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EFFECTS OF FREEZE-THAW CYCLES AND INITIAL SOIL WATER CONTENT ON SOIL SHEAR STRESS IN CHINESE MOLLISOL REGION

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西北农林科技大学

硕 士 学 位 论 文

中国东北黑土区冻融循环与
初始土壤含水量对土壤抗剪强度的影响

学 科 专 业	水土保持与荒漠化防治
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2019 届攻读硕士学位研究生（毕业）论文

中国东北黑土区冻融循环与初始土壤含水量对土壤抗剪强度的影响

Myadagbadam BATDORJ

本论文在西北农林科技大学水土保持研究所“黄土高原土壤侵蚀与旱地农业国家重点实验室”和“中美水土保持与环境保护联合研究中心”完成。

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EFFECTS OF FREEZE-THAW CYCLES AND INITIAL SOIL WATER CONTENT ON SOIL SHEAR STRESS IN CHINESE MOLLISOL REGION

Myadagbadam BATDORJ

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ABSTRACT

Seasonal freeze-thaw cycles with different initial soil water contents have great impacts on soil shear strength. During the past decades, there were many studies conducted on the effects of the freeze-thaw cycle on soil anti-erosivity such as soil shear stress in China and in the World. However, the effects of a freeze-thaw cycle on hillslope water erosion mechanism are still weak, especially, there are less information related to the effects of freeze-thaw cycles on soil shear stress in the croplands in Chinese Mollisol region. Thus, this study collects tested soils from Binxian (BX) and Keshan (KS) counties in the Chinese Mollisol region to measure soil shear stress by using a direct shear test. The experimental treatments include five levels of freeze-thaw cycles (0, 1, 3, 5, and 7), three levels of initial soil water contents (16.5%, 24.8%, and 33.0%), and remolded and undisturbed soil samples from KS and BX sites. The main objective of this study is to investigate the influences of freeze-thaw cycles and initial soil water contents on soil shear stress and to compare differences of soil shear stress between remolded and undisturbed soils. The results can reveal the mechanisms of freeze-thaw effects on hillslope water erosion and provide a scientific basis for protecting Chinese Mollisol resources. The main results are as follows:

(1) Soil shear stress, soil cohesion, and soil internal friction angle for both BX and KS tested soils declines with an increase of freeze-thaw cycle and initial soil water content. For BX tested soil, soil shear stress decreased by 8.6% to 9.2% and 13.1 to 18.0% when freeze-thaw shifts from 0 to 7 freeze-thaw cycles under 16.5%, 24.8% and 33.0% of initial soil water contents, respectively. For KS soil, it decreased 15.1%, 18.0% and 13.1%, respectively. In addition, soil shear stress decreased linearly with the increase of initial soil water content. Comparison between 16.5% and 33.0% of initial soil water content of BX soil shear stress showed that declined by 8.4% to 11.3 and for KS tested soil declined by 10.7% to 16.9%. Soil shear stress for the BX tested soils was lower than that for KS tested soils and the differences in soil shear stress between BX and KS soils decrease with an increase of initial soil water content. Soil cohesion decreased with an increase of freeze-thaw cycles for both tested soils, then soil cohesion stabilizes gradually after 5 freeze-thaw cycles. BX soil cohesion decreases by 70.9%, 71.1%, and 65.9%, respectively, under five freeze-thaw cycles with three initial soil water content of 16.5%, 24.8%, and 33.0%, and KS soil cohesion decreases by 56.6%, 61.7%, and 71.9%, respectively. Compared with BX soil with freeze-thaw treatment, soil cohesion for KS soil is 0.8 to 2.2 times higher when freeze-thaw cycles shifts from 1 to 7 times under three initial

soil water contents. Soil internal friction angle showed decreasing or increasing trends with increasing of freeze-thaw cycles and initial soil water content for both tested soils.

(2) Soil shear stress for undisturbed soils at both BX and KS sites is lower than that for remolded soil. Under 24.8% and 33.0% initial soil water content, when freeze-thaw cycles increases from 0 to 5, soil shear stress for BX undisturbed soil decreased by 23.8% to 26.11% and 17.6%-21.3% respectively, compared with remolded soil; and for KS undisturbed soil, soil shear stress decreased by 0.2% to 11.0% and 4.2% to 9.7%, respectively. The main reason for that soil shear stress under remolded soil is larger than that under undisturbed soil is due to remold soil samples for remolded soil.

(3) The initial soil water content and the freeze-thaw cycle are essential factors affecting soil shear stress. When the initial soil water content and freeze-thaw cycles are increased, soil shear stress decreased for both remolded and undisturbed soils. These results proved the effects of the freeze-thaw cycle and initial soil water content on soil shear stress in the Chinese Mollisol region, thus it is important to quantify mechanisms of freeze-thaw cycle influences on hillslope water erosion in the future work.

KEYWORDS: Soil shear stress; Initial soil water content; Freeze-thaw cycle; Direct shear test; Remolded and Undisturbed soil; Chinese Mollisol region

Abbreviation: KS means Keshan; BX means Binxian; F-T means Freeze-thaw cycle; IWC means Initial Water Content; TC means Field capacity.

摘 要

季节性冻融循和不同初始土壤含水量对土壤剪切应力有重要影响，其进而影响坡面水蚀过程；然而目前冻融循环对坡面水蚀过程机理的影响研究还不十分清楚，特别是冻融循环对东北黑土区农地土壤抗侵蚀能力的影响研究还相对薄弱。因此，本研究以黑龙江省黑土区的克山县（KS）和宾县（BX）为研究区，通过设计 5 个冻融循环次数（0、1、3、5 和 7 次）、3 个初始土壤含水量（16.5%、24.8%和 33.0%）和 2 种试验土壤处理（扰动土和原状土）和采用土壤直剪试验，研究了冻融循环次数和土壤初始含水量对土壤剪切应力的影响，研究结果加深了对冻融作用影响坡面土壤侵蚀机理的认识，同时也为黑土区侵蚀防治提供了科学依据。主要研究结论如下：

(2) 土壤剪切应力和土壤粘聚力皆随冻融循环次数和前期土壤含水量的增加而减少。当冻融循环从 0 次增加到 7 次，BX 和 KS 土壤剪切应力分别降低 8.6%~18.0% 和 13.1%~18.0%。当前期土壤含水量分别为 16.5%、24.8%和 33.0%，5 次冻融循环使 BX 土壤粘聚力分别减少 70.9%、71.1% 和 65.9%和 KS 土壤粘聚力分别减少 56.6%、61.7% and 71.9%。同时，两种试验土壤剪切应力随冻融循环次数增加的减少幅度呈逐渐降低趋势，并在 5 次冻融循环后，BX 和 KS 土剪切应力趋于稳定。另外，KS 试验土壤剪切应力是 BX 试验土壤的 0.8-2.2 倍。

(2) BX 和 KS 两种原状土的剪切应力均低于扰动土。在 24.8%和 33.0%初始土壤含水量下，当冻融循环次数从 0 次增加到 5 次时，BX 原状土的剪切应力较原状土分别降低 23.8%~26.1%和 17.6%~21.3%；而 KS 原状土的剪切应力分别降低 0.2%~11.0%和 4.2%~9.7%。扰动土的剪切应力大于原状土的主要原因是扰动土样经过重塑过程，改变了土壤结构。

(3)土壤初始含水量和冻融循环次数是影响土壤剪切应力的重要因素。当初始含水量和冻融循环次数增加时，扰动土和原状土的剪切应力均有所减小。这些结果证实了冻融循环和初始含水量对中国东北黑土区土壤剪切应力的影响。因此量化冻融循环对坡面水蚀的影响机理应是今后需要研究的重点。

关键词：土壤剪切应力；初始土壤含水量；冻融循环；直剪试验；扰动土和原状土；中国东北黑土区

缩写：KS：克山县；BX：宾县；F-T：冻融循环；IWC：前期土壤含水量；TC：土壤田间持水量

CONTENTS

CHAPTER 1 INTRODUCTION

1.1 Background

Land degradation, which results from soil erosion, organic matter, and nutrient losses are of great concern in the world. Furthermore, the moderately and severely water erosion area accounted for 31.4% and 7.9% of the total in China. Erosion rate is 1.24–2.41 mm/year (Liu 2010). Besides, Mollisol is extensively dedicated to cereals, maize, and legume production, and are also consider ass important soil for pasture, range and forage systems, and thus form the world's natural granary. Due to the increasing population in the world, the increasing demand for food security is leading to an intensification of agriculture on Mollisol regions in the world. Moreover, in these seasonally frozen soil regions in the world, freeze-thaw impacts on soil shear strength have received more attention from scholars all over the world (Asare 1997; Guo and Shan 2011; Kværnøand Øygarden 2006), particularly in spring snow melting period, the freeze-thaw cycle occurs daily, which greatly affects soil erodibility. Therefore, it is important to quantify how freeze-thaw impacts on soil anti-erosivity in order to reveal mechanisms of freeze-thaw influences on water erosion and wind erosion.

1.2 Research significances

Soil is affected by freeze-thaw cycles in the Mollisol region of Northeast China, which are subjected to more freeze-thaw cycles each year, especially in the spring snow melting period. Currently, many studies on the effects of freeze-thaw cycles on loess shear strength had been reported; whereas relatively few studies concerned on the effects of seasonal freeze-thaw cycles on the Mollisol shear strength in the Chinese black soil region. The interaction of initial soil water content and freeze-thaw cycles on soil shear strength is still unclear. Therefore, this research is done to investigate the influences of different freeze-thaw cycles and the different initial soil water contents on Mollisol shear stress under the two different kind of soils which are collected from Keshan and Binxian counties. Furthermore, this study also compared remolded and undisturbed soil effects on soil shear stress. The research results will reveal mechanisms of freeze-thaw cycles impacts on soil erosion and provides a scientific basis for controlling soil erosion and protecting Mollisol resources.

1.3 Literature review

1.3.1 The distribution of mollisol

There is approximately 916 million ha of Mollisol in the world, which accounted for 7% of the world's ice-free land surface. They are most extensive in the mid-latitudes of North

America, Eurasia, and Northeast China (Fig.1-1). There are 200 million ha in the United States of America, about 50 million ha of Mexico and more than 40 million ha of Canada lands are comprised of Mollisol whereas in Eurasia it takes up approximately 450 million ha of land, extending from southern Russia in western 148 million ha and 35 million ha in the northeast of China and 34 million ha in Ukraine to the eastern, respectively. They are all comprehensive to South America's which are about 89 million ha of Argentina and 13 million ha of Uruguay land (Liu et al. 2012). In Asia, Mollisol is principally located in Northeast China overlaying Heilongjiang Province, Jilin Province, Liaoning Province, and the Hulunbeier League of the Inner Mongolian Autonomous Region (Fig.1-2). Therefore, the Mollisol total area in China is 124.9×104 km^2 and its 1400 km wide in the north-south axis and 1600 km long in the east-west axis (Liu 2010). Mollisol are usually observed as inherently productive and fertile soils. They are greatly and effectively farmed, and progressively devoted to grains production, which needs significant profit of fertilizers and tillage. Mollisol is also essential soil in grazing, range and forage systems. Consequently, it is not unpredictable such these soils are subjected to soil erosion, humidification (organic matter and loss of stable aggregates). Therefore, soil scientists from the world are concerned about the sustainability of present tendencies in agricultural practices and land use. The average thickness of the topsoil layer was 43.7 cm in 1982, an area with a thickness of the topsoil layer less than 30 cm accounted for 40.9% of the total in 2002 (Liu 2010). Previous studies informed that there are 14.7×104 km^2 of Mollisol in Northeast China that was used for crop cultivation. This accounts for 42.3% of the total continuous cultivable area of 34.8×104 km^2. Although the total area of Mollisol in Heilongjiang Province accounts for 89.36×103 km^2 of China's Mollisol, it has 47.1% of Mollisol under cultivation. Some areas of Mollisol areas were cultivated 200 years ago, most of these soils have been under agricultural production for about 50 years (Liu 2012).

