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Slow recovery of soil biodiversity in sandy loam soils of Georgia after 25 years of no-tillage management

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Abstract

There is little data on the time required for recovery of soil species richness from disturbance such as tillage. We identified commercial no-till fields that represented a chronosequence of 4–25 years of reduced disturbance at the start of the study. These were compared to adjacent fields in conventional tillage as regularly disturbed reference sites. Five cotton fields in southern Georgia sandy loam soils were sampled four times over 2 years to determine the abundance of soil organisms at each site. Our results show an increase in organic matter content, profile stratification, and diversity of morphotypes within samples, with age in no-tillage management. Some groups of organisms responded more quickly to the no-till management, while most increase in diversity over several years. However, abundance values for each taxonomic category was not always significant. We also identified a pattern between our Spring and Fall samples for microbial biomass, organic carbon content and certain categories of organisms. During the first 8 years of no-tillage there was some increase in the abundance of organisms, but only the two older fields (8–26 years) had accumulated both abundance and species richness that approached that of undisturbed sites. Our results point to a greater importance of species diversity estimates in samples, compared to abundance estimates for taxonomic categories. We recommend that soil management studies in agro-ecosystems be conducted long enough to allow time for the changes in the below-ground community structure and its species diversity to occur.

Keywords: Agro-ecosystem; Bio-indicators; Farming systems; Micro-arthropods; Nematodes; Tillage; Protozoa; Soil ecology; Succession

1. Introduction

An agro-ecosystem is a regularly disturbed system. It includes physical disturbance of the above- and below-ground species, as well as biomass removal, nutrient input and addition of pesticides and herbicides (Neher, 1999). Fields are managed to produce plant biomass that is regularly harvested. Field management in commercial operations, aims to maximize biomass output while maintaining its quality. It also strives to do so by minimizing input costs, and maximizing profit from the crop or forage. This is not easily achieved on the long term, without additional input into the system (Hendrix et al., 1986; Paul et al., 1997; Biggelaar et al., 2001). The crop biomass removed from the system annually constitutes a removal of nutrients from the agro-ecosystem. After repeated annual cycles of removing biomass from the system, the soil becomes poorer in nutrients and organic matter. Long-term data sets indicate an exponential decrease in soil organic matter (SOM) over the first two or three decades of harvesting (Paul et al., 1997). One consequence is loss of the soil biodiversity, as the organic matter that supports nutrient recycling through decomposition food webs are lost (Hendrix et al., 1986). There is a scarcity of data about the time required for species richness to recover in soils after disturbance.

Some no-tillage systems with organic amendments, such as the one described here, aim to increase soil organic matter and to restore a favourable habitat for species implicated in decomposition, through minimizing disturbance to the agro-

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ecosystem. It is expected that when the management of agro-ecosystems is changed from traditionally ploughed fields to a no-tillage method, recovery of the decomposer food web would follow the increase in soil organic matter substrate. The recovery of the food web should proceed as the soil becomes replenished with organic matter, structured, and stratified. The role of microbial community members, particularly the filamentous fungi, in enhancing soil aggregate stability is well known (Beare et al., 1994a,b; Dighton, 2003). The roles of other members of the biota including micro-, meso-, and macro-fauna in enhancing soil aggregate stability and SOM accumulation are much less well known (Coleman et al., 1994, 2004). The increase in species richness as the decomposer food web recovers, may not be reflected in abundance values. The abundance values for a particular group of organisms may be similar at two fields, but one field could have few species and the other many species. Furthermore, abundance values tend to fluctuate widely with weather conditions and seasons (Adl and Coleman, 2005). Species richness, or biodiversity indices, may be better indicators of long-term changes, as they reflect changes in functional groups and complexity of the food web. Although there have been many comparisons of ploughed and no-till systems (El Titi and Mebs, 2002), we do not know how long it takes the soil food web to recover. We took advantage of several commercial fields under no-till and tillage management that were near each other to address this issue. The objective of this study was to determine the time frame for significant changes in organism abundances or species richness to be detected in these no-till fields. We addressed this question by sampling a chronosequence of land-use histories, ranging from 0 to 25 years in no-tillage management commercial agro-ecosystems that grow cotton (*Gossypium hirsutum*) in southern Georgia (USA). Our results provide an idea of the time scale required for recovery of biodiversity in these agro-ecosystems.

