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Soil morphology, depth and grapevine root frequency influence microbial communities in a Pinot noir vineyard

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Abstract

The composition of microbial communities responds to soil resource availability, and has been shown to vary with increasing depth in the soil profile. Soil microorganisms partly rely on root-derived carbon (C) for growth and activity. Roots in woody perennial systems like vineyards have a deeper vertical distribution than grasslands and annual agriculture. Thus, we hypothesized that vineyard soil microbial communities along a vertical soil profile would differ from those observed in grassland and annual agricultural systems. In a Pinot noir vineyard, soil pits were excavated to ca. 1.6–2.5 m, and microbial community composition in 'bulk' (i.e., no roots) and 'root' (i.e., roots present) soil was described by phospholipid ester-linked fatty acids (PLFA). Utilization of soil taxonomy aided in understanding relationships between soil microbial communities, soil resources and other physical and chemical characteristics. Soil microbial communities in the Ap horizon were similar to each other, but greater variation in microbial communities was observed among the lower horizons. Soil resources (i.e., total PLFA, or labile C, soil C and nitrogen, and exchangeable potassium) were enriched in the surface horizons and significantly explained the distribution of soil microbial communities with depth. Soil chemical properties represented the secondary gradient explaining the differentiation between microbial communities in the B-horizons from the C-horizons. Relative abundance of Gram-positive bacteria and actinomycetes did not vary with depth, but were enriched in 'root' vs. 'bulk' soils. Fungal biomarkers increased with increasing depth in 'root' soils, differing from previous studies in grasslands and annual agricultural systems. This was dependent on the deep distribution of roots in the vineyard soil profile, suggesting that the distinct pattern in PLFA biomarkers may have been strongly affected by C derived from the grapevine roots. Gram-negative bacteria did not increase in concert with fungal abundance, suggesting that acidic pHs in lower soil horizons may have discouraged their growth. These results emphasize the importance of considering soil morphology and associated soil characteristics when investigating effects of depth and roots on soil microorganisms, and suggest that vineyard management practices and deep grapevine root distribution combine to cultivate a unique microbial community in these soil profiles.
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Keywords: Vineyard; Grapevine; Soil resources; Carbon availability; Microbial community; Roots; PLFA; Fungi

1. Introduction

Gradients in soil resources, such as soil organic matter, soil nutrients, and moisture, are important drivers of soil microbial community composition (Bååth et al., 1995; Bossio and Scow, 1998). Roots are a major contributor to soil organic matter due to fine root turnover and rhizodeposition (Helal and Sauerbeck, 1989; Robinson and Scrimgeour, 1995; Shamoot et al., 1968). The vertical distribution of these root-derived organic carbon (C) inputs likely varies due to differences in rooting depth among plant species and communities (Gill et al., 1999; Jackson et al., 1996), but the extent of this variation is not

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well characterized. Soil microorganisms existing in horizons less strongly influenced by C inputs from litter (e.g., C horizons) rely partly on root-derived C for maintaining activity and growth (Pietikainen et al., 1999). Thus, it may be hypothesized that the vertical composition and distribution of soil microorganisms would be impacted by root distribution (Fierer et al., 2003; Potthoff et al., 2005). In annual grasslands, the quantity of soil organic matter has been correlated with the vertical distribution of soil microbial communities (Fierer et al., 2003). However, annual grasses have a considerably more shallow vertical root distribution than the dominant species in woody perennial ecosystems (Jackson et al., 1996) or a cultivated vineyard (Smart et al., 2006). As such, one might expect the distribution of soil microorganisms associated with grapevines in vineyards to differ from comparatively shallow-rooted grasslands and annual cropping systems, which could lead to distinctions in decomposition processes and nutrient turnover.