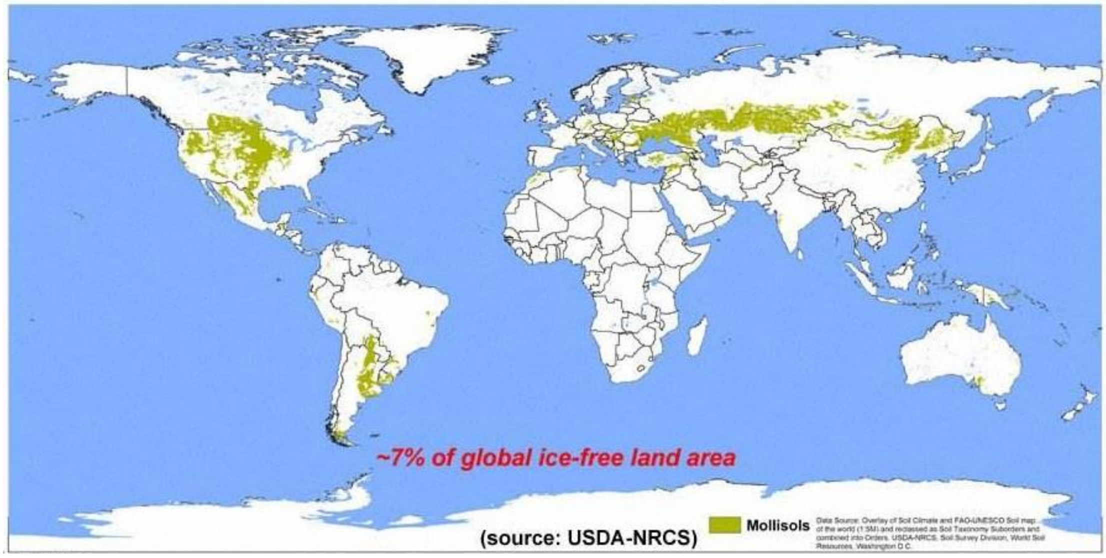


Fig. 1-1 Distribution of Mollisol in the world

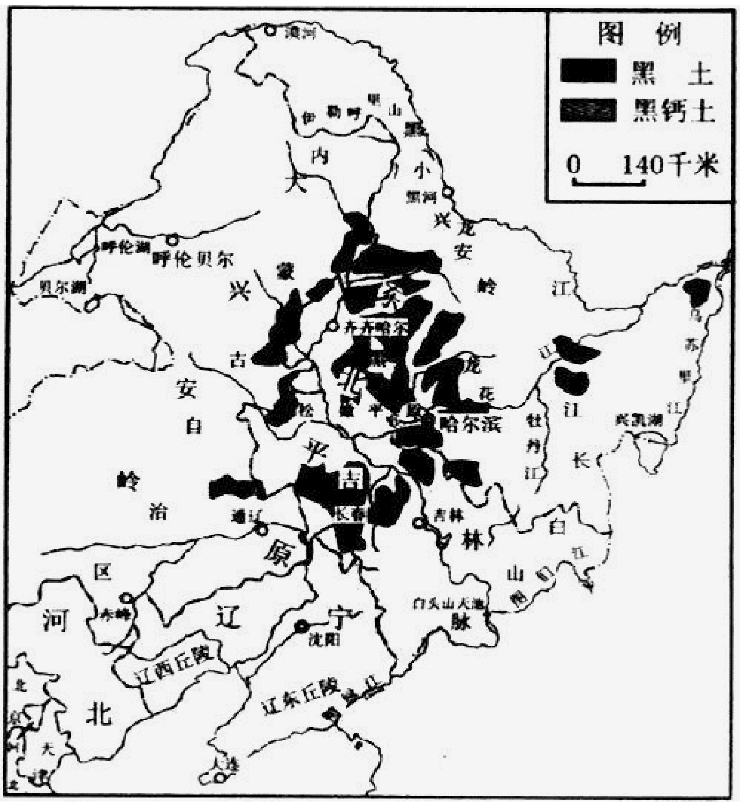


Fig. 1-2 Distribution of Mollisol in northeast China

1.3.2 Freeze-thaw effects

There are about 35,760,000 km^2 of frozen soil in the world, which is 24% of the total world land. There is about 70% frozen soil in Russia, 60% in Alaska, 50% in Canada, 65% in Mongolia, and 22% in China. It is also distributed in other areas, such as Norway, Greenland, the Arctic islands and Antarctic (Gavrilova 1993). In addition, the permafrost area is about 22.3% of Chinese territory, ranking third in the world after Russia and Canada, while the total frozen soil area including seasonally frozen soil accounts for about 70% of the total area. The Northeast Chinese climate is continental monsoon with a cold temperature zone, and the frost-free period spans from 122 to 114 days in Heilongjiang Province (Feng 2018). In Northeast China mean annual precipitation is 300 to 600 mm and the temperature is 2.5 ℃ to 5.68 ℃. The annual temperature is greater than 10 ℃ and the depth of frozen soil is 1.1 to 2.0m.

Mollisol is accumulated and developed in the prairies of cold temperate and freezing conditions. In cold regions, the freeze-thaw cycle is one of the fundamental elements affecting the structure and shear stress of clay soil. The decrease in snowpack in the winter occurs during the heat insulation function of the snowpack, resulting in a decrease in strength, then the soil freeze-thaw cycle process occurs in Northeast of China. Freeze-thaw cycles refer to the freeze and thaw of water within a certain range in soil caused by daily, seasonal, and multi-annual variations of surface temperature in a specific climatic region (Fiench 2007). Thus, the most important factor which affects freeze-thaw is temperature. Even though the air temperature is below freezing, the ground temperature probably does not go below freezing since dirt is a pretty good insulator. If the ground has been frozen solid for a few days, having air temperatures above freezing for a few hours is not enough to thaw the ground. Snow can be a factor in that it has a relationship with the soil temperature. Snow is a great insulator that can either buffer the warmer soil from colder air temperatures or buffer the colder soil temperatures from warmer air temperatures. Such a phenomenon happens mostly in cold regions at high altitudes and latitudes and may occur as surface temperatures fluctuate above and below zero degrees Celsius. During the freeze-thaw cycle, the volume of water expands as it freezes in the soil so that exerting high pressure on the pore walls in soils and rocks hence altering physical and mechanical properties of those soils and rocks (Bing 2009 and Hazirbaba 2010). The freeze-thaw cycle affects soil properties, including soil permeability, hydraulic conductivity, porosity, particle size, water content, volume, soil strength, bulk density and aggregate stability (Xie 2015). Therefore, the effects of the freeze-thaw cycle on soil structures commence from water migration through the soil particles, while the temperature gradient from the positive and negative variations of surface temperature drives this phenomenon.

1.3.3 Effects of freeze-thaw cycle on soil structure

A freeze-thaw cycle is the freezing and thawing of water inside soil pores. As the temperature drops, the initial soil water content in the soil freezes, and water expands as it freezes. This causes the water inside pores to freeze in very frigid temperatures and thaw when temperatures rise a little. When this happens on a soil structure, the composition of the soil is much easy to blow apart by the expansion of the frozen water molecules. Then, as the temperatures rise, the blown up soil compresses and, with water, makes soil structure damaged. This alternate freezing and thawing can crack soil. According to the existing research, freezing cause the development of the ice lens, which produced dispersed packing in the soil particles and separate them from adjacent particles by ice. Therefore, the freeze-thaw cycle directly influences soil mechanical properties and cause a landslide, soil degradation, soil erodibility, and soil aggregates stability and water erosion. Besides, soil phsysical and mechanical properties have changed after freeze-thaw cycle, because it changed the original structure of soil (Xie 2015). In other manner, the relations between soil particles and connecting forces between soil particles are wrecked by freeze-thaw cycles. Related researches proposed that freeze-thaw cycles can impacts soil water content, permeability, compressibility intensity, bulk density, soil porosity, parameters of shear strength, geotechnical properties and so on (Eigenbrod 1996; Guo and Shan 2011; Lacković 2009; Sterpi 2015a; Yaling and Binbin 2014).

The freeze-thaw cycles effects were more significant in the northeast, southwest regions, west and northern region of China. In addition, the quality of the undisturbed soil sample plays an important role in the geotechnical investigation, but it is hard to get undisturbed soil samples. Frozen soil has a great influence on the construction of the road engineering, such as part typical long divisions of Jilin Province over the Changyu highway along which severe lateral deflection occurred due to the winter frost heave and near the shoulder also generated obvious collapse and lateral deformation (Chang 2013). Engineering construction and soil erosion research in these areas must be performed for consideration of the effect of freeze-thaw action on soil mechanical properties. The melting of seasonally frozen soil caused severe frost boiling of the road surface in Baoquanling divisions of the Halo highway in Heilongjiang Province. The concavo-convex fluctuation is as high as 0.5 to 1.0 m, which triggered a serious bus rollover accident (Chen 2016). Furthermore, agricultural tillage equipment and alternating freeze-thaw are two critical factors associated with soil structure change and damage which thus accelerate soil erosion in the Mollisol region Wang (2017) as well as during the last decades, substantial research has been devoted to investigate soil physical and mechanical properties affected by freeze-thaw cycles.

However, the severe effects of freeze-thaw cycles in seasonally frozen areas and related damage drive the need for investigating frozen soil behavior under different freeze-thaw cycles. Many researchers have conducted a great deal of experimental works on the impacts of the change of seasonal temperature on practical engineering in seasonal frost region. Soil shear strength decrease by freeze-thaw cycles attracted the attention of other researchers and problems of how to remove the effects of freeze-thaw cycles on soil behavior arise (Colback and Wiid 1965; Ghosh 2013; Ishikawa and Miura 2011; Kværnø and Øygarden 2006). Consequently, The physical process of freezing affects the soil microstructure and hydraulic conductivity of compacted clays, which have been experimentally investigated by several authors, who also highlighted the importance of relating sensitivity to freezing cycles of other factors, such as the physical properties of the clay (plasticity index, microstructure, water retention, and swelling potential, etc.) and the initial compaction conditions (Sterpi 2015). Furthermore, the freeze-thaw process affects soil mechanical properties, for example, in terms of soil shear strength response, geometric compressibility, and particle crushability (Graham 1985 and Ishikawa 2011).

1.3.4 Effect of initial soil water content on soil shear strength

The initial soil water content is another principal factor affecting soil properties considerably. Soil shear strength decreases with the increase of initial soil water content. The initial soil water content has a major impact on how well the soil will be compacted. In due course, the soil is compacted to its greatest possible dry density. If the soil is wetted further, the extra water replaces some of the soil particles and the dry density reduces as there is less material present (Ghosh 2013). Likewise, the water exerts a controlling influence on most of the soil physical, chemical and mechanical processes that take place in the soil. Water in the soil acts both as a binding agent among the soil particulate materials and as a lubricant, so affecting the strength of the soil and geologic materials (Topp and Ferré 2002).

1.3.5 Measurement of soil shear strength

1.3.5.1 Soil shear stress

Soil shear strength typically depends on basic two shear strength parameters of soils cohesion (c) and soil internal friction angle (φ) which can be determined experimentally. These experimental tests can be performed in field or laboratory based on soil properties and conditions available. In addition, soil shear strength gravity generates stresses (force per unit area) in the ground at different points (Fig.1-3). Currently, a direct shear stress test is still applied to measure soil shear stress. The stress on a plane at a given point is viewed in terms of two components: 1) Normal stress: which acts normal to the plane and tends to compress soil grains towards each other which cause volume change of soil; 2) Shear stress: these forces acts tangential to the plane and tends to slide grains relative to each other (distortion and ultimately sliding failure).

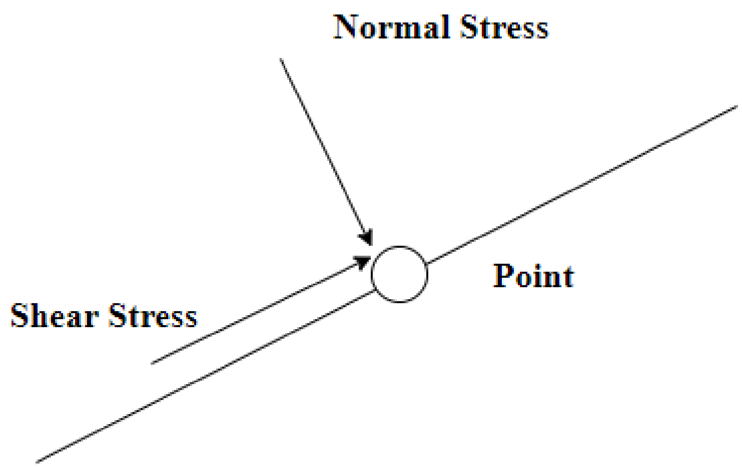


Fig. 1-3 Stress types in soil

The soil shear strength is the resistance to deformation by continuous shear displacement of soil particles or upon the action of tangential shear stress. The soil shear strength is mainly derived from the following forces: 1) The structural resistance to displacement of the soil because of the interlocking of the soil particles; 2) The frictional resistance to the translocation between the individual soil particles at their contact points, and Cohesion or adhesion between the surfaces of the soil particles. These two parameters, define the soil maximum ability to resist shear stress under a defined load. Cohesion mobilizes at the beginning of stress conditions and extends to maximum values around the plastic limit, i.e. at the start of the structural collapse. Cohesion increases towards the shrinkage limit and decreases as water content heading towards the liquid limit. Normally cohesion does not increase with an increase of stress, but it is different for clay soil, where the increase in stress causes an increase in molecular binds. Internal friction is defined as the resistance of two planes moving against each other and can be measured by their grading. Internal friction increases with an increase in normal load provided that the soil specimen is allowed to consolidate.In addition, soil shear stress which acts parallel to the surface of the soil mass and result in to slip or slide that soil mass from the rest of the soil mass.

Soil shear stress depends on friction, cohesion, type of soil along with normal stress (Czurda and Hohmann 1997). Furthermore, soil shear stress effects dynamic properties and index for soil erodibility, and water erosion (Besalatpour 2012). In addition, initial soil water content, soil compaction, and freeze-thaw cycle factors are effecting on soil shear stress, as well as these factors affect the bilinear trends of shear force versus horizontal displacement soil profile and vertical displacement curves to increase constantly (Manuwa 2012).

1.3.5.2 Laboratory Measurement of Soil Shear Strength

The most common laboratory tests to determine the shear strength parameters are the direct shear test and triaxial compression test, which are the most suitable sandy soil where drained strength parameters are needed. Other laboratory tests include, direct simple shear test, torsional ring shear test, plane strain triaxial test, laboratory vane shear test, laboratory fall cone test, and these tests are most suitable for clay soil. In this study, the direct shear stress test is conducted under four different vertical pressures which are 50, 100, 150 and 200kPa with two kinds of soils.

1.3.5.3 Field Measurement of Soil Shear Strength

Soil shear strength is a property expected to affect the efficiency of cultivation implements. Laboratory methods of measuring soil shear stress have been found to be inappropriate for cultivated top soils, generally because of the difficulty to collect an undisturbed sample. Field methods of determining shear strength are observed to be more appropriate for such kinds of soils. In the field method, Standard Penetration Test (SPT) is the most common and main source to find strength information for sand. Field Vane Shear Test is used for soft clays. Some other commonly used field test includes the Cone Penetration Test (CPT), Pressure meter, Flat dilatometer, and Iowa Borehole Shear Test.

