 48 h. The resulting soil layer in the funnel apparatus was 35–40 mm thick. The funnel apparatus used 50 W lamps, placed approximately 150 mm above the surface of the soil samples, to provide gentle heating