2. Materials and methods

2.1. Site descriptions

Cotton fields were selected near Douglas, in Coffee County (31°32′N, 82°52′W) in southern Georgia U.S.A. The soils were sandy loams, Acrisol (FAO soil classification), classified in the Cowarts, Pelham, and Tifton series, encompassing fine-loamy kaolinitic, thermic Kanhapludults, Kandiudults and arenic Paleaquults (Soil Survey Staff, 1996). Mean monthly rainfall is 110 mm with a mean annual rainfall of 1330 mm. Mean annual temperature is 18.6 °C, with maximum Summer highs of 41–45 °C. Fields were level <2% slopes, and unhindered drainage all year. The fields selected had been under no tillage and no fallow management for 4, 8 and 25 growing seasons at the beginning of this study. Two fields in conventional tillage were selected for comparison because they were across from, or adjacent to the conservation fields sampled. One woodland site was also sampled adjacent to the 25-year conservation site. This 90-year-old loblolly pine (*Pinus taeda*) forest had been cropped in the 19th Century and underwent secondary succession. For this 2-year study, the fields were labelled 4–5 y, 8–9 y, 25–26 y for the no-tillage fields, representing the number of growing seasons in no-tillage management. The conventionally ploughed and managed fields were labelled 0 y and 0_R y, with 0_R indicating that crop roots were left in the soil and not removed from the field. The pine forest site is labelled as 90–91 y.

Conventional practice in this area involved seeding fields with cotton in the Spring, with recommended application of herbicides and pesticides (State of Georgia Agriculture Extension Office, Douglas, Coffee Co., 2000–2001) as in the fields under no-tillage management. After harvest, the cotton was mowed and all litter removed off-site for burning. The fields were then mouldboard ploughed and kept fallow and clean until the next Spring. In the 0_R site, the roots were not removed and were left behind as litter.

No-tillage, as practiced in the area, was by direct drilling of Summer cash crop and Winter cover crops, with simultaneous application of inorganic fertilizers, and moderate use of herbicides and insecticides. The Winter cover crops of mixed cereals were rolled flat during seeding of the Summer cotton crop, and left to decompose. Stems were broken or bent by tractor passage, without additional machinery. The Summer cotton crop was mowed-down and the litter left on-site after harvest, for decomposition. Both the 8–9 y and 25–26 y sites no longer required annual seeding of Winter cover cereals, as the seed bank persisted. The 4–5 y and 8–9 y no-tillage sites also received an application of chicken litter from broiler chicken operations, annually after mowing the cotton.

2.2. Sampling procedure

Sites were sampled one week prior to Summer crop seeding (Spring samples) and 1 week prior to Summer crop harvest and mowing (Fall samples). All soil samples were collected randomly along a single transect at 10 sampling points and sealed undisturbed in plastic freezer bags. At each sampling point soil was collected separately for microbial biomass, nematode extraction, protozoa and microarthropod extractions. To determine the microbial biomass, ten 200–300 g samples were collected with a hand shovel to 15 cm depth along the transect. The remaining soil was used for C and N assay and to determine soil moisture content. Soil moisture content was obtained simply to ensure that field sites held about the same moisture content at each sampling, as it has an effect on active abundances of soil biota. Samples for nematode and protozoa extraction were each collected with a 2 cm diameter soil probe to 15 cm depth. Micro-arthropods were sampled at 0–5 cm depth using a 5 cm diameter split-core probe and intact cores were sealed in aluminium foil. Lastly, at each sampling point soil was