CHAPTER 2 RESEARCH CONTENTS AND METHODS

2.1 Objectives

The freeze-thaw cycle and the initial soil water content are very important factors affecting soil shear stress. Thus, the objectives of this study are to investigate how the freeze-thaw cycle and initial soil water content effects soil shear stress in KS and BX counties by using direct shear tests in a laboratory. In addition, the comparison of soil shear stress between remolded and undisturbed soil is also discussed. The results of the study can help to understand soil erosion mechanisms in the freeze-thaw area and provide scientific support for controlling soil erosion.

2.2 Research contents

2.2.1 Effects of freeze-thaw cycles on soil shear stress

Freeze-thaw cycles disturb the original structure of Mollisol soil in northeast China especially during the snow melting period, which causes many changes in soil physical and mechanical properties such as soil shear stress (Chen et al. 2016). Thus, the direct shear test under four different vertical pressures which are 50,100,150 and 200 kPa is used to quantify the effects of freeze-thaw cycles on soil shear stress. The test was conducted for five different levels of freeze-thaw cycles (0, 1, 3, 5 and 7) and two tested soils (Keshan-KS, Binxian-BX). Each treatment has at last three replications.

2.2.2 Effects of initial soil water content on soil shear stress

Initial soil water content extremely impacts soil shear strength, especially if the soil contains high clay materials (Bláhová et al., 2013). Thus, the direct shear test under four different vertical pressures 50,100,150 and 200 kPa is used to investigate effect of initial soil water content on soil shear stress and the treatments includes three different levels of initial soil water contents (50% TC, 75% TC and 100% TC) for both tested soils (KS and BX). Each treatment has at last three replications. The 50% TC, 75%TC and 100% TC corresponds to 16.5%, 24.8% and 33.0% initial soil water content, respectively.

2.2.3 Comparison of soil shear stress between remolded and undisturbed soils

Conservation tillage has pronounced advantages over conventional tillage in conserving soil, preventing soil erosion, promoting carbon sequestration and other benefits to the environment (Samarajeewa et al. 2005). Compared with other conservation tillage methods, no-tillage leads to the least disturbance of soil and the most residue cover, which is greatly beneficial to soil properties as well as air and water quality (Yang 2004). However, it has frequently been observed that no-tillage reduced crop production on fine-textured and poorly drained soils compared with moldboard plow or other traditional tillage systems (Lopez-Fando 2005). Several studies on these soil types found that no-tillage cropland has lower soil temperature and higher soil moisture, which delayed crop planting, germination or plant growth and decreased crop production(Graven 1991; Vyn 1993). In addition, remolded and undisturbed soil activities greatly affect the freeze-thaw cycle and soil texture. Accordingly, the direct shear test under four different vertical pressure 50,100,150 and 200 kPa is applied to compare soil shear stress of remolded and undisturbed soil.

2.3 Research methods

2.3.1 Study area

Keshan County which belongs to the Qiqihar City of Heilongjiang Province, the western part of Heilongjiang Province (126°04'59 E, 48°08′27″ N). It is located in the transition zone between mountains and plains. Its terrain is quite undulating, showing the situation of low terrain in the southeast and high terrain in the northeast. Keshan County fall in the eastern part of the Eurasian Continent. Affected by longitude and latitude, it belongs to the cold temperate continental monsoon climate. The annual average temperature is 2.4 ˚C. The frost lasts for a long time, the longest in 274 days, the shortest in 220 days, and the average frost in 242 days. The annual precipitation is concentrated in June to August in Keshan County (Feng et al. 2018). The average annual precipitation is about 500 mm. The total precipitation accounts for about 67.4% of the total precipitation in the whole year. Due to the influence of Mongolian low pressure, what gale weather is there from the beginning of April to the beginning of June and the end of September every year, and the maximum wind force sometimes reaches level 8 (Feng 2018). The wind is smaller in July, August, and December to February of the next year.

The second study area is located in Binzhou River Basin of Binxian County (BX), Heilongjiang Province with longitude and latitude of (127°25'36 E, 45°45'22″ N), which belongs to the typical thin black soil area. The Binzhou River Basin is located at the eastern edge of the Songnen Plain. The overall topography of Binxian County is high in the southeast and inclined to the Northwest with an average elevation of about 450 m. The slope ranges between 1 °~8 °and the slope length range is 400~1000 m. The climate type of area belongs to the cold temperate continental monsoon climate. The annual average temperature is 4.4˚C with an average annual rainfall of 570 mm. The distribution of rainfall in Binxian is uneven in June to August, accounting for 64% of the annual rainfall. Frost free period is about 146 days annually. The soil in the study area is mainly black soil, followed by dark brown soil, white pulp soil, meadow soil and so on (Feng 2018).

2.3.2 Experimental design

Two kinds of test soil Binxian (BX) and Keshan (KS) were used in this study. The experiment includes three different parameters, which are initial soil water content, freeze-thaw cycle, and remolded and undisturbed soils. The initial soil water contents are represented to 50% field capacity (16.5% of initial soil water content), 75% field capacity (24.8% of initial soil water content), and 100% field capacity represent (33% of initial soil water content) respectively. Freeze-thaw cycles have five different times (0, 1, 3, 5 and 7); and soil shear stress under four different vertical pressures (50, 100, 150 and 200kPa). Each treatment has at least 3 replications for remolded and undisturbed soil samples (Table 2-1). In addition, soil properties are also analyzed (Table 2-2). According to the experimental design, the tests are selected randomly to control the standard deviation and coefficient of variation. There were totally 180 soil samples and 45 treatments.

A direct shear stress test is conducted according to Geotechnical Test Rules (SDS01-79) issued by The Ministry of Water Conservancy and Beijing Water Conservancy Press, 1980, PRC. The purpose of the direct shear soil test is to obtain its ultimate shear resistance, its internal friction angle, its cohesion, and its shear stress deformation characteristics. The direct shear test method is used to estimating the shear strength parameters (internal friction angle and cohesion) of a soil sample.

Table. 2-1 The list of total experimental design

Factors	Levels
Initial soil water content (%)	3 (16.5, 24.8, 33.0)
Freeze-thaw cycle (times)	5 (0, 1, 3, 5, 7)
Vertical pressures (kPa)	4 (50, 100, 150, 200)
Soil structure	2 (Remolded, Undisturbed)
Soil site	2 (KS, BX)

Table 2-2 Soil properties of the tested samples.

Sampling sites	Soil particle composition (%)			Soil organic matter content (g kg^{-1})	Soil bulk density (g cm^{-3})
	Silt (0.002-0.05 mm)	Sand (0.05-2 mm)	Clay (<0.002 mm)		
BX	61.3	9.3	29.4	20.2	1.20
KS	48.7	10.7	40.6	37.0	1.20

2.3.3 Direct shear test

Direct shear test equipment consists of the following: 1) Shear box with 6.18 cm diameter and 50 cm deep (Fig.2-1 a); 2) A direct shear apparatus reaction from load ring; 3) Vertical pressures (50, 100, 150 and 200 kPa); 4) Two porous stones; 5) Top perforated plate in the shear box; 6) Loading cap with a steel ball on its top; 7) Loading frame, which distributes the load from the yoke over the specimen normal to the shear plane; 8) Loading ring with dial gauge accurate to 0.002 mm to measure the shear force; 9) Micrometer dial gauge to measure horizontally and vertically displacement during shear; 10) Liner low friction bearing; and 11) Carriage.

(a) (b) (c)

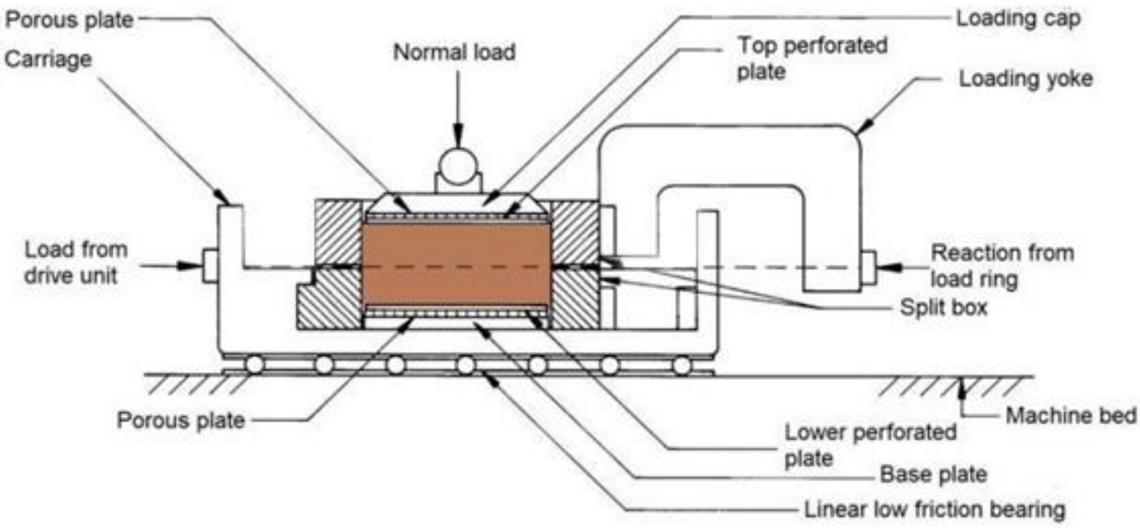


Fig.2-1 A typical setup for a direct shear test

2.3.4 Soil sampling processes

Soil direct shear test was conducted in the State Key Laboratory of Soil Erosion and Dryland Agriculture in the Loess Plateau. The laboratory testing sequences were designed to determine the influences of freeze-thaw cycles and initial soil water content on soil shear stress. The experimental procedures include 1) sample preparation process; 2) soil shear sample preparation process, and 3) direct shear test. A summary of the laboratory procedures for measuring remolded soil shear stress are presented in the following:

(1) Sample preparation process: The soil samples were collected from topsoil (0-20 cm) in the maize field in KS and BX countries, Heilongjiang province of China and put in the plastic

bags and then brought back to the laboratory. Afterward, all samples are air-dried and then impurities such as crop straw and roots were removed. Later on, soil samples are sieved through 2 mm mesh.

(2) Soil shear sample preparation process: a) Soil water content of tested samples is measured to adjust designed target soil water content (16.5%, 24.8%, and 33.0%); 2) According to a volume of an aluminum box with 22.3 cm long, 13.2 cm wide and 6.5 cm deep) and soil bulk density (1.20 g/cm^3), tested soil sample were weighted to determine how much soil is need to pack in the aluminum box; c) The aluminum box was packed with tested soil sample by three layers (2.2 and 1.5 cm) separately, in order to form uniform boundary conditions for all tested samples; d) According to designed initial soil water content (16.5%, 24.8%, and 33.0%), additional deionized water (DI) is added into the aluminum box with packing soils to adjust that soil water content reaches to target soil water content by slow spraying water; then immediately the aluminum box with filling soils was covered by film to eliminate water loss; e) The aluminum box with film cover was placed at overnight (8-12 hr) in order that soil water in the whole box reaches to equilibrium; f) The aluminum box with film cover was placed into the refrigerator at -15 ℃ for 6 to 8 hour to ensure that the whole soil layer is completely frozen; g) After completely frozen, the aluminum box was carefully removed to constant room at 8 ℃ for 6 to 8 hour to make sure that the whole soil layer is completely melted. Finally, 1-time freeze-thaw cycle was completed. For 3-time freeze-thaw cycles, the above f and g steps were repeated for 3 times; for 5-time freeze-thaw cycles and 7-time freeze-thaw cycles, the above f and g steps were repeated for 5 and 7 times, respectively.

(3) Direct shear test. a) For each aluminum box with filling soils after completing required freeze-thaw cycles, fours samples for test soil shear stress were cut by the ring knife with 6.18 cm diameter and 2 cm deep within 3-5 minutes ; b) Cutting sample was then slowly placed into shear box of direct shear device; c) all parts of direct shear device were put right position then dial gauge is adjusted to zero; d) Soil shear stress measurement start under two groups of vertical pressures (50 and 100 kPa; 150 and 200 kPa,) respectively.

For undisturbed soil samples process was the same as the remolded soil samples except that soil sample preparation process. For undisturbed soil sample preparation, 120 ring knifes with 6.18 cm diameter and 2 cm deep were used to collect soil samples from topsoil (0-20 cm) in the maize field in Keshan and Binxian countries, Heilongjiang province of China and all samples were brought back to laboratory in order that all samples keep their original structure. With 120 ring knifes soils were randomly divided into two groups, one group with 10 ring knifes is used to measure soil water content, other group with 110 knifes is used to measure soil shear stress.

2.3.5 Technical route

This study investigates the influence of the freeze-thaw cycle and initial soil water content on Mollisol shear stress. Firstly, the literature review is written according to the content of the study. After that, tested soils were collected from Binxian and Keshan counties, Heilongjiang Province in Northeast of China. Remolded and undisturbed soil samples were collected from two soil sites. Experimental design includes three parameters, i.e., freeze-thaw cycles with five different times (0, 1, 3, 5 and 7), three different initial soil water contents (16.5%, 24.8%, and 33.0%) and remolded and undisturbed soils. Afterward, direct shear tests were conducted in the laboratory, and data analysis were performed after obtaining the basic data. The Technical route is showed in (Fig. 2-2).

