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Long-term no-tillage and organic input management enhanced the diversity and stability of soil microbial community

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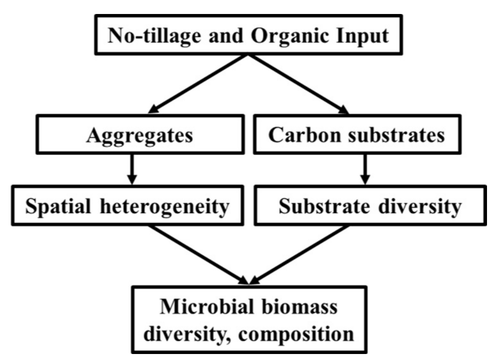
HIGHLIGHTS

- Both no-tillage and organic farming improved soil microbial diversity and stabilize soil microbial community.
- No-tillage combinate organic management enhanced soil microbial properties more than either individual practice.
- Sustainable farming practices promote soil biological characteristics and may alleviate nonpoint source pollution.

GRAPHICAL ABSTRACT



Organic inputs and reduced tillage enhance microbial diversity and activities through increasing substrate availability and habitat heterogeneity.

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ABSTRACT

Intensive tillage and high inputs of chemicals are frequently used in conventional agriculture management, which critically depresses soil properties and causes soil erosion and nonpoint source pollution. Conservation practices, such as no-tillage and organic farming, have potential to enhance soil health. However, the long-term impact of no-tillage and organic practices on soil microbial diversity and community structure has not been fully understood, particularly in humid, warm climate regions such as the southeast USA. We hypothesized that organic inputs will lead to greater microbial diversity and a more stable microbial community, and that the combination of no-tillage and organic inputs will maximize soil microbial diversity. We conducted a long-term experiment in the southern Appalachian mountains of North Carolina, USA to test these hypotheses. The results showed that soil microbial diversity and community structure diverged under different management regimes after long term continuous treatments. Organic input dominated the effect of management practices on soil microbial properties, although no-tillage practice also exerted significant impacts. Both no-tillage and organic inputs significantly promoted soil microbial diversity and community stability. The combination of no-tillage and organic management increased soil microbial diversity over the conventional tillage and

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led to a microbial community structure more similar to the one in an adjacent grassland. These results indicate that effective management through reducing tillage and increasing organic C inputs can enhance soil microbial diversity and community stability.

1. Introduction

Intensive tillage and high inputs of chemical has been widely used in conventional agriculture to meet increasing food demand. Intensive tillage often leads to surface runoff of agricultural topsoils, which has significant implications for nonpoint source pollution scenarios throughout the world (Davis and Fox, 2009). The resulting pollutants, such as soil sediment, fertilizer nutrients, and chemical pesticides, can be transported by irrigation or natural precipitation events from field to surface waters. Kok et al. (2009) estimates that nearly one third of the eroded soil and associated nutrients from farm fields discharge into rivers and lakes. These sediments and nutrients from agricultural nonpoint sources reduce topsoil quality and applied plant nutrients on farm fields, and degrade downstream water quality and lead to pollution of water bodies (Rong et al., 2017). Conservation farming practices, which can maintain soil sustainability by stabilizing the soil surface from runoff, provide an effective management to control soil erosion and nonpoint source pollution.

No-tillage has been adopted in agricultural field management as a conservation practice in the past decades. The purpose of traditional tillage is to increase crop production by providing optimum seedbed preparation and at planting weed control. However, this practice directly leads to soil erosion, nutrient and organic matter losses. No-tillage agricultural practices can minimize soil disturbance, decrease soil organic C oxidation and increase C content, and enhance soil aggregation and water infiltration (Guo et al., 2016). Consequently, better soil structure reduces soil particle detachment, depresses suspended solid losses (Larsen et al., 2014), decreases soil erosion, and minimizes pollutant transport (Carkovic et al., 2015). Choi et al. (2016) reported that compared to conventional tillage, no-tillage reduced runoff ratio by 64.9% and nonpoint source pollution loads by 66.4–88.3%. It is estimated that no-tillage practices are adopted on 1.55×10^8 ha and comprise 11% of the arable farmland worldwide (Zuber and Villamil, 2016). No-tillage has been adopted on nearly 32% of agricultural cropland in North America (Zuber and Villamil, 2016).

