Applied Soil Ecology 43 (2009) 122–130

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Response of soil microbial and invertebrate communities to tracked vehicle disturbance in tallgrass prairie☆

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ARTICLE INFO

Article history:
Received 25 February 2009
Received in revised form 17 June 2009
Accepted 19 June 2009

Keywords:
Biological indicators
Earthworms
Military training
Microbial biomass
Nematodes
Tallgrass prairie

ABSTRACT

Soil biota drive fundamental ecosystem processes such as decomposition, nutrient cycling, and maintenance of soil structure. They are especially active in grassland ecosystems such as the tallgrass prairie, where much of the net primary productivity is allocated belowground and ultimately processed by heterotrophic soil organisms. Because both soil microbes and soil fauna display perturbation responses that integrate the physical, chemical, and biological changes to their environment, the structure of belowground microbial and faunal communities is used widely as an indication of the ecological status of soils. To investigate the effects of military training on tallgrass prairie soil communities, a replicated small-plot study of tracked vehicle disturbance effects was initiated at Fort Riley, Kansas in 2003. This article reports subsequent rates of recovery for soil microbial and invertebrate communities over a range of disturbances encompassing different soil types (silty clay loam and silt loam soils), environmental conditions (wet vs. dry traffic events), traffic intensities (single vs. repeated traffic), and track areas (curve vs. straightaway). Microbial biomass in wet silty clay loam soil treatments and on curve areas in silt loam soil was suppressed for 1–2 years following disturbance but increased to levels greater than undisturbed plots in all treatments by the fourth year. Nematode abundance, family richness, trophic composition, and community structure also displayed maximum disturbance for wet treatments and curve areas. Trophic composition and community structure continued to exhibit disturbance effects throughout the 4-year study period, even after recovery of nematode abundance. Earthworm abundance displayed the most severe reductions (78% across soil types, treatments and areas) immediately following tank traffic but, like microbial biomass, subsequently increased to levels greater than undisturbed plots. Nematode community structure provided a reliable and comprehensive assessment of the status of the soil food web and was an effective bioindicator of ecosystem recovery following traffic disturbance. In addition, given the dominant role of earthworms in ecosystem processes and their extreme sensitivity to tracked vehicle disturbance, it is recommended that this group be included in monitoring protocols for military training land managers.

1. Introduction

Soil biota are important drivers of fundamental ecosystem processes such as decomposition, nutrient cycling, and maintenance of soil structure. In grassland ecosystems, where much of the net primary productivity is allocated belowground and ultimately processed by heterotrophic soil organisms, their importance is amplified (Elliott et al., 1988). The tallgrass prairie, in particular, is characterized by high belowground productivity and large accumulations of soil organic matter and nutrients resulting in a large and diverse assemblage of soil biota (Ransom et al., 1998; Rice et al., 1998). Ecosystems display characteristic structural and functional signatures in soil communities, suggesting that the biological status of soils reflects soil quality as well as overall ecosystem health (Ritz et al., 2004). Indeed, the structure of belowground microbial and faunal communities has been used widely as an indication of the ecological status of soils (Linden et al., 1994). Soil fauna provide several advantages over microbial communities, however, because they reflect higher trophic levels in the soil food web, generally are easier to assess, and their populations are relatively stable (Neher, 2001). Nematodes are among the most popular soil faunal indicators because they represent a comprehensive array of functional or trophic groups occupying multiple positions in the soil food web (Yeates et al., 1993).

☆ Contribution no. 09-069-J from the Kansas Agricultural Experiment Station, Manhattan. Research was funded by the U.S. Army Military Installation, Integrated Training Area Management Program.

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doi:10.1016/j.apsoil.2009.06.011

Soil macroinvertebrates such as earthworms play a dominant role in ecosystem processes, making them particularly significant indicators of soil health. Earthworm burrowing and feeding activities result in improved aeration and water infiltration, incorporation of organic matter into the soil, and stabilization of soil aggregates (Tomlin et al., 1995; Edwards and Bohlen, 1996), leading to their designation as ‘ecosystem engineers’ (Jones et al., 1994). The tallgrass prairie soils of the Flint Hills region of eastern Kansas contain a mixture of native and exotic earthworm species which together account for most of the faunal biomass (James, 1995; Rice et al., 1998). Departures from historical disturbance regimes of frequent fire and grazing facilitate the expansion of exotic earthworms, possibly with the displacement of native species (Callaham and Blair, 1999; Callaham et al., 2003).

There is a clear need for the further identification and development of biological indicators for soil quality (Loveland and Thompson, 2001; Ritz et al., 2004). Belowground systems exhibit great complexity, with extremely high levels of biological diversity, although it is the functional aspects of these systems that appear to be the most descriptive (Ritz et al., 2004). Since the complexity of soil communities is related largely to the spatial heterogeneity and diversity of resources (Maire et al., 1999), disturbance of soil physical and chemical properties are expected to have profound effects on both their structure and function. The rate of recovery in community structure and/or function following such perturbation provides a useful indicator of soil and, therefore, ecosystem resilience (Ritz et al., 2004).