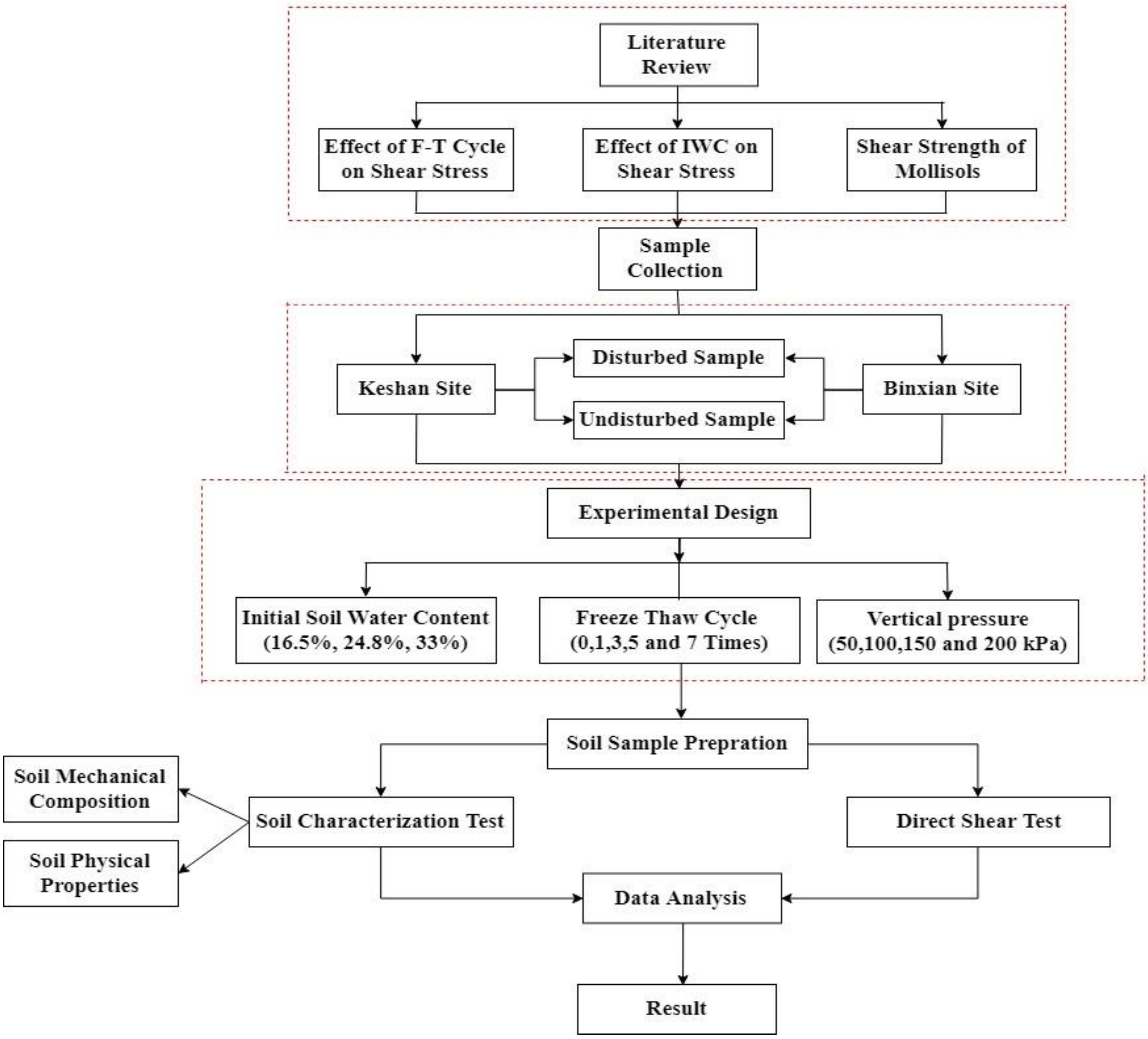


Fig. 2-2 Technical route

2.4 Data analysis and calculating method

2.4.1 Data analysis

The soil shear under four vertical pressures was measured by weighted average to represents soil shear stress. Excel 2016 and SPSS 22.0 software were used for statistical analysis and mapping. Difference testing and one way ANOVA between indicators were performed using the LSD method and two-sided test analysis.

2.4.2 Calculating method

The laboratory tests were cohesion instead of field tests so that identical soil samples can be prepared. DSJ-3 electric strain-controlled direct shear apparatus produced by Nanjing Ningxia Soil Instrument Factory was used for soil direct shear test. The tested soil samples after different treatments were pressed into the shear box. The initial positions of the measuring force ring and the percentile meter were adjusted. The shear velocities were set to be 0.8 mm/min. The shear rates were 50, 100, 150 and 200 kPa, respectively. After running the instrument, the time was recorded by the stopwatch after the percentile pointer begins to change. At the same time, the percentile reading was observed and the percentile meter in the percentile force ring was set. The pointer was no longer moving forward or backward, then the percentile reading and time were recorded. When the soil sample deformation exceeds 4 mm, the shear was determined. If the percentile reading does not appear peak value, the deformation of the soil sample reaches 6 mm, which was considered to have been sheared. The shear stress of the specimen was calculated according to the formula:

$$\tau = 10CR / A \qquad (2\text{-}1)$$

Where: τ is the soil shear stress (kPa), R is the reading of the force ring meter (0.01 mm), C is the correction coefficient of the force ring (6 N/0.01 mm), A is the stress area of the sample (cm^2).

2.4.2.1 Mohr-Coulomb’s law principle

According to Mohr-Coulomb's law, the shear strength parameter, cohesive force c and the soil internal friction angle φ were obtained by the formula:

$$\tau = c + \sigma \tan \varphi \qquad (2\text{-}2)$$

Where: τ is a horizontal shear force (kPa) φ is a soil internal friction angle (º); σ is vertical pressure (kPa) C is a cohesive force (kPa).

The test was carried out under lateral conditions, that was, the lateral deformation of the soil is not allowed; the shear plane is an artificial horizontal plane, not necessarily a true shear failure surface.

2.4.2.2 Calculation of soil shear stress

Since each group of specimens was tested under four different vertical pressures (50, 100, 150 and 200 kPa), the shear stress of soil under different vertical pressures was weighted and the weighted average shear stress was obtained in the following:

$$\tau = \frac{\sum_{i}^{4} \tau_i \sigma_i}{\sum_{i=1}^{4} \sigma_i} \tag{2-3}$$

where, τ is the soil shear stress (kPa), σ is the vertical pressure (kPa)

CHAPTER 3 EFFECTS OF FREEZE-THAW CYCLES ON SOIL SHEAR STRESS

3.1 Introduction

The freeze-thaw cycle is a common external factor affecting soil physical and mechanical properties of the Chinse Mollisol region (Liu 2016). Multiple freeze-thaw cycles cause irreversible alterations in some physical characteristics and further change soil physical and mechanical characteristics, then intensify soil erosion. Currently, the effects of the freeze-thaw cycle on soil strength in the Chinse Mollisol region are still not understood well. Thus, the direct shear test under four different vertical pressure 50,100,150 and 200 kPa is used to quantify the effects of freeze-thaw cycles on Mollisol shear stress.

3.2 Material and method

The test soil is collected from croplands in Keshan and Binxian countries, Heilongjiang province. The device used in this study is the DSJ-3 electric strain-controlled direct shear apparatus produced by Nanjing Ningxia Soil Instrument Factory. The experiment treatments include three levels of initial soil water contents (16.5%, 24.8%, and 33.0%), five different levels of freeze-thaw cycles (0, 1, 3, 5 and 7) and two kinds of tested soils (Keshan-KS, Binxian-BX). The experimental procedures include 1) sample preparation process, 2) soil shear sample preparation process, and 3) direct shear test (Fig. 2-1). The more detailed description is seen in Chapter 2. Each treatment has at last three replications (Table 3-1).

(a) **(b)** **(c)**

Fig.3-1: A Direct shear test equipment and procedure: (a) Freeze-thaw cycle (F-T) (b) Preparation of soil sample, (c) The soil after the shear test.

Table 3-1 The experimental design of freeze-thaw and initial soil water content

Tested Soil	Initial soil water content (%)	Freezing and thawing cycle (%)	Replication
BX	16.5	0	3
BX	16.5	1	3
BX	16.5	3	3
BX	16.5	5	3
BX	16.5	7	3
BX	24.8	0	3
BX	24.8	1	3
BX	24.8	3	3
BX	24.8	5	3
BX	24.8	7	3
BX	33.0	0	3
BX	33.0	1	3
BX	33.0	3	3
BX	33.0	5	3
BX	33.0	7	3
KS	16.5	0	3
KS	16.5	1	3
KS	16.5	3	3
KS	16.5	5	3
KS	16.5	7	3
KS	24.8	0	3
KS	24.8	1	3
KS	24.8	3	3
KS	24.8	5	3
KS	24.8	7	3
KS	33.0	0	3
KS	33.0	1	3
KS	33.0	3	3
KS	33.0	5	3
KS	33.0	7	3

3.3 Results and discussion

3.3.1 Effects of freeze-thaw cycle and initial soil water content to soil shear stress

Fig.3-1a showed the variation of soil shear stress with a freeze-thaw cycle under the different initial soil water contents for BX soil. Soil shear stress ranged from 82.58 kPa to 102.62 kPa at different freeze-thaw cycles with three initial soil water content in BX site (Table 3-2a). Moreover, soil shear stress decreases significantly with the increase of freeze-thaw cycles ($p<0.05$).Compared with non-freeze-thaw tested soils, when the freeze-thaw cycles increased from 1 to 7 times, soil shear stress decreased by 13.2%, 8.6%, and 9.2%, respectively, under 16.5%, 24.8% and 33.0% of initial soil water contents. Additionally, soil shear stress decreased gradually with the increase of initial soil water content. Compared with 16.5% of initial soil water content, soil shear stress under 24.8% and 33% initial soil water content declined by 8.4% and 11.3% respectively, when freeze-thaw cycles changed from 0 to 7 times.

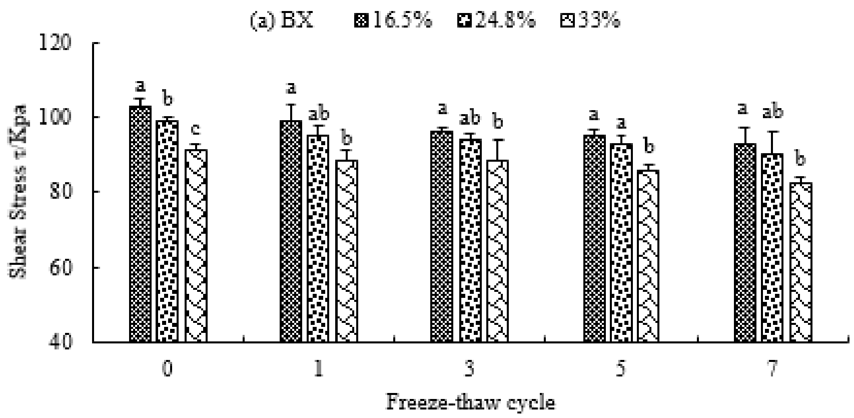
For KS tested soils, there is the same trend as BX tested soils. Soil shear stress ranged from 81.21 kPa to 112.41 kPa at different freeze-thaw cycles with three initial soil water content (Table 3-2b). Moreover, soil shear stress decreases significantly with the increase of freeze-thaw cycles, under same initial soil water contents ($P<0.05$). Under three initial soil water contents, soil shear stress for non freeze-thaw treatment was higher than all freeze-thaw treatments. Compared with non-freeze-thaw tested soils, when the freeze-thaw cycles increased from 1 to 7 times, soil shear stress decreased 15.1%, 18.0% and 13.1% under 16.5%, 24.8% and 33.0% of initial soil water contents. Additionally, soil shear strength decreased linearly with the increase of initial water content. Compared with 16.5% of initial soil water content, soil shear stress under 24.8% and 33% initial soil water content declined by 10.7% and 16.9% respectively, when freeze-thaw cycles changed from 0 to 7 times.

Table 3-2 Soil shear stress, soil cohesion and internal friction angle for both testes soils under different freeze-thaw cycles with three initial soil water contents

Initial soil water content (%)	Freeze-Thaw cycles (time)	Tested soils					
		KS			BX		
		Soil shear stress(kPa)	Cohesion (kPa)	Soil internal friction angle(°)	Soil shear stress (kPa)	Cohesion (kPa)	Soil internal friction angle(°)
16.5	0	112.41	23.05	33.61	102.62	18.56	28.73
	1	103.31	14.51	30.94	98.98	12.89	28.19
	3	97.64	10.54	31.59	96.36	11.68	31.71
	5	96.57	7.22	35.81	95.2	9.97	36.37
	7	95.47	6.7	32.07	93.1	8.05	30.54
24.8	0	106.85	19.59	22.9	98.77	16.24	28.27
	1	94.71	14.18	23.02	95.02	12.03	28.32
	3	92.27	10.31	27.35	93.92	10.02	28.77
	5	90.26	7.17	26.97	92.58	8.32	27.49
	7	87.64	5.67	24.06	90.25	6.22	26.8
33	0	93.41	16.15	21.49	90.93	8.59	28.29
	1	89.9	13.06	24.4	88.56	8.27	27.19
	3	87.12	9.19	25.22	88.25	7.36	26.37
	5	85.06	7.07	24.33	85.88	6.19	24.92

Continue of Table 3-2 Soil shear stress, soil cohesion and internal friction angle for both testes soils under different freeze-thaw cycles with three initial soil water contents

Initial soil water content（%）	Freeze-Thaw cycle (time)	Tested soils					
		KS			BX		
		Soil shear stress(kPa)	Cohesion (kPa)	Soil internal friction angle(°)	Soil shear stress (kPa)	Cohesion (kPa)	Soil internal friction angle(°)
	7	81.21	2.41	24.60	82.58	5.50	27.36



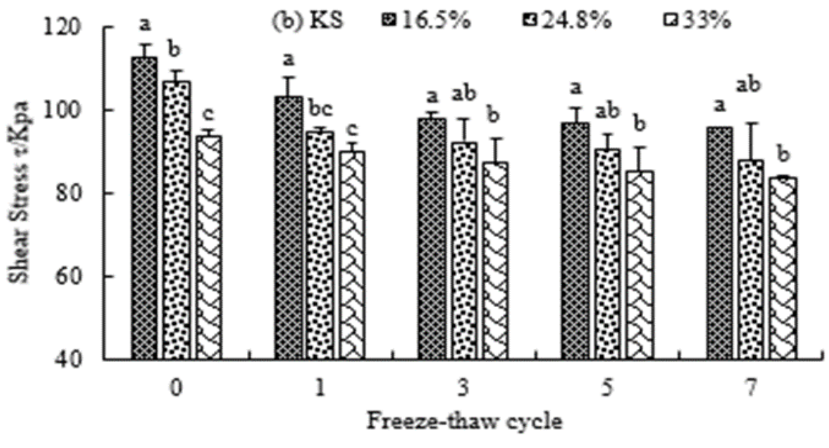


Fig. 3-2 Comparisons of shear stress of two soils under different freeze-thaw cycles (Note: The same letter indicates that there is no significant difference in shear stress under different freeze-thaw cycles (P > 0.05).