Organic farming, which eliminates the use of artificial chemical fertilizers and pesticides, is more sustainable than traditional agriculture (Hartmann et al., 2015). Organic systems mainly use carbon-based amendments, various crop rotations and multiple cover crops for maintaining soil fertility, and protect crops from pathogens and pests through augmenting biological processes. Organic farming began in the early twentieth century and has quickly increased since the 1980s due to consumer demand and scientific aspects. It has been estimated that about 4.4×10^7 ha of farming land are now managed as organic agricultural systems worldwide and this production practice continues to grow (Bonanomi et al., 2016). Organic farming practices generally have positive effects on various soil properties (Hartmann et al., 2015), enhancing field soil structure by increasing soil organic matter content (Francioli et al., 2016), and thus reducing soil erosion (Reganold et al., 1987). One of the main challenges in organic farming is to enhance the soil nutrient status through improving soil biological properties (Tuomisto et al., 2012).

Maintaining the complexity and diversity of soil microorganisms is critical to sustain soil fertility, because soil microbes mediate the biogeochemical cycles of C and N, as well as serve as an important reservoir for plant nutrients (Malik et al., 2016; Trivedi et al., 2017). The soil microbial community is closely related to the quantity and quality of carbon and nutrients from plant residues and organic inputs, so it has been used as a sensitive indicator to predict soil biological conditions and the effect of agricultural practice in soil ecosystem (Hartmann et al., 2015). Understanding the impact of management practices on the microbe community structure and diversity is important for evaluating the effectiveness of a management regime (Ling et al., 2016). Phospholipid fatty acids (PLFA) analysis offers a quantitative approach to assess the microbial diversity and community structure through quantifying microbial biomass and microbial groups (White and Findlay, 1988), and has been successfully applied to compare the effects of different farming practices on microbes (Frostegard and Baath, 1996; Lupwayi et al., 2017).

Despite the irreplaceable role of the soil microbe in maintaining the productivity of agricultural lands, we still have a limited understanding of the response of soil microbial diversity and community structure to long-term management practices in humid and warm regions of the Appalachian Mountains, USA. Taking advantage of a long-term field experiment established in the southern Appalachian mountains of Western North Carolina in1994, we investigated the effects of various production practices on soil microbial diversity and community structure after continuous treatments for 15 years. We hypothesized that (1) there will be greater microbial diversity and, more stable microbial community structure in the sustainable management system (no-tillage system and organic input system) than the plowed, chemical conventional system, and (2) the combination of sustainable agronomic practice (no-tillage plus organic input) will optimize soil microbial diversity, resulting in a microbial community more similar to the one in natural grassland.

2. Materials and methods

2.1. Site description

A long-term field experiment was established in fall 1994 at the Mountain Horticultural Crops Research Station (N 35°25′39″, W 82°33′21″, Elevation 624 m) in Mills River, NC. This location resides in the Appalachian Mountains of the Southeast US and within the French Broad River Basin. Field plots are sloped at 2–7% and have been in continuous cultivation with fumigation with methyl bromide for over 30 years. The soil type is a typical Delanco fine sandy loam (fine-loamy, mixed, mesic, Aquic Hapludult).

Six production practice systems were designed in this experiment: (1) tillage with chemical inputs (TC), (2) tillage with organic inputs (TO), (3) no-tillage with chemical inputs (NC), (4) no-tillage with organic inputs (NO), (5) tillage with no chemical or organic inputs (Control, TN), (6) fescue grasses (FG). A detailed description of these six production practices was shown in Table 1 (Wang et al., 2011). The experiment was a randomized complete design with four replications and each plot was at a 12.2 m × 22.4 m scale. Plots were separated by 12.2 m alleyways of grass (*Festuca elatior* L.) in order to minimize fertilizer and pesticide drift.

2.2. Soil sampling

Soil samples were collected from all plots in October 2009 after final harvest. Five sampling points were randomly selected within each plot. At each point, twenty soil cores of 2.5 cm diameter and 15.0 cm depth were taken in a 1 m radius of the point. All soil cores from each point were put in a plastic bag and thoroughly bulked, crumbled and mixed. The plastic bags were then sealed and stored at −20 °C. All composite samples were separately passed through a 3.0 mm diameter sieve, and all visible living plant material, visible organism and stones were removed. The sieved soil samples were freeze-dried at −20 °C for phospholipid fatty acids (PLFA) analysis. The general soil properties of the six treatments in this experiment were showed in Table 2 (Wang et al., 2011).