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Material Cycling of Wetland Soils Driven by Freeze–Thaw Effects

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Material Cycling of Wetland Soils Driven by Freeze–Thaw Effects

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Author
Dr. Xiaofei Yu
Northeast Institute of Geography
and Agroecology
Chinese Academy of Sciences
Changchun
People's Republic of China

Supervisor
Prof. Dr. Guoping Wang
Northeast Institute of Geography
and Agroecology
Chinese Academy of Sciences
Changchun
People's Republic of China

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Supervisor's Foreword

Ongoing global warming may cause permafrost thaw to accelerate in high-latitude regions. Meanwhile, thawing permafrost will likely accelerate global warming in the coming decades, driven by increasing greenhouse gases production and emission from soil partially controlled by freeze–thaw cycles. Although freeze–thaw cycles can alter soil physical properties and microbial activity, their overall impact on soil functioning remains unclear. The question of how freeze–thaw events affect soil processes has attracted more and more attention in recent years, especially as climate change scenarios predict that the frequency of such events might increase in many ecosystems in the future.

Wetlands are among the most important ecosystems on Earth as they store more carbon than other terrestrial ecosystems, despite the fact that they cover only approximately 7 % of the total land surface. Peatland is an important type of wetlands and estimates of carbon stored in the global boreal peatlands range from 20 to 35 % of global terrestrial carbon. Many of the world's northern peatlands are underlain by rapidly thawing permafrost. The permafrost prevents soil drainage and thus deprives the oxygen in soil environment, which plays a crucial role in the accumulation and decay of organic matter. Freezing and thawing of soils occur regularly in high latitudes above 45°N as a result of the climatic conditions. Freezing and thawing of soils may affect the turnover of soil organic matter and thus the losses of carbon and nitrogen from soils. Soil freeze–thaw cycles can substantially affect soil carbon and nitrogen cycling, and deserve special consideration for wetlands in the winter-cold zone.

This thesis was written by Dr. Xiaofei Yu, and addresses the freeze–thaw of wetland soils with regard to several aspects: the dynamics of dissolved carbon and nitrogen in wetland soils, overlying ice and water during the freeze–thaw period; the freeze–thaw effects on the sorption/desorption of dissolved organic carbon and NH_4^+, and the mineralization of organic carbon and organic nitrogen; the dynamics of accumulation and release of dissolved carbon and nitrogen in intact wetland soils. Therefore, the freeze–thaw effects on the accumulation and release process of carbon and nitrogen in wetland soils were systematically investigated in the dissertation. It is a good step toward the investigation of wetland biogeochemical process in permafrost and seasonal freeze– thaw areas. It is also developing strategies aimed at global warming effects on the accumulation and release of carbon and nitrogen in wetlands. The studied process might be important in many wetland soils of cold regions. Globally, investigations in terms to cold climate processes are relatively sparse and need more attention.

This thesis also compared the effects of successive events of freezing and thawing the release of nutrients in natural and arable soils in northern China. The documentation of this process is an interesting and important contribution to the understanding of nutrient and release in northern wetlands. The results provide information on the timing of nutrient release related to freezing and thawing in natural versus arable soils, and has implications for the timing of nutrient application in farm fields in relation to water quality protection.

The major value of this work is twofold: it constitutes a useful methodological baseline for accumulation and release of carbon and nitrogen in wetland soils under freeze–thaw conditions, and it presents a novel approach in soil freeze–thaw cycle experiment, which is applicable not only for wetland soils but also for other soils. The thesis has already spawned several journal papers, and opens new perspectives for scientific problems in freeze–thaw processes and soil chemistry, biogeochemistry of wetlands, and global warming.