Soil shear stress decreased with the increase of freeze-thaw cycles, this trend was similar to both testes soils at BX and KS site. Nevertheless, soil shear stress for the BX tested soils was lower than that for KS tested soils. Compared with BX tested soils, KS soil shear stress under non freeze-thaw treatments increased by 9.5%, 8.2% and 2.7% when initial soil water content changes from 16.5% to 24.8% and 33.0%, indicating that the differences of soil shear stress between BX and KS soils decrease with an increase of initial soil water content. For freeze-thaw treatments, the differences in soil shear stress between BX and KS soils also decrease with an increase of initial soil water content and freeze-thaw cycles.

3.3.2 Effects of freeze-thaw cycle and initial soil water content on soil cohesion

Soil cohesion is an important indicator reflecting the soil shear strength. Fig.3-3 showed that soil cohesion changes from 23.05 kPa to 5.5 kPa and 18.56 kPa to 2.41kPa for BX and KS tested soils as the freeze-thaw cycles increased from 0 to 7 times, respectively (Table 3-2). Soil cohesion mostly decreased with the increase of freeze-thaw cycles for both tested soils, then soil cohesion stabilizes gradually after 5 freeze-thaw cycles.

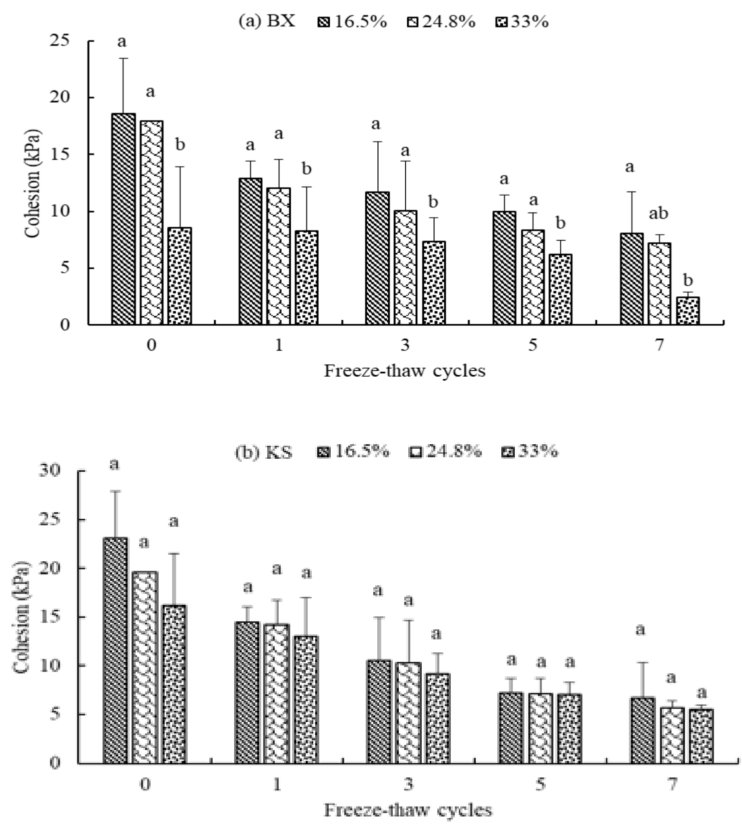


Fig.3-3 Comparisons of cohesion of two soils under different freeze-thaw cycles and initial soil water content (Note: The same letter indicates that there is no significant difference in cohesion angle under

different freeze-thaw cycles ($P>0.05$)

For the BX tested soil, soil cohesion ranged from 23.05 to 6.70 kPa, 19.59 to 5.67 kPa and from 15.15 to 5.50 kPa, respectively, under five freeze-thaw cycles with three initial soil water content of 16.5%, 24.8%, and 33.0% and it decreases by 70.9%, 71.1%, and 65.9%, respectively, indicating that the freeze-thaw cycle has great impacts on soil cohesion (Table 3-2).Thus, the BX soil cohesion decreases by 53.2%, 47.4 and 45.2%, respectively, when the freeze-thaw cycle increases from 0 to 3 times at three levels of initial soil water contents.

For the KS soils, soil cohesion ranged from 18.56 to 8.05 kPa, 16.24 to 6.22 kPa and from 8.59 to 2.41 kPa, respectively, under five freeze-thaw cycles with three initial soil water content of 16.5%, 24.8%, and 33.0% and it decreases by 56.6%, 61.7%, and 71.9%, respectively, showing that the freeze-thaw cycle also has great impacts on soil cohesion. Thus, the KS soil cohesion decreases 37.1%, 38.3% and 14.1%, respectively, when the freeze-thaw cycle increase from 0 to 3 at three level of initial soil water contents.

Compared with BX soil without freeze-thaw treatment, KS soil cohesion is 1.2 to 1.8 times higher under 16.5%, 24.8% and 33.0% of initial soil water contents. Meanwhile, compared with BX soil with freeze-thaw treatment, soil cohesion for KS soil is 0.8 to 2.2 times higher when freeze-thaw cycles shifts from 1 to 7 times under three different initial soil water contents.

3.3.3 Effects of freeze-thaw cycle and initial soil water content on soil internal friction angle

Soil internal friction angle is one of the important indicator reflecting shear strength of the soil. Fig. 3-4 and Table 3-2 showed the soil internal friction angle under different initial soil water contents and freeze-thaw cycles. It is seen that the soil internal friction angle showed decreasing or increasing trends with increasing of freeze-thaw cycles and initial soil water content. Compared with non-freeze-thaw treatment, under 16.5% of initial soil water content, soil internal friction angle for BX soil decreased by 4.6% after soil samples experience seven freeze-thaw cycles, while for KS it increased by 6.3%. Under for 24.8% and 33.0% of initial soil water content, soil internal friction angle for BX soil increased by 5.1% and 27.3% respectively, after soil samples experience seven freeze-thaw cycles, while for KS soil it decreased by 5.2% and 13.0%, respectively.

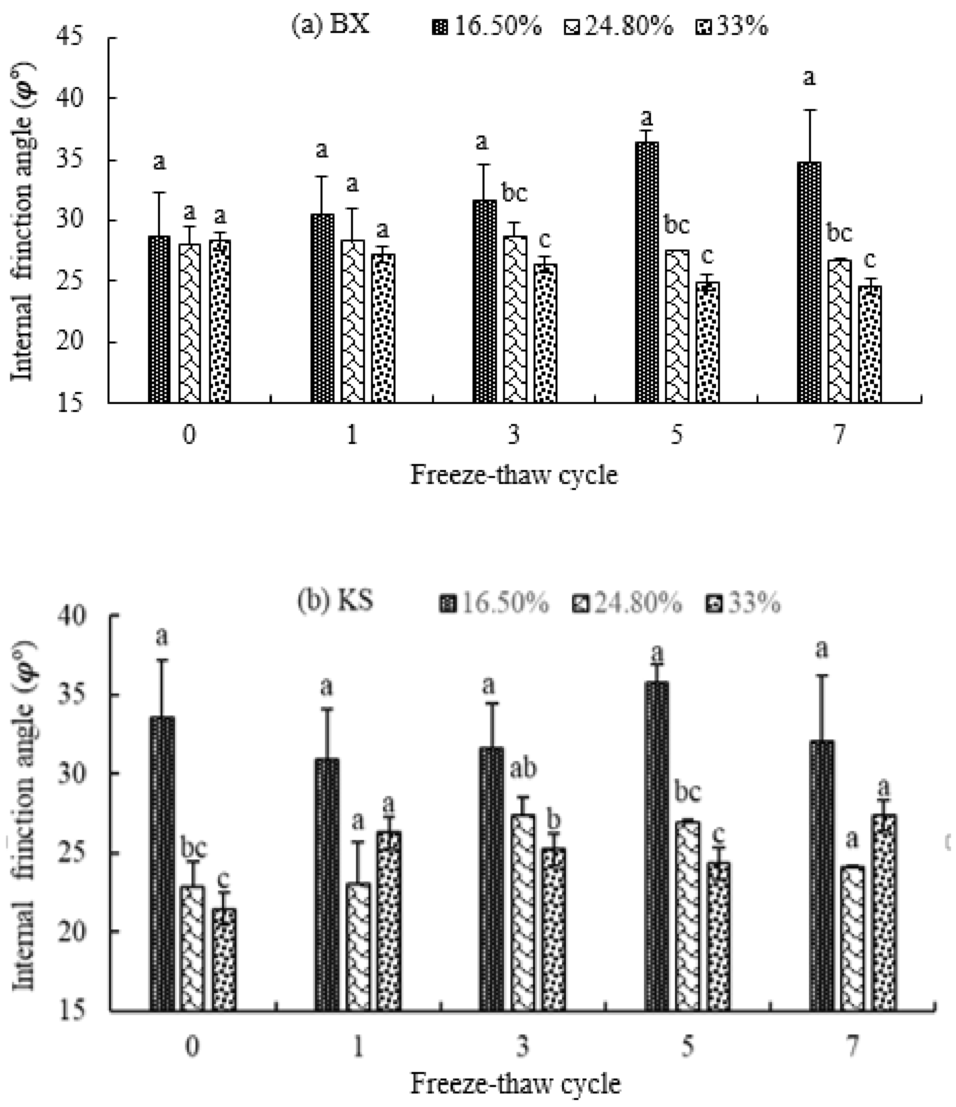


Fig. 3-4 Comparisons of soil internal friction angle of two soils under different freeze-thaw cycles and initial soil water content (Note: The same letter indicates that there is no significant difference in soil internal friction angle under different freeze-thaw cycles (P>0.05)

The effects of the freeze-thaw cycle and initial soil water content on soil shear stress, soil cohesion, and soil internal friction angle are the responses of soil characteristics. In essence, during the processes of freeze-thaw cycles with different initial soil water contents, soil structure is a development from an unstable state to a steady state (Lee 1995). During the initial 5 freeze-thaw cycles, volume strain and porosity of the tested sample increased significantly, causing soil particle gaps and altered arrangement. With the increase in a number of freeze-thaw cycles (0 to 7 times), the uniaxial compression strength of the tested sample tended to become stable due to the stabilizing of the volume strain and porosity.

After 5 freeze-thaw cycles, soil cohesion decreases slowly as the number of freeze-thaw cycles increases. The main cause of soil cohesion weakening is particle structure rearrangement in the soil samples during the freeze-thaw process. Previous studies conclude and agreed that with increasing numbers of freeze-thaw cycles, soil cohesion and the static strength tended to decrease, but after a certain number of freeze-thaw cycles it exhibits the stable value of soil cohesion (Czurda and Hohmann 1997; Guo and Shan 2011). However, some results indicate that soil cohesion tends to increase and found no obvious laws about the cohesion exist. Experiments on increasing soil internal friction angles under the freezing thaw cycle have also done in previous studies. Under freeze-thaw cycles soil, internal friction angle sometimes remains unaffected yet other researchers present decreasing trends, or constant or irregular trends (Tommik 2017).

3.4 Conclusion

This chapter investigated the effect of freeze-thaw cycles and initial soil water contents on soil shear strength in the Chinese Mollisol region. A series of direct shear tests were carried out with various freeze-thaw cycles under different initial soil water contents. The main conclusions of this chapter are as follows:

(1) Soil shear strength was significantly reduced with the increase of freeze-thaw cycles under same initial soil water content. For the BX soil, the shear stress decreased gradually by 8.6% to 9.2% and 13.1 to 18.0% when freeze-thaw shifts from 0 to 7 freeze-thaw cycles under 16.5%, 24.8% and 33.0% of initial soil water contents, respectively. The BX soil shear stress shifted from 102.62 to 98.77 and 90.93 kPa when non-freeze-thaw cycle at three levels of initial soil water contents. Thus, soil shear stress under non freeze-thaw treatment was higher than that under freeze-thaw treatments. Compared with non-freeze-thaw treatments, when the freeze-thaw cycles increased from 1 to 7 times, soil shear stress decreased by 13.2%, 8.6%, and 9.2%, respectively, under 16.5%, 24.8% and 33.0% of initial soil water contents. For KS soil, compared with non-freeze-thaw treatment, when the freeze-thaw cycles increased from 1 to 7 times, soil shear stress decreased 15.1%, 18.0%, and 13.1%, respectively, under 16.5%, 24.8% and 33.0% of initial soil water contents. In addition, soil shear strength decreased linearly with the increase of initial water content. Soil shear stress for the BX tested soils was lower than that for KS tested soils and the differences in soil shear stress between BX and KS soils decrease with an increase of initial soil water content.

