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Standing corn residue effects on soil frost depth, snow depth and soil heat flux in Northeast China

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ABSTRACT[1]

Standing corn residue has been proven to reduce wind erosion in Northeast China, but how standing corn residue affects soils during winter remained unclear. Our objective was to compare soil frost depth associated with two zero-tillage methods [i.e., chopping corn stalks into small sections then spread them on soil (hereafter referred to as 'CCR') and standing corn residue (hereafter referred to as 'SCR')]. Frost tubes were used to determine soil frost depth, and soil heat flux plates were used to measure soil heat flux 8-cm beneath the soil surface. Compared with CCR treatment, SCR reduced maximum soil frost depth significantly ($p < 0.05$) due to thicker snow cover, which insulated the soil surface from cold winter air. And the thicker snow cover hastened the frozen soil completely thawed approximate 20 days, which has implications for early sowing. Early sowing meant that corn could have longer growing time, which could help long-growing-time corn varieties become maturity before killing frost in cold areas, longer growing time could also result in fully filled grain, and increase economic profit for farmers.

1. Introduction

Mollisols make up about 916 million hectares in the world, which prevalent in the mid-latitudes of North America, Eurasia, and South America (Liu et al., 2012). There are many differences among these locations, such as climate, topography, the formation of Mollisols and so on. Chinese Mollisols occur where mean annual temperature is −2.5 to 5.6 °C, while they are 5–20 °C, −4 to 8 °C, 14–19 °C in North America, Russia and South America, respectively (Kravchenko et al., 2011; Liu et al., 2012). Chinese Mollisols occur where mean annual precipitation is 300- to 600-mm, while they are 500- to 1500-mm, 350- to 700-mm, 490- to 550-mm, and 500- to 1500-mm in North America, Russia, Ukraine and South America, respectively (Kravchenko et al., 2011; Liu et al., 2012). The majority of Chinese Mollisols region has undulating to rolling topography with gentle slopes in the range of 1–5°; but sizeable areas of Mollisols are present in the more mountainous in North America; the topography of Russian chernozemic zone is characterized by severely eroded uplands; the Ukrainian Chernozems are located on a plain, physiographically speaking. Chinese Mollisols are mostly from Steppe, Prairie to Forest-Steppe vegetation; Mollisols in the United States are formed mostly in Quaternary materials on gentle or moderate slopes; the majority of Russian Chernozems are formed on sandy and clastic (gravelly to cobbly) alluvial-colluvial deposits; Ukrainian Chernozems developed on loess and loess-like sediments, eluvium of limestone, sandstone, slates and dark forest soils; the South American Mollisols are formed from loess, loessoid sediments, metamorphic, illite, kaolinite, and wide variety of sediments (Kravchenko et al., 2011; Liu et al., 2012).

Among different modalities of conservation tillage, zero tillage is frequently preferred worldwide by many farmers (Salem et al., 2015). As of 2009, there are approximate 105 million hectares farm land under zero tillage worldwide (Derpsch and Friedrich, 2009). Zero tillage is combined with stalk returning in order to replenish

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[1] Returning the whole corn stalk into field was designated as 'CCR', which means the whole corn stalk was chopped into small pieces then spread them on soil surface; leaving standing corn residue in the field was designated as 'SCR', which means cutting and removing the top stalk but leaving the bottom stalk standing; Daily average soil heat flux was designated as 'DG'. Complete thawing time is defined as the time in which no ice remained in the soil.

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organic matter to soil. In terms of corn, leaving corn stalks in field after harvesting is a major method. One method of leaving corn stalk in field is returning whole corn stalk into field; another method is leaving standing corn residue in field. A lot of corn harvesters have the function of returning corn stalk into field (Johnson et al., 2003; Zhang et al., 2003; Herrmann et al., 2011), these corn harvesters will chop the whole corn stalk into small pieces then spread them on soil surface (Kay and VandenBygaart, 2002; Alvarez, 2005); actually, the small stalk sections and soil were mixed due to the shattering process. Standing corn residue cuts the upper stalk and leaving the bottom stalk standing, so the upper stalk can be used in other ways (Wang et al., 2014; Jia et al., 2015). Besides the standing stems anchored in field, some loose residue materials are also held in place by the standing residue (Turmel et al., 2015). SCR not only promotes soil organic-matter stabilization level which is similar to CCR, but also has its own special advantages compared with CCR in controlling soil wind erosion (Jia et al., 2015).

Growers concern about the sowing date of corn (*Zea mays* L.). Early sowing is recommended because full-season hybrids utilize the entire growing season, achieve physiological maturity before a killing frost, and start to dry, thereby increasing profit by reducing drying costs (New Zealand, 1946; Wiersma et al., 1993; Lauer et al., 1999). The development of soil frost interferes with spring plowing, and the low soil temperature delays the sowing of spring crops. Therefore, an evaluation of the winter soil thermal regime is essential for understanding and proper management of agricultural soil environment in cold regions.

Tillage and crop residue management can influence the occurrence and depth of soil freezing, especially in regions where wind is likely to redistribute snow (Sharratt et al., 1998). Pikul et al. (1986) had presented that different tillage and residue managements could influence the formation of soil frost (Pikul et al., 1986), their experimental location was the Columbia Basin and Plateau of Oregon and Washington, the results showed that standing stubble consistently reduced the depth of frost penetration by an average of 35% compared to bare soil surface. Kay et al. (1985) did a research to compare the soil frost depth between conventional and zero tillage, they found that soil under zero tillage accumulated more snow over winter and did not freeze as deeply as soil that were plowed in the fall (conventional tillage) (Kay et al., 1985). The study of Sharratt et al. (1998) was conducted in west central Minnesota, their study showed that compared with residue lying prostrate on soil surface or bare soil surface, stubble standing and loose residue lying on soil could reduce frost penetration by as much as 0.5-m, and let the soil thawed up to 20-d sooner (Sharratt et al., 1998).

There are also some models to predict soil frost depth under different tillage systems (Benoit and Mostaghimi, 1984; Lin and McCool, 2006), one of the research results present that no till residue plots are found to have the greatest snow depth and shallowest frost development while fall plow no-residue plots have the least snow depth and deepest frost penetration (Benoit and Mostaghimi, 1985). It is a truth that different residue managements could influence soil frost depth, but among all these literatures, no reports compare soil frost depth between SCR and CCR of Mollisols in Northeast China have been found. In addition, the differences of snow depth and soil heat flux under SCR and CCR are not clear until now.

Finding answers about the differences of soil frost depth, snow depth and soil heat flux under SCR and CCR are the objectives of this paper. Different corn stalk managements could influence soil thermal regime. And soil thermal regime has close relationship with seedling. So the results of this study could direct early sowing at which has similar climate or soil classification to Northeast China.

2. Material and methods

2.1. Study site

The experiments were conducted at Agricultural Testing Farm (44°15′N; 125°18′E; elevation of 239 m) of Jilin University in Changchun City, China. Winter is usually from mid November to late March in this location. Air temperature at the experimental location varies with the seasons, with temperature below 0 °C for about 5 months during winter. The temperature slowly rises above 0 °C in late winter. The average maximum temperature over the past 30 years was 23.1 °C in July, and the average minimum temperature over the past 30 years was −15.1 °C in January. The mean annual temperature is 4.8 °C, and the mean annual precipitation is from 522 to 615 mm. One character of the soil in this region is subject to annual freeze-thaw cycles (Zhou et al., 2000), which means only