In addition to root-derived C inputs, soil management practices and soil chemical and physical characteristics such as moisture, texture, pH, and fertility influence microbial community properties like activity, biomass and composition (Bååth et al., 1995; Bardgett et al., 1997, 1999; Bossio et al., 1998; Lundquist et al., 1999). The effects of soil resource availability (i.e., soil C and moisture), soil physical and chemical characteristics, and abiotic conditions on soil microbial community composition have been studied in annual cropping systems, grasslands, wetlands, and forest systems (Bardgett et al., 1999; Fritze et al., 2000; Kelley and Hentzen, 2001; Pankhurst et al., 2002; Steenwerth et al., 2002). Comparatively less information exists on soil microbial community composition in woody perennial agroecosystems like vineyards, and previous investigations only examined such composition in the surface horizon (Drenovsky et al., 2005; Ingels et al., 2005). Vineyard microbial communities may be unique compared to other agroecosystems because vineyards have lower nitrogen fertilization inputs and experience relatively less-frequent tillage and fewer herbicide applications. These management practices have been linked to shifts in soil microbial communities in other ecosystems (Engelen et al., 1998; Calderón et al., 2000; Okano et al., 2004).

As soil microorganisms play a crucial role in ecosystem processes, it is important to understand influences of soil heterogeneity and grapevine root distribution on soil microbial communities in vineyards due to recent expansion of vineyard systems worldwide (USDA-NASS, 2004). In this study, we investigated how vertical root distribution and changes in soil resource availability and soil chemical and physical properties characteristics alter vineyard soil microbial communities with increasing depth in the soil profile. Due to deeper grapevine root distributions, we hypothesized that changes in microbial communities with increasing depth would differ from other ecosystems with more shallow rooted species. The vineyard used in this study exists on a heterogeneous site containing two soil types and a diverse array of slope characteristics. Therefore, we addressed the secondary hypothesis that soil heterogeneity may exert a greater influence over the soil microbial community composition than soil depth, per se.

2. Methods

2.1. Site description

Our investigations took place in August 2004 at a vineyard in the Carneros region of Napa County, CA (lat. 38° 14′ 49″ and long. 122° 21′ 59″). The climate is Mediterranean, with warm, dry summers and cool, wet winters. Mean annual precipitation for the region is 585 mm (10-year average; CIMIS), with small annual amplitudes in daily mean temperatures (14.1 °C in fall, 8.8 °C in winter, 12.3 °C in spring, 17.1 °C in summer; CIMIS). The slope on which the vineyard was established was modified to fill a pre-existing gully. The resulting topography is that of a series of concavities and convexities, with slope angle varying from 2 percent to 24 percent (Fig. 1). On the lower slopes of the vineyard, the soils are Haire Clay Loam series (fine, mixed, superactive, thermic Typic Haploxerult) while on the upper slopes the soils are Diablo Clay series (fine, montmorillonitic, superactive, thermic Typic Pelloxerert).

The vineyard covers ca. 6.25 ha. It is planted to Pinot noir UC 2A on 3309C rootstock, and the grapevines were planted in 1991. Vine rows are spaced 2.5 m apart and within row spacing is 1.5 m. The vines are trained as unilateral cordons with vertical shoot positioned (VSP) trellising and are drip irrigated. Annual grasses and forbs are allowed to grow in the middle region between the vine rows and are disced in the spring. Berms underneath the grapevines are kept clean with herbicide applications of glyphosate (RoundUp Ultramax™) and oryzalin (Goal2XL™) at recommended label rates.

Three sets of soil pits were excavated to a depth of ca. 1.5–2 m at three slope positions to capture the variation in topography and soil type, as determined by previously collected soil cores from 0 to 2 m (J.-J. Lambert, unpublished data). Three parallel transects were established on the slope, along which three pits per transect were excavated. To account for slope heterogeneity in the vineyard, three soil pits were on the shoulder of the slope, three were in the midslope, and three were in the toeslope. The pits had the dimensions of 0.6 m width by 2.0–2.5 m depth and 4 m in length at approximately 0.25 m away from the vine rows. In each pit, the top four horizons were sampled for soil microbial communities in soil around grapevine roots (‘root’) and in bulk soils (‘bulk’, i.e., without roots) and for soil characteristics in ‘bulk’ soil.

2.2. Soil morphology and analyses

The soil profile in each pit was classified according to the USDA method of soil taxonomy (Soil Survey Staff, 1997).

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