(2) Soil cohesion changes from 23.05 kPa to 5.5 kPa and 18.56kPa to 2.41kPa for BX and

KS soil as the freeze-thaw cycles increased from 0 to 7 times, respectively and it decreased with an increase of freeze-thaw cycles for both tested soils, then soil cohesion stabilizes gradually after 5 freeze-thaw cycles. Moreover, soil cohesion for BX soil decreases by 70.9%, 71.1%, and 65.9%, respectively, under five freeze-thaw cycles with three initial soil water content of 16.5%, 24.8%, and 33.0%; and for KS soil, it decreases by 56.6%, 61.7%, and 71.9%, respectively. Compared with BX soil with freeze-thaw treatment, soil cohesion for KS soil is 0.8 to 2.2 times higher when freeze-thaw cycles shifts from 1 to 7 times under three initial soil water contents. Soil cohesion stabilizes gradually after 5 freeze-thaw cycles.

(3) Soil internal friction angle showed decreasing or increasing trends with increasing of freeze-thaw cycles and initial soil water content for both tested soils.

CHAPTER 4 EFFECTS OF INITIAL SOIL WATER CONTENT ON SOIL SHEAR STRESS

4.1 Introduction

Initial soil water content is the main index which has a significant effect on the soil shear stress. The soil shear strength was observed to decrease with the increase of initial soil water content (Panwar and Siemens 1972). In addition, the transport of water in the soil is specified by the initial soil water content; i.e., the higher the initial water content, the faster the downward propagation of rainwater through the soil. Accordingly, the initial soil water content employs an important role in affecting the value of soil shear strength (Zhao et al. 2009). Currently, the effect of initial soil water content on Mollisol shear strength is still unclear. Thus, the direct shear test is used to quantify the effects of initial soil water content on Mollisol shear stress.

4.2 Materials and method

The test soil collected from croplands in Keshan and Binxian countries, Heilongjiang province too. The device used in this study is the DSJ-3 electric strain-controlled direct shear apparatus produced by Nanjing Ningxia Soil Instrument Factory. The experiment treatments include five different levels of freeze-thaw cycles (0, 1, 3, 5 and 7), three levels of initial soil water contents (16.5%, 24.8%, and 33.0%) and two kinds of tested soils (Keshan--KS, Binxian--BX). The experimental procedures include 1) sample preparation process, 2) soil shear sample preparation process, and 3) direct shear test (Fig. 2-1). The more detailed description is seen in Chapter 2. Each treatment has at last three replications (Table 3-1).

4.3 Results and discussion

The results showed that soil shear stress for the two tested decreases with the increase of the initial soil water contents (Fig. 4-1). For non-freeze-thaw treatment, soil shear stress changes from 102.62, 98.77 and 90.93 kPa for KS soil and from 112.41, 106.85 and 93.41 kPa for BX soil, respectively, when the initial soil water content increased from 16.5% to 24.8% and 33.0% (Table 4.1 and Table 4-2). Generally, soil shear strength for KS soil decreased greater than that for BX soil with an increase of initial soil water content. For the freeze-thaw treatment, soil shear stresses significantly declines after one freeze-thaw cycle treatment. Compared with non-freeze-thaw treatment, soil shear stress for BX soil decreases by 3.5%, 3.8%, and 2.6%, respectively, under 16.5%, 24.8% and 33.0% of initial soil water contents, and for KS soil it declines by 8.1%, 11.3%, and 3.8%, respectively. When freeze-thaw cycles increased from 3 to 7 times, there were no significant differences in soil shear stress significantly.

Table 4-1 Comparisons of soil shear strength, cohesion, and soil internal friction angle of BX soil under different initial soil water contents

Freeze-thaw cycle	Soil shear stress (kPa)			Cohesion (kPa)			Soil internal friction angle (°)		
	Initial soil water content			Initial soil water content			Initial soil water content		
	16.5%	24.8%	33.0%	16.5%	24.8%	33.0%	16.5%	24.8%	33.0%
0	102.62	98.77	90.93	18.56	16.24	8.59	28.73	28.27	28.29
1	98.98	95.02	88.56	12.89	12.03	8.27	28.19	28.32	27.19
3	96.36	93.92	88.25	11.68	10.02	7.36	31.71	28.77	26.37
5	95.20	92.58	85.88	9.97	8.32	6.19	36.37	27.49	24.92
7	93.10	90.25	82.58	8.05	6.22	2.41	30.54	26.80	24.60

Table 4-2 Comparisons of soil shear strength, cohesion, and soil internal friction angle of KS soil under different initial soil water contents

Freeze-thaw cycle	Soil shear stress (kPa)			Cohesion (kPa)			Soil internal friction angle (°)		
	Initial soil water content			Initial soil water content			Initial soil water content		
	16.5%	24.8%	33.0%	16.5%	24.8%	33.0%	16.5%	24.8%	33.0%
0	112.41	106.85	93.41	23.05	19.59	16.15	33.61	22.90	21.49
1	103.31	94.71	89.90	14.51	14.18	13.06	30.94	23.02	24.40
3	97.64	92.27	87.12	10.54	10.31	9.19	31.59	27.35	25.22
5	96.57	90.26	85.06	7.22	7.17	7.07	35.81	26.97	24.33
7	95.47	87.64	81.21	6.70	5.67	5.50	32.07	24.06	27.36

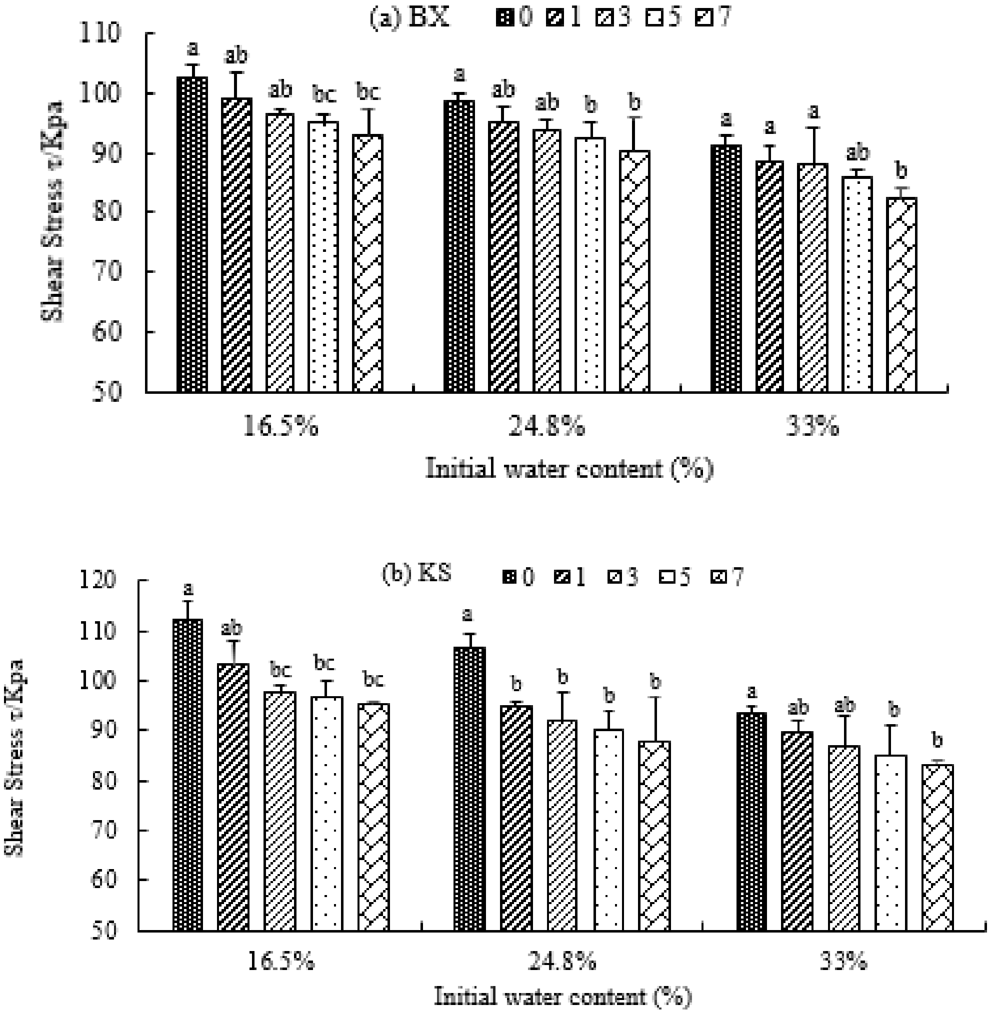


Fig.4-1 Comparisons of shear stress of two soils under different initial soil water contents (Note: The same letter indicates that there is no significant difference in soil shear stress under different initial soil water contents (P >0.05)

As shown in Fig.4-2, Table 4-1 and Table 4-2， soil cohesions for the KS soils showed a decreasing trend as soil initial soil water content increased. For KS soil, soil cohesion declines by 37.4%, 27.6%, and 19.1% respectively, for one freeze-thaw cycle treatment under 16.5%, 24.8% and 33.0% of initial soil water contents, and they decreased by 68.7%, 63.3% and 56.2% for three initial soil water contents, respectively, after 5 freeze-thaw cycles. For BX soil, soil cohesion has the same trend as the BX soil. Soil cohesion for BX soil declines by 30.5%, 25.9% and 3.7% respectively, for one freeze-thaw cycle treatment under 16.5%, 24.8% and 33.0% of initial soil water contents, and they decreased by 46.2%,48.8% and 27.9% for three initial soil water contents, respectively, after 5 freeze-thaw cycles.

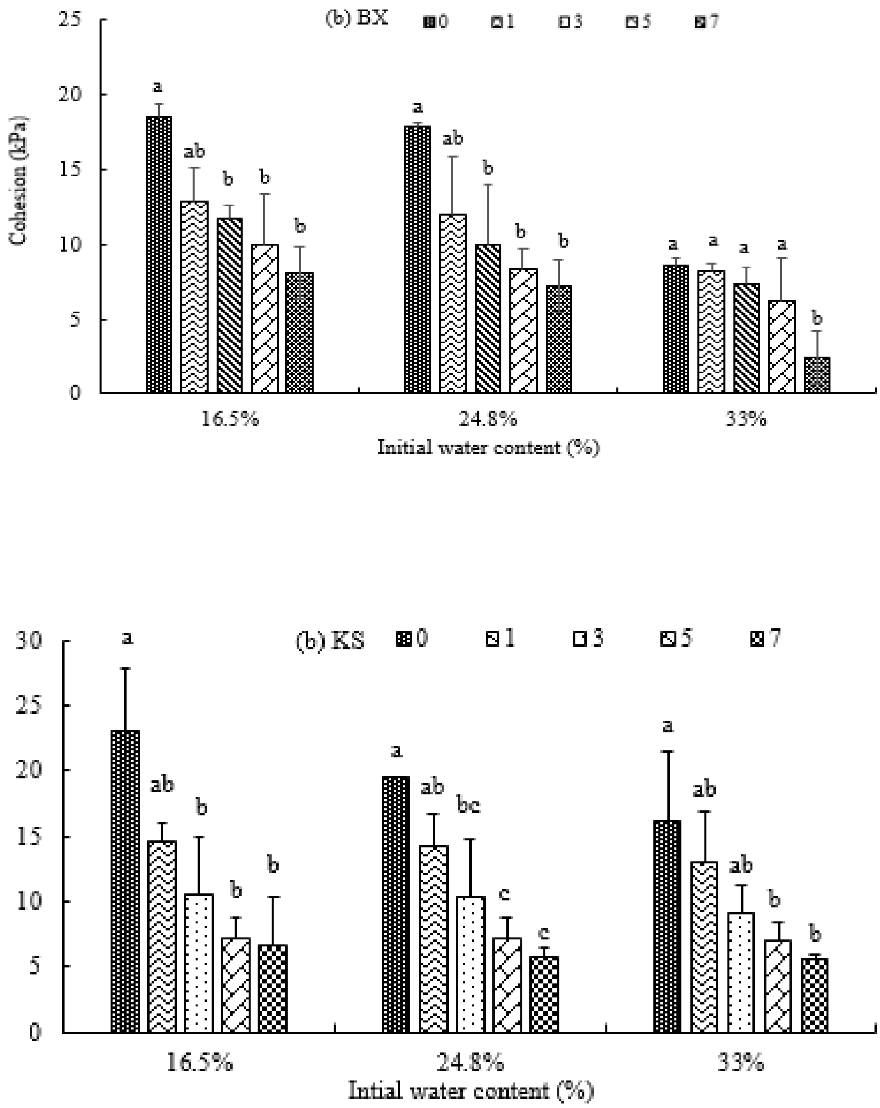
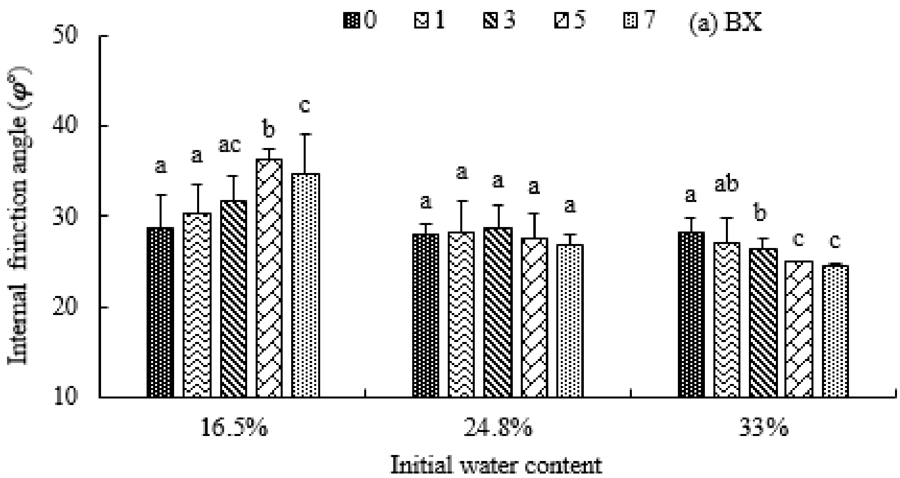


Fig. 4-2 Comparisons of soil cohesion of the under different initial soil water contents (Note: The same letter indicates that there is no significant difference in soil cohesion under different initial soil water contents (P>0.05)

Fig. 4-4, Table 4-1, and Table 4-2 also showed the impact of initial soil water content on soil internal friction angle. Soil internal friction angle showed different trends with the increase of initial soil water content and the number of freeze-thaw cycles. With an increase of soil water content from 16.5% to 24.8% and 33.0%, soil internal friction angle for non-freeze-thaw treatment decreases by 31% and 36.1% for BX soil and by 1.6 % and 1.5% for KS soil. After 5 freeze-thaw cycles, the soil internal friction angle for BX declines by 56.2% to 70.9% for three initial soil water contents; and for KS soil, it decreases by 27.9% to 48.8% for three initial soil water contents after 5 freeze-thaw cycles.

