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Effect of Freeze-Thaw on Water Stability of Aggregates in a Black Soil of Northeast China*[1]

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ABSTRACT

Soil aggregate stability, an important index of the physical characteristics of a soil, can provide a good indication of a soil's erodibility, and deserves special consideration in regions with cold climate. The objective of this study was to study the effect of freeze-thaw on soil water-stable aggregates in the black soil region of Northeast China. Samples of a typical black soil in the region were collected to measure water-stable aggregates after freeze-thaw under different conditions (*i.e.*, initial moisture contents, freeze-thaw cycles and freezing temperatures) by wet-sieving into eight particle size groups (> 10, 10–6, 6–5, 5–3, 3–2, 2–1, 1–0.5, and 0.5–0.25 mm). Freeze-thaw had the most effect on aggregate stability when the samples had an initial moisture content of 400 g kg^{-1}. The water-stable aggregates of the four larger particle size groups (> 5, 5–3, 3–2, and 2–1 mm) reached a peak stability value, but those of the two smaller particle size groups (1–0.5 and 0.5–0.25 mm) reached a minimum value when the soil moisture content was 400 g kg^{-1}. Water-stable aggregates of the four larger particle size groups decreased while those of the two smaller particle size groups increased with the increase of freeze-thaw cycles. As temperatures fell, the water-stable aggregates of the four larger particle size groups decreased while those of the two smaller particle size groups increased.

Key Words: freezing temperature, moisture content, particle size, water-stable aggregates

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INTRODUCTION

Freeze-thaw events often occur in the regions at mid-high latitude and high altitude (Wang *et al.*, 2008). In China, freeze-thaw events are mainly distributed in the Tibetan Plateau and the alpines in the west and northeast regions (Jing *et al.*, 2008). Freezing has been shown to have a significant effect on soil physical properties, microbial activity and microbial community composition (Schadt *et al.*, 2003; Lipson and Schmidt, 2004; Six *et al.*, 2004; Sjursen *et al.*, 2005). Due to its ability to change soil structure, freeze-thaw is an important factor affecting aggregate stability (Wang *et al.*, 2010).

Soil aggregate is an important index of a soil's physical characteristics and indirectly affects crop production as it affects the moisture content, air-void ratio, temperature and mechanical properties of the soil (Letey, 1985). Soil aggregate stability has been shown to provide a good index of soil erodibility (Kay, 2000; Díaz-Zorita *et al.*, 2002). The abundance of water-stable aggregates at the soil surface determines the potential for sheet erosion and crust formation (Shouse *et al.*, 1990). Wischmeier and Smith (1978) emphasized that thawed surface strata overlying frozen strata are highly susceptible to erosion. These strata may produce large amounts of runoff and sediment from snowmelt or low-intensity rainfall. Soil aggregate stability may be affected by soil texture, organic matter, soil moisture content, freezing temperature, freeze-thaw cycles and other factors (Mostaghimi *et al.*, 1988; Oztas and Fayetorbay, 2003).

One of the processes that affect soil aggregate stability is freezing and thawing. Consecutive freeze-thaw cycles in soil may affect aggregation either positively or negatively (Sahin *et al.*, 2008). Lehrsch *et al.* (1991) indicated that the effect of freezing-thawing stress on soil aggregate stability depends on degrees to which the samples are frozen. Attentions have been drawn to the non-uniformity of structural changes induced by frost. For example, by freezing a soil sample, some parts of the sample always become wetter and other parts are dried. In the wetter parts, frost disrupted aggregates due to the expansion of ice crystals in pores which broke the particle-to-particle bonds. In contrast, drying is believed to cause a shrinkage of soil mass and

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precipitation of bonding agents at particle-to-particle contacts. These contrasting processes may act in different parts of the soil sample, resulting in decreased or increased aggregate stability. Therefore, accurate aggregate stability measurements should be based only on the average of these opposing changes. Lehrsch (1998) suggested that the freeze-thaw cycle could increase the soil aggregate stability near the surface. Perfect *et al.* (1990) indicated that there also existed evidence that frost action may actually increase soil aggregate stability. Wang *et al.* (2010) indicated that the seasonal freeze-thaw cycle aggravated the disruption of air-dried aggregates, but strengthened the aggregation of water-stable aggregates and lowered their rate of destruction.

