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Soil Microbiological Activity and Carbon Dynamics in the Current Climate Change Scenarios: A Review

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ABSTRACT

Microbial activities are affected by a myriad of factors with end points involved in nutrient cycling and carbon sequestration issues. Because of their prominent role in the global carbon balance and their possible role in carbon sequestration, soil microbes are very important organisms in relation to global climate changes. This review focuses mainly on the responses of soil microbes to climate changes and subsequent effects on soil carbon dynamics. An overview table regarding extracellular enzyme activities (EAA) with all relevant literature data summarizes the effects of different ecosystems under various experimental treatments on EAA. Increasing temperature, altered soil moisture regimes, and elevated carbon dioxide significantly affect directly or indirectly soil microbial activities. High temperature regimes can increase the microbial activities which can provide positive feedback to climate change, whereas lower moisture condition in pedosystem can negate the increase, although the interactive effects still remain unanswered. Shifts in soil microbial community in response to climate change have been determined by gene probing, phospholipid fatty acid analysis (PLFA), terminal restriction length polymorphism (TRFLP), and denaturing gradient gel electrophoresis (DGGE), but in a recent investigations, omic technological interventions have enabled determination of the shift in soil microbe community at a taxa level, which can provide very important inputs for modeling C sequestration process. The intricacy and diversity of the soil microbial population and how it responds to climate change are big challenges, but new molecular and stable isotope probing tools are being developed for linking fluctuations in microbial diversity to ecosystem function.

Key Words: carbon cycling, carbon dioxide, carbon exchange, carbon sequestration, microbe community, soil enzymes, soil moisture, soil temperature

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INTRODUCTION

The ongoing climate changes caused by anthropogenic activities include emissions of 292 Pg C from the combustion of fossil fuels (Holdren, 2008) and at 136 ± 30 Pg C from land-use change, deforestation, and soil cultivation (Houghton *et al.*, 2001). It is very important to understand the biological mechanism regulating the carbon exchanges between land, oceans, and atmosphere and how these exchanges will respond to climate changes through climate-ecosystem feedbacks which could amplify or attenuate regional or global climate changes (Heimann and Reichstein, 2008). Terrestrial ecosystems release and absorb greenhouse gases (GHGs) like carbon dioxide (CO_2), methane, and nitrous oxide, and also act as a sink while storing carbon (C) in vegetation and soil (Schimel *et al.*, 1994). Sink activity of soil is affected by many factors including natural and anthropogenic disturbances (Magnani *et al.*, 2007), agricultural land use (Smith *et al.*, 2008), nitrogen (N) enrichment (Beedlow *et al.*, 2004), sulphur (S) deposition (Monteith *et al.*, 2007), and changes in atmosphere ozone concentration (Sitch *et al.*, 2007). Our knowledge of the assimilatory component (photosynthesis) of the C cycle and its responses to climate changes is well advanced (Bahn *et al.*, 2008);

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however, there are considerable gaps in our understanding of the responses of soil respiration (Trumbore, 2006). This lack of understanding of soil respiration and its sensitivity to climate changes stems from the fact that it is regulated by a number of complex interactions and feedbacks from climate, plants, their herbivores and symbionts, and free-living heterotrophic soil microbes (Wardle *et al.*, 2004; Högberg and Read, 2006; De Deyn *et al.*, 2008).

Soil microbial communities are responsible for the cycling of C and nutrients in ecosystems and their activities are regulated by biotic and abiotic factors such as the quantity and quality of litter inputs, temperature, and moisture. Atmospheric and climatic changes will impact both abiotic and biotic drivers in ecosystems and the responses of ecosystems to these changes. Feedbacks from ecosystem to the atmosphere may also be regulated by soil microbial communities (Bardgett *et al.*, 2008). Although microbial communities regulate important ecosystem processes, it is often unclear how the abundance and composition of microbial communities correlate with climatic perturbations and interact to affect ecosystem processes. As such, much of the ecosystem climate change research conducted to date has focused on macroscale responses to climatic changes such as changes in plant growth (Norby *et al.*, 2001, 2004), plant community composition (Bakkenes *et al.*, 2002), and coarse-scale soil processes (Emmett *et al.*, 2004; Franklin *et al.*, 2009; Garten *et al.*, 2008). Responses to climate change have been addressed to often targeted gross parameters, such as microbial biomass, enzymatic activity, and basic microbial community profiles (Zak *et al.*, 1996, 2000; Janus *et al.*, 2005; Kuever *et al.*, 2005; Kandeler *et al.*, 2006; Haase*et al.*, 2008).

The climatic variables such as atmospheric CO_2 concentration, precipitation regimes, temperature can potentially have both direct and indirect impacts on soil microbial communities. However, the direction and magnitude of these responses are uncertain. For example, the response of soil microbial communities to changes in atmospheric CO_2 concentrations can be positive or negative, and consistent overall trends between sites and studies have not been observed (Janus *et al.*, 2005; Lipson *et al.*, 2005; Lipson *et al.*, 2006; Lesaulnier *et al.*, 2008; Austin *et al.*, 2009). Precipitation and soil moisture changes may increase or decrease the ratio of bacteria to fungi, as well as shift their community composition (Schimel *et al.*, 1999; Chen *et al.*, 2007; Williams, 2007). Increasing temperatures can increase microbial activity, processing, and turnover, causing the microbial community to shift in favor of representatives adapted to higher temperatures and faster growth rates (Zogg *et al.*, 1997; Zak *et al.*, 1999; Pettersson and Bååth, 2003; Zhang *et al.*, 2005; Bradford *et al.*, 2008). Single-factor climate change studies described above have enabled better understanding how microbial communities may respond to any one factor, but how multiple climate change factors interact with each other to influence microbial community responses is poorly understood. For example, elevated atmospheric CO_2 concentration and precipitation changes might increase soil moisture in an ecosystem, but this increase may be counteracted by warming (Dermody *et al.*, 2007).

Assays of extracellular enzymes activity (EEA) have become one of the important tools for assessing microbial responses to climate changes (Weedon *et al.*, 2011). Prolonged drought, high temperature, elevated-CO_2 concentration, *etc.*, are the main actors in climate change and it has been reported that in Mediterranean shrublands, warming and drought have changed some soil enzyme activities related to P turnover in some seasons of a year (Sardans *et al.*, 2006), while in Mediterranean forests, urease, protease, and β-glucosidase activities decreased in spring and autumn in some cases (Sardans and Peñuelas, 2005).

Rhizodeposition consists of a continuous flow of C-containing compounds from roots to soil. Simple molecules such as sugars, amino acids, sugar alcohols, organic acids, and more structurally complex secondary metabolites are among the chemical groups that make up a plethora of root exudates (Bais *et al.*, 2006) that can be rapidly (hours to days) respired following their deposition to soil (Müller *et al.*, 1993). However, polymers (lignin, cellulose, and hemicelluloses) requires extracellular enzymes for depolymerization before they can be taken into the microbial cell and metabolized (Kögel-Knabner, 2002). The decomposition kinetics of these complex molecules is accelerated to a greater extent in anticipated global warming.

This review aims to fill the knowledge gap how soil microbes respond to changing climatic variables, their consequent effects on soil C sequestration, terrestrial C cycle climate feedbacks, and novel techniques like omic technological interventions to determine soil microbial community shifts at taxa level.

MICROBIAL ACTIVITY AND C DYNAMICS

Soil microbial activities are of significant importance in defining the ecosystem properties; understanding how soil microbe-microbe and soil microbe-plant interactions respond to climate change is a rese-