Moreover, soil shear stress is significantly influenced by initial soil water content with a freeze-thaw cycle. Tested soil samples also showed variance in soil shear stress, soil cohesion, and soil internal friction angle. The reason of soil shear strength and soil cohesion decreased with the increase of initial soil water contents is that changed the soil porousness and then the soil structure. Previous studies have demonstrated that changes in soil properties of pore water would markedly affect the shear stress when the clay content of the soil is greater than 10%. In this study, the soil clay content is 29.42% for BX soil and 40.58% for KS soil. Zhang (2006) observed that clay cementation progressively replaced water bonding among soil particles thus affecting the total shear strength. These studies are similar to the results of this study to some extent. Moreover, for unsaturated soil, soil shear strength, as well as its parameters, originate from both net normal stress and suction; and generally, soil shear strength increases with increasing water suction of soil (Çokça and Tilgen 2010). The soil shear strength is a function of its initial soil water content and soil properties. Besides, soil cohesion increase with the initial soil water content decreases gradually. When the initial soil water content increases, the soil internal friction angle of soil samples has changed a little under different freeze-thaw cycles, but soil cohesion greatly changed with initial soil water content. According to the previous study, the friction angle and soil cohesion might decrease when the soil was saturated (Pellet, 2013).



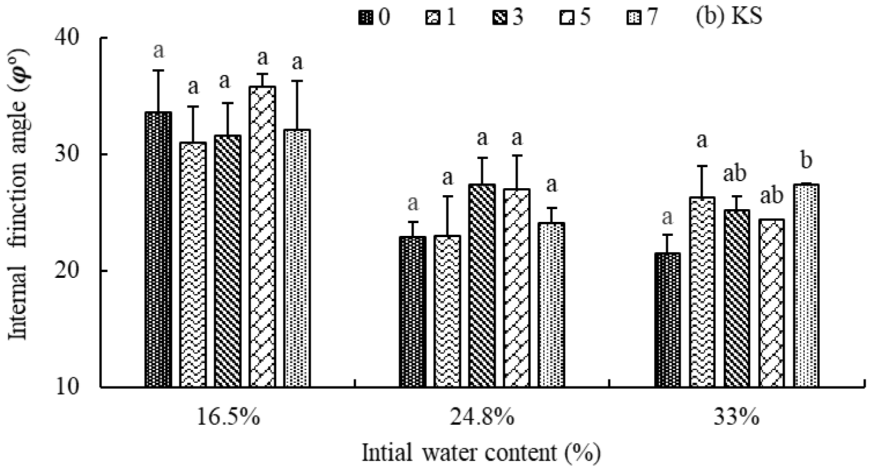


Fig.4-4 Comparisons of soil internal friction angles of two soils under different initial soil water contents

(Note: The same letter indicates that there is no significant difference in soil internal friction angles under different initial soil water contents (P >0.05)

4.4 Conclusion

The soil shear stress decreased with the increase of initial soil water content under different freeze-thaw cycles. The values of maximum shear stress for two tested soils with 16.5 % soil water content were higher than those at 33% soil water content. Soil shear stress for KS soil decreased greater than that for BX soil with an increase of initial soil water content. For the freeze-thaw treatment, soil shear stress significantly declines after one freeze-thaw cycle treatment. Compared with non-freeze-thaw treatment, soil shear stress for BX soil decreases by 3.5%, 3.8%, and 2.6%, respectively, under 16.5%, 24.8% and 33.0% of initial soil water contents, and for KS soil it declines by 8.1%, 11.3%, and 3.8%, respectively. When freeze-thaw cycles increased from 3 to 7 times, there were no significant differences in soil shear stress significantly. Soil cohesion for both tested soils showed a decreasing trend as soil initial soil water content and freeze-thaw cycles increase. For KS soil, soil cohesions declines by 37.4%, 27.6%, and 19.1% respectively, for one freeze-thaw cycle treatment under 16.5%, 24.8% and 33.0% of initial soil water contents, and they decreased by 68.7%, 63.3% and 56.2% for three initial soil water contents, respectively, after 5 freeze-thaw cycles. For BX soil, soil cohesion has the same trend as the BX soil. Soil cohesions for BX soil declines by 30.5%, 25.9% and 3.7% respectively, for one freeze-thaw cycle treatment under 16.5%, 24.8% and 33.0% of initial soil water contents, and they decreased by 46.2%,48.8% and 27.9% for three initial soil water contents, respectively, after 5 freeze-thaw cycles. Soil internal friction angle showed different trends with the increase of initial soil water content and the number of freeze-thaw cycles.

CHAPTER 5 COMPARISONS OF SHEAR STRESS BETWEEN REMOLDED AND UNDISTURBED SOILS

5.1 Introduction

Soils are the material basis of agricultural development and their quality directly affects the yield and quality of crop production (Lal et al., 1991). One of the necessary conditions for obtaining high yields is proper soil cultivation. In addition, soil tillage, which disturbed surface soil, is one of the important factors affecting soil properties and crop yield. Among the crop production factors, tillage contributes up to 20% affects the sustainable use of soil resources through its influence on soil properties (Lal and Stewart et al., 2013). However, cultivation changes the physical and chemical properties of soils (Huang et al., 1999). Especially, soil erosion is part of the overall deterioration of land (Soane et al., 1995). Northeastern China is the country's major grain-producing region and enjoys a higher level of agricultural mechanization than other regions of China. However, conventional tillage, which induces much-remolded surface soil, changes of soil mechanical properties such as tensile strength and shear strength, which plays an important role in soil anti-erosivity. Previously, the effect of soil disturbance on soil mechanical properties has been widely recognized (Greene et al., 2002). But there are few reportes related to disturbance affecting soil shear stress in the Chinese Mollisol region. Thus, this study compares differences of soil shear stress between remolded and undisturbed soils through indoor experiments.

5.2 Material and method

Soil samples were collected from the top 20 cm layer of arable field of two different sites which are KS (126°04'59 E, 48°08′27″N), and BX (127°25'36 E, 45°45'22″ N) counties of Heilongjiang Province, Northeast region of China. For undisturbed soil samples, 120 ring knifes with 6.18 cm diameter and 2 cm deep are used to collected soil samples from topsoil (0-20 cm) and all samples are brought back to laboratory in order that all samples keeps their original structure. 120 ring knifes with soils is randomly divided two groups, one group with 10 ring knifes is used to measured initial soil water content, other group with 110 knifes is used to measure soil shear stress. Other procudures for measuring soil shear stress for undisturbed soils are the same as the precedures for remolded soil. For remolded soil samples, after air-dried, soil samples are sieved through a 2-mm mesh (Fig.5-1). Soil sample preparation procedures are seen in Chapter 2.

The experimental treatments have three variables, i.e., five freeze-thaw cycles (0, 1, 3 and 7 times), two initial soil water content (24.8% and 33.0%), and two kinds of undisturbed and remolded soils. Each treatment has at least 3 replications (Table 5-1).

(a) (b) (c)

Fig 5-1 (a) Field site KS and BX, (b) To take undisturbed soil sample, (c) Undisturbed specimens

Table 5-1. Experimental design for the comparison of soil shear stress between remolded soil and undisturbed soils

Soil properties	Soil structure	Soil initial water content (%)	Freeze-thaw cycles	Replication
KS	Remolded	24.8	0 (control)	3
			1	
		33.0	3	
			7	
	Undisturbed	24.8	0 (control)	
			1	
		33.0	3	
			7	

Continues of Table 5-1. Experimental design for the comparison of soil shear stress between remolded soil and undisturbed soil.

Soil properties	Soil structure	Soil initial water content (%)	Freeze-thaw cycles	Replication
BX	Remolded	24.8	0 (control)	3
			1	
		33.0	3	
			5	
	Undisturbed	24.8	0 (control)	
			1	
		33.0	3	
			5	

5.3 Results and Discussion

Fig 5-2 presents a change of soil shear stress with a freeze-thaw cycle for BX and KS remolded and undisturbed soil. Under 24.8% of initial soil water content, soil shear stress shifts from 98.77 to 92.58 kPa for BX remolded soil and from 106.85 to 90.26 kPa for KS remolded soil when the freeze-thaw cycle changes from 0 to 5 times, both are reduced by 6.3% and 15.5%, respectively (Table 5-2). For both BX and KS undisturbed soils, soil shear stress shifts from 74.03 to 68.48 kPa and from 95.11 to 89.08 kPa respectively, when the freeze-thaw cycle changes from 0 to 5 times, both are reduced by 7.5% and 7.8% (Table 5-2). This result indicates that soil shear stress decreases with an increase of freeze-thaw cycles for both remolded and undisturbed soils. Moreover, soil shear stress for the BX remolded soil with 24.8% of initial soil water content was 25.0%, 23.8% and 26. 1% higher than that for undisturbed soil, respectively, when freeze-thaw cycle increase from 0 to 5 times; under 33.% of initial soil water content, it was 17.6%, 21.8% and 21.2% higher than that or undisturbed soil, respectively.

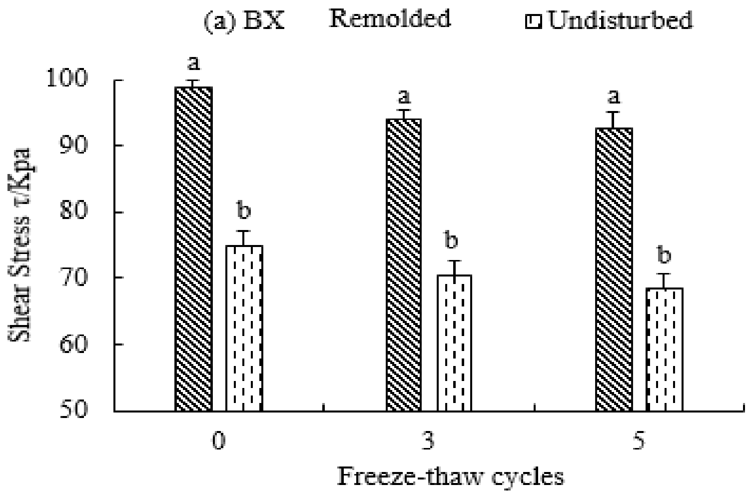
Table 5-2 BX and KS soil shear stress at different freeze-thaw cycles and initial soil water contents.

F-T	BX Site				KS Site			
	Remolded soil	Undisturbed soil	Remolded soil	Undisturbed soil	Remolded soil	Undisturbed soil	Remolded soil	Undisturbed soil
	Initial Soil Water Content (%)							
	24.8		33.0		24.8		33.0	
0	98.77	74.03	90.93	74.95	106.85	95.11	93.41	84.34
3	93.92	71.55	88.25	69.08	92.27	92.07	87.12	83.10
5	92.58	68.46	85.88	67.63	90.26	89.08	85.06	81.45

Soil shear stress for the KS remolded soil with 24.8% of initial soil water content was 11.0% higher than that for undisturbed soil under non freeze-thaw process, while for 3 and 5 freeze-thaw cycles, soil shear stress with 24.8% of initial soil water content is not different for both remolded and undisturbed soils. Besides, KS remolded soil was 0.8 times higher than that undisturbed soil.

Fig.5-3 shows the relation between soil shear stress and the freeze-thaw cycle for BX and KS remolded and undisturbed soil. Under 33.0% of initial soil water content, soil shear stress shifts from 90.93 to 85.88 kPa for BX remolded soil and from 93.41 to 85.06 kPa for KS remolded soil when the freeze-thaw cycle changes from 0 to 5 times, both are reduced by 5.6% and 8.9% (Table 5-2). For both BX and KS undisturbed soils, soil shear stress shifts from 74.95 to 67.73 kPa and from 84.34 to 81.45 respectively, when the freeze-thaw cycle changes from 0 to 5 times, both are reduced by 9.6% and 3.4% (Table 5-2). These results also indicate that soil shear stress decreases with an increase of freeze-thaw cycles for both disturbed and undisturbed soils.

It is seen from Table 5-2, Fig 5-2 and 5-3 that soil shear stress for undisturbed soil at both BX and KS sites is lower than that for remolded soil. Under 24.8% and 33.0% initial soil water content, soil shear stress for BX undisturbed soil decreased by 23.8% to 26.1l% and 17.6% to 21.3% respectively, compared with remolded soil; and for KS undisturbed soil, soil shear stress decreased by 0.2% to 11.0% and 4.2% to 9.7%, respectively. Compared with KS undisturbed soil, the decreasing trend of soil shear stress for BX undisturbed is more obvious. Why soil shear stress for undisturbed soil is lower than that for remolded soil? The reason can be explained as follows: 1) Remolded soil has larger soil bulk density than undisturbed soil. 1.20 g/cm^3 soil bulk density is used to prepare a direct shear test for remolded soil, but for undisturbed soil, soil bulk density in the field is 1.08 g/cm^3. 2) For disturbed soil, soil samples for test soil shear stress are remolded and it contends less porousness, while for undisturbed soil, soil samples contend more porousness because they are directly collected from the field and maintains their original structure. 3) For remolded soil, soil samples are grounded the sieved through 2 mm mesh, so soil samples for test shear stress have the uniform surface condition; but for undisturbed soil, soil samples for test shear stress has different soil particle size. The above three matters may induce soil shear stress for undisturbed soil is lower than for remolded soil. Moreover, soil shear stress decreases when initial soil water content changes from 24.8% to 33.0% for remolded and undisturbed soils at both BX and KS sites (Table 5-2). For BX remolded and undisturbed soils, soil shear stress decreases by 6.0%-7.9% and 1.2%-3.4%, respectively, when freeze-thaw increased from 0 to 5 times. For KS remolded and undisturbed soils, soil shear stress decreases by 5.8%-12.6% and 8.6%-11.3%, respectively, when freeze-thaw increased from 0 to 5 times. This shows that initial soil water content has great impacts on KS soil, compared with BX soil. The reason is that clay content in KS soil is higher 1.38 times than that in BX soil (Table 2-2), which induces more damage of soil structure by mineral swelling action as increasing initial soil water content, which causes a decline of soil shear stress.



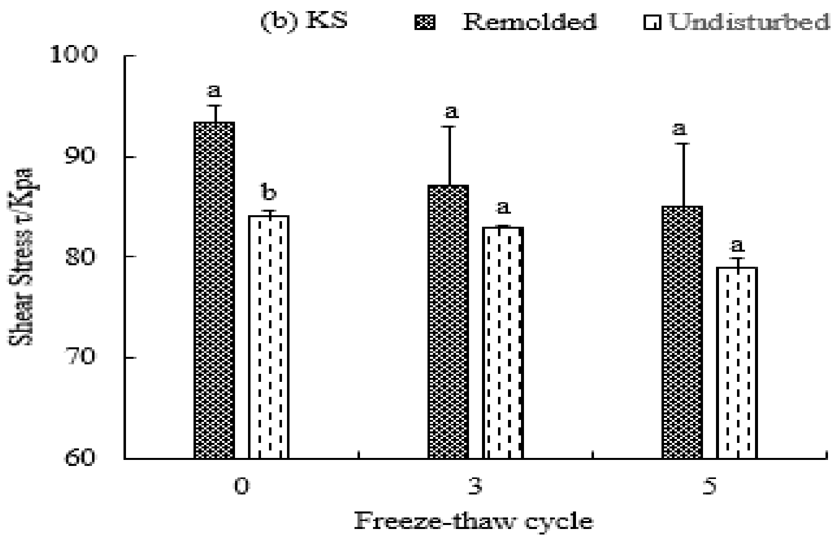
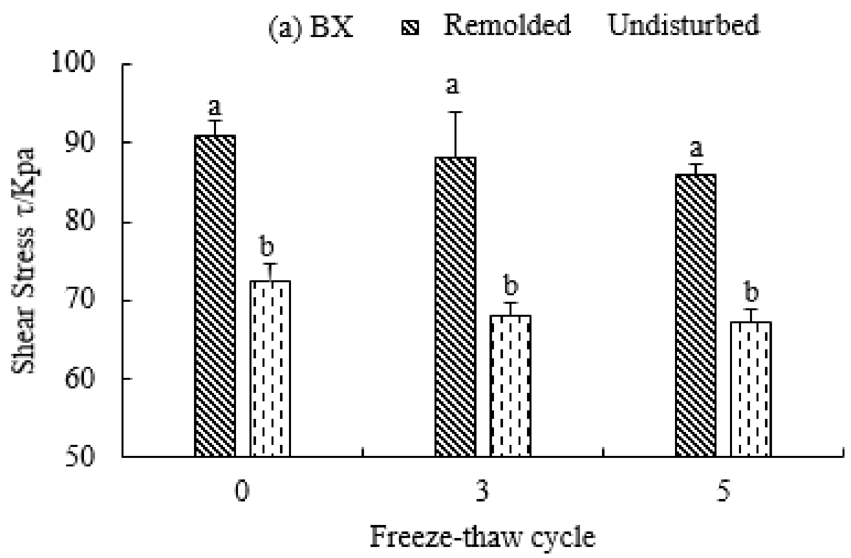


Fig. 5-2. Soil shear stress change with the freeze-thaw cycle for BX and KS soils under 24.8% initial water contents (Note: The same letter indicates that there is no significant difference in soil shear stress between remolded and undisturbed soils under different initial water content (P > 0.05)



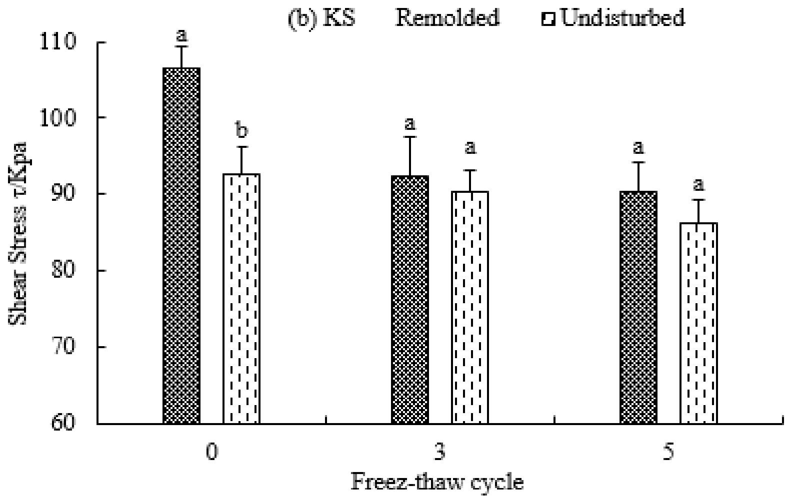


Fig. 5-3. Soil shear stress change with the freeze-thaw cycle for BX and KS soils under 33.0% initial water contents (Note: The same letter indicates that there is no significant difference in soil shear stress between remolded and undisturbed soils under different initial water content($P > 0.05$)

5.4 Conclusion

This study designs indoor experiments to measure soil shear stress by using direct shear test to compare differences of soil shear stress between remolded and undisturbed soils under three freeze-thaw cycles (0, 3 and 5 times), two initial soil water content (24.8% and 33.0%). The main conclusions are as follows:

(1) Soil shear stress decreases with an increase of freeze-thaw cycles and initial soil water content for both remolded and undisturbed soils at BX and KS sites. For 24.8% of initial soil water content, soil shear stress decreases by 6.3% and 15.5% for BX and KS remolded soil respectively when the freeze-thaw cycle changes from 0 to 5 times and it reduces by 7.5% and 7.8% for BX and KS undisturbed soil, respectively. For 33.0% of initial soil water content, soil shear stress decreases by 9.6% and 3.4% for BX and KS remolded soil respectively when the freeze-thaw cycle changes from 0 to 5 times and it reduces by 5.6% and 8.9% for BX and KS undisturbed soil, respectively

(2) Soil shear stress for undisturbed soil at both BX and KS sites is lower than that for remolded soil. Under 24.8% and 33.0% initial soil water contents, soil shear stress for BX undisturbed soil decreased by 23.8% to 26.1l% and 17.6% to 21.3% respectively, compared with remolded soil and for KS undisturbed soil, soil shear stress decreased by 0.2% to 11.0% and 4.2% to 9.7%, respectively. Compared with KS undisturbed soil, the decreasing trend of soil shear stress for BX undisturbed is more obvious. The main reason for that soil shear stress under remolded soil is larger than that under undisturbed soil is due to change of soil structure

by remolding soil samples.

(3) Soil shear stress decreases when initial soil water content changes from 24.8% to 33.0% for remolded and undisturbed soils at both BX and KS sites. For BX remolded and undisturbed soils, soil shear stress decreases by 6.0%-7.9% and 1.2%-3.4%, respectively, when freeze-thaw increased from 0 to 5 times; for KS remolded and undisturbed soils, soil shear stress decreases by 5.8%-12.6% and 8.6%-11.3%, respectively.

CHAPTER 6 CONCLUSIONS AND PERSPECTIVES

6.1 Main conclusions

This study designs a series of indoor experiment with five levels of freeze-thaw cycles (0, 1, 3, 5 and 7) and three levels of initial soil water contents to (16.5%, 24.8%, and 33%) quantify how freeze-thaw cycles and initial soil water content affects soil shear stress in Chinese Mollisol region by using direct shear test. The main conclusions are as follows:

（1) Soil shear strength was significantly declined with the increase of freeze-thaw cycles and initial soil water content. For the BX soil, the shear stress decreased by 8.6% to 9.2% and 13.1 to 18.0% when freeze-thaw shifts from 0 to 7 freeze-thaw cycles under 16.5%, 24.8% and 33.0% of initial soil water contents, respectively. Additionally, soil shear stress decreased linearly with the increase of initial water content. For KS soil, compared with non-freeze-thaw tested soils, when the freeze-thaw cycles increased from 1 to 7 times, soil shear stress decreased 15.1%, 18.0%, and 13.1%, respectively, under 16.5%, 24.8% and 33.0% of initial soil water contents. In addition, soil shear strength decreased linearly with the increase of initial water content. Soil shear stress for the BX tested soils was lower than that for KS tested soils and the differences in soil shear stress between BX and KS soils decrease with an increase of initial soil water content.

（2) Soil cohesion changes from 23.05 kPa to 5.5 kPa and 18.56kPa to 2.41kPa for BX and KS soil as the freeze-thaw cycles increased from 0 to 7 times, respectively and it decreased with an increase of freeze-thaw cycles for both tested soils, then soil cohesion stabilizes gradually after 5 freeze-thaw cycles. Moreover, soil cohesion for BX soil decreases by 70.9%, 71.1%, and 65.9%, respectively, under five freeze-thaw cycles with three initial soil water content of 16.5%, 24.8%, and 33.0%; and for KS soil, it decreases by 56.6%, 61.7%, and 71.9%, respectively. Meanwhile, compared with BX soil with freeze-thaw treatment, soil cohesion for KS soil is 0.8 to 2.2 times higher when freeze-thaw cycles shifts from 1 to 7 times under three initial soil water contents. Soil cohesion stabilizes gradually after 5 freeze-thaw cycles. Soil internal friction angle showed decreasing or increasing trends with increasing of freeze-thaw cycles and initial soil water content for both tested soils.

(3) Soil shear stress for undisturbed soil at both BX and KS sites is lower than that for remolded soil. For the remolded soil, soil shear stress was decreased greater than that for undisturbed soil. For 24.8% of initial soil water content, soil shear stress decreases by 6.3% and 15.5% for BX and KS remolded soil respectively when the freeze-thaw cycle changes from 0 to 5 times and for 33.0% of initial soil water content, soil shear stress decreases by 9.6% and

3.4% for BX and KS remolded soil respectively when the freeze-thaw cycle changes from 0 to 5 times and under 24.8% and 33.0% initial soil water content, soil shear stress for BX undisturbed soil decreased by 23.8% to 26.1% and 17.6% to 21.3% respectively, compared with remolded soil; and for KS undisturbed soil, soil shear stress decreased by 0.2% to 11.0% and 4.2% to 9.7%, respectively. Compared with KS undisturbed soil, the decreasing trend of soil shear stress for BX undisturbed is more obvious. Soil shear stress decreases when initial soil water content changes from 24.8% to 33.0% for remolded and undisturbed soils at both BX and KS sites. For BX remolded and undisturbed soils, soil shear stress decreases by 6.0%-7.9% and 1.2%-3.4%, respectively, when freeze-thaw increased from 0 to 5 times; for KS remolded and undisturbed soils, soil shear stress decreases by 5.8%-12.6% and 8.6%-11.3%, respectively.

6.2 Perspectives

In this study, we observed that freeze-thaw cycle and initial water content affects Mollisol shear stress, including remolded and undisturbed soils. There was no such report before. The direct shear stress method was used to determine the effect of the freeze-thaw cycle and initial water content on Mollisol shear stress. The direct shear test method is easy to perform and the apparatus is also cheap. Research result found that both parameters of freeze-thaw cycles and initial soil water content have significant effects on soil shear stress in the Chinese Mollisol region. However, we just used one method to examine the effect. It is suggested that in future studies other different methods need to be used to determine the effect of freeze-thaw cycle and initial soil water content soil shear stress in order to compare and validate the results of this study. Moreover, due to the time, we did not pay attention to investigating influences of other soil properties on soil shear strength, which should be studied in the future.

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