Mechanized military training provides a dramatic example of landscape-scale soil disturbance, impacting soil quality in multiple ways, most notably through displacement and compaction. The environmental impacts of military vehicle use on natural areas have been reviewed recently by Anderson et al. (2005). While numerous studies have identified ecological processes sensitive to military training activities, additional research is needed to identify soil quality-related indicator variables for inclusion in monitoring programs on military lands. Fort Riley Military Installation, located in the Flint Hills of northeastern Kansas, is the site of ongoing research on the effects of military training on the mesic tallgrass prairie ecosystem. Fort Riley is a major training reservation, with seventy percent of its 40,434 ha used for mechanized maneuvers. In an early comparison of training sites on Fort Riley with an undisturbed, native tallgrass prairie site, soil invertebrates, including macro- and microarthropods, and native earthworm species, were identified as sensitive indicators of compaction resulting from mechanized maneuvers, even in the absence of observable effects on plant productivity (Schaeffer et al., 1990). A subsequent landscape-scale evaluation on Fort Riley identified nematode family richness as a strong indicator of disturbance due to mechanized maneuver training (Althoff et al., 2007). Althoff (2005) monitored the status of soil microbial and invertebrate communities following M1A1 tank traffic disturbance during wet and dry conditions in two soil types on Fort Riley and observed dramatic reductions in both the abundance and richness of macroinvertebrate and nematode assemblages. Earthworms were the most sensitive group, with reductions in numbers approaching 100% in plots with the maximum disturbance regime.

Land maintenance on military training lands is currently guided by regulations set forth by the integrated training area management (ITAM) Program, which outlines procedures for achieving sustainable use of training lands (Army Regulation 350-4, 1988). A key component of this program, range and training land assessment (RTLA), provides information and recommendations to range managers regarding the condition of training lands to assist scheduling of training areas and monitoring of the effectiveness of rehabilitation projects (US Army Environmental Center, 2006). Fort Riley started implementing portions of the assessment protocol under the land condition trend analysis (LCTA) Program, monitoring trends in plant communities related to military vehicle traffic patterns during 1994–2001 (Althoff et al., 2006). Assessment of soil quality indices, including physical, chemical, and biological properties began in 2002 (Althoff, 2005; Althoff and Thien, 2005; Althoff et al., 2007).

A replicated small-plot study of tracked vehicle disturbance effects on tallgrass prairie soils and communities was initiated on Fort Riley in 2003. The objectives were to evaluate rates of recovery in a suite of plant and soil-quality indicators over a range of disturbances encompassing different soil types, environmental conditions, and traffic intensities. Results from the first two years are reported in Althoff (2005) and Althoff and Thien (2005). This manuscript reports longer-term trends in recovery of soil biota subsequent to military training disturbance.

2. Materials and methods

2.1. Site description

Research was conducted at Fort Riley Military Installation, an Army base in operation since 1853, located in Clay, Geary, and Riley counties in the Flint Hills of northeastern Kansas (39°15′N, 96°50′W) (Pride, 1997; McKale and Young, 2000). The installation, located in a mesic, tallgrass-prairie ecosystem, uses 29,542 ha of its 40,434 ha for maneuver training. The Flint Hills grasslands encompass more than 1.6 million ha, covering much of eastern Kansas from near the Kansas-Nebraska border south into northeastern Oklahoma, and contain the largest remaining areas of untilled tallgrass prairie in North America (Knapp and Seastedt, 1998). Hot summers and cold, dry winters characterize the climate. Mean monthly temperatures range from −2.7 °C in January to 26.6 °C in July. Annual precipitation averages 835 mm, with 75% of precipitation occurring during the growing season (Hayden, 1998). Three major vegetative communities are found at Fort Riley: grasslands (ca. 32,200 ha), shrublands (ca. 6,000 ha), and woodlands (ca. 1,600 ha). The soil at the study plots was classified as a Wymore series consisting of very deep, moderately drained, slowly or very slowly permeable soils that formed in loess (Jantz et al., 1975). This soil series is found on most of the fort's training area. Wymore soils are classified as fine, smectitic, mesic Aquertic Argiudolls.

2.2. Experimental treatments

A randomized complete block design composed of three treatments (a non-trafficked control, tank traffic during wet soil conditions, and tank traffic during dry soil conditions) and three replications (blocks) was established in each of two soil types, a silty clay loam and a silt loam, in 2003 (Althoff and Thien, 2005). An Abrams M1A1 main battle tank created disturbances by driving five circuits around a figure eight pattern in designated plots either during wet or dry soil conditions. The M1A1 weighs 57.2 t with a ground pressure of 0.96 kg cm^{-2}. The tracks are approximately 63.5 cm wide and 4.57 m long. It has a maximum cross country speed of 48 km h^{-1}. Tank speed was maintained at approximately 8 km h^{-1}. Treatment during wet soil conditions occurred at soil saturation (gravimetric water content of ∼30% for both soils). Treatment during dry soil conditions occurred at a gravimetric water content of 8% for both soils.

In 2004, one-half of each of the previously disturbed plots received five additional tank passes during wet or dry conditions similar to 2003. On a randomly selected half of the original figure eight, five additional passes were made with an M1A1 tank, producing an S-shaped pattern (Althoff, 2005). This second year of treatments allowed comparison of different levels of traffic