Changchun, April 2012 Prof. Dr. Guoping Wang

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Chapter 1
Introduction

1.1 Background and Significance of the Research

1.1.1 Research Background

Climate is the main determinant of ecosystem conditions in a region. For many years, research has focused on the effects of climate factors such as water and heat on ecosystems, whereas research on the effects of freeze–thaw on ecosystems is relatively rare. Freeze–thaw is an abiotic stress applied to soils and is a natural process in medium and high latitudes. Freeze–thaw can change soil physical and chemical properties, and therefore affect the circulation and loss of nutrients in soils. In recent years, although some studies have investigated freeze–thaw effects on soil physical and chemical properties, most have focused on agricultural soils or forest soils, while little attention has been paid to the effects of freeze–thaw on carbon and nitrogen accumulation and release in wetland soils.

Freeze–thaw can change the size and stability of soil aggregates. When soils are frozen, disruptive forces affecting aggregates come from the expansion of ice crystals in soil pores. Expansion of these ice crystals breaks particle-to-particle bonds and splits the aggregates into smaller ones. Large particles are broken and the resulting fine particles have a tendency to re-form into medium size particles (Bullock 1988). For aggregates themselves, freeze–thaw applies a more disruptive force to larger than smaller aggregates (Six et al. 2004) and to moist soil aggregates (Oztas and Fayetorbay 2003). The broken aggregates will expose a greater granular surface area, which can provide more habitats for microbes, and more absorption points and opportunities for dissolved carbon and nitrogen. Freeze–thaw will also affect the microbial biomass and microbial community composition in soils. Freeze–thaw can lead to the death of some microbes because the quickly-formed ice crystals in soil in freezing conditions break microbial cell membranes through physical effects (Macleod and Calcott 1976). Soulides and Allison (1961) and Skogland et al. (1988) found that freeze–thaw could reduce the number of bacteria in soils. Autotrophic

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nitrifying bacteria are particularly sensitive to injury, and take a long time to recover from injury (Focht and Verstraete 1977). When the soil is frozen, the intracellular content of soil microbes is released into the soil environment in the process of the killing of microorganisms. The population of soil microorganisms typically declines by 30–50 % (Macleod and Calcott 1976) and large amounts of nutrients are released following microorganism death. The decline in microorganism populations will lead to lower biological activity by the microbial biomass, which will affect the accumulation, release and cycling of carbon and nitrogen. Current studies of freeze–thaw effects on carbon and nitrogen release in soils are mainly focused on freeze–thaw effects on gas release. For forest ecosystems (Skogland et al. 1988), agriculture ecosystems (Prieme and Christensen 2001), peatland ecosystems in the temperate zone (Bubier 2002), tundra ecosystems (Mikan et al. 2002) and alpine grassland ecosystems (Kato et al. 2005), soil respiration is significantly enhanced after a freeze–thaw period. The amounts of released microbially-produced greenhouse gas released annually, in particular N_2O, are largely controlled by the alternation of soil freeze–thaw and soil dry-moist conditions. Therefore, the melting of permafrost can lead to an increase in released N_2O (Christen and Tiedje 1990; Chang and Hao 2001; Prieme and Christensen 2001). However, most of these studies were limited to indoor simulation tests or field observation experiments, and little attention has been paid to gas emission modeling in wetland soils in large-scale freeze–thaw conditions. Gas emission is only one part of carbon and nitrogen accumulation and release, and the processes of adsorption and desorption of dissolved carbon and nitrogen in soils and the mineralization of organic carbon and nitrogen in soils as well as other processes are also very important.

1.1.2 Significance of the Research

This study focused on understanding the mechanisms by which freeze–thaw affects wetland soil carbon and nitrogen accumulation and release, and to explore the far-reaching environmental effects of the response of wetland soil carbon, nitrogen accumulation and release to freeze–thaw. The results should improve our understanding of the mechanism of wetland material cycles in seasonal freeze–thaw areas. They should also help in understanding the effects of global warming and wetland reclamation on wetland carbon and nitrogen accumulation and release.

1.2 Research Progress: A Worldwide Review

1.2.1 The Effect of Freeze–Thaw on Soil Material Circulation

1.2.1.1 The Soil Freeze–Thaw Process

The term "frozen soil" refers in general to ice-containing soil, and to soil with a temperature at or below 0 °C. When the soil temperature is at or below 0 °C, but does not