However, the results from other researchers (Mostaghimi *et al.*, 1988; Staricka and Beniot, 1995; van Bochove *et al.*, 2000; Oztas and Fayetorbay, 2003; Kværnø and Øygarden, 2006) differed from those of Lehrsch *et al.* (1991) and Lehrsch (1998). Staricka and Beniot (1995) found that freezing decreased wet aggregate stability in 85 of 96 soil cores. In addition, it was found that freezing may destroy the aggregate stability to a higher degree in macro-aggregates (> 0.25 mm) than in micro-aggregates (van Bochove *et al.*, 2000). Sahin and Anapali (2007) indicated that wet aggregate stability was significantly reduced by the freeze-thaw cycles when the electrical conductivity was high and the percentage exchangeable sodium relatively low; moreover, for aggregate sizes of 1–2 and 2–4 mm, a significant reduction ($P < 0.01$) was found in the wet aggregate stability of the samples that underwent 6 freeze-thaw cycles compared to those that underwent 2 cycles. Also, the degree of destruction of macro-aggregate stability was more noticeable when the moisture content was higher at freezing (van Bochove *et al.*, 2000; Oztas and Faytorbay, 2003).

The processes of freezing and thawing and low temperatures in soil reduce the stability of soil aggregates (Oztas and Fayetorbay, 2003; Kværnø and Øygarden, 2006). In the controlled laboratory conditions, freeze-thaw cycles decreased soil aggregate stability, particularly at high soil moisture, and these effects accumulated over successive freeze-thaw cycles (ranging from 3 to 9 cycles) (Oztas and Fayetorbay, 2003). Edwards (1991) investigated the effect of freezing and thawing on aggregate stability of three kinds of soils (loam, sandy loam and fine sandy loam) in Prince Edward Island, and found that the loam retained many macro-aggregates, with a decrease from an 80% macro-aggregate content to 60% of total mass by the 15th cycle; the macro-aggregate (> 4.75 mm) content of the fine sandy loam decreased from 40% initially to 12% of total mass by the 15th cycle, while the micro-aggregate (< 0.5 mm) content increased from 19% to almost 70% of total mass; the sandy loam, with the least clay but the most organic matter, was intermediate in behaviour. Mostaghimi *et al.* (1988) determined an inverse relationship between soil moisture content at the time of freezing and aggregate stability, and found that the rate of freezing had little or no effect on aggregate stability. The effects of freeze-thaw are more severe for macro-aggregates than for micro-aggregates (Six *et al.*, 2004). Kværnø and Øygarden (2006) showed that there was no evident effect of moisture content on aggregate stability, probably due to experimental limitations.

In general, most studies indicate that freeze-thaw cycles can decrease aggregate stability and destroy aggregates (van Bochove *et al.*, 2000; Oztas and Fayetorbay, 2003), but there is contrary evidence which indicates that freeze-thaw cycles can increase aggregate stability (Lehrsch *et al.*, 1991; Lehrsch, 1998).

Despite the achievements of previous studies on the effects of freeze-thaw on soil aggregate stability, few researchers have studied the effect of freeze-thaw on different particle size aggregates. Therefore, building on the base of former studies, the objective of this research was to study the effects of freeze-thaw processes under different conditions (*i.e.*, initial moisture contents, freeze-thaw cycles and freezing temperatures) on the aggregate stability of black soils, a typical agricultural soil in Northeast China, thereby adding to the research on the effect of freeze-thaw on soil aggregate water stability and also providing a reference to aid in soil improvement and better crop production.

MATERIALS AND METHODS

Soil

This study was carried out using samples collected from typical black soil region of Heilongjiang Province, Northeast China. Black soils are a typical agricultural soil in Northeast China and mainly located in Jilin and Heilongjiang provinces. Black soils belong to Udic Isohumisols according to Chinese Soil Taxonomy (Gong, 1999), corresponding to Mollisols in the US Soil Taxonomy (Soil Survey Staff, 1999), which are defined as a prairie soil and are characterized by both deep and dead colour surface layer.

The black soil region is cold in the winter, is regularly exposed to subzero temperatures and has a mean annual temperature of 3 °C, ranging from −21 to 22 °C (average for 1998–2008). Soil is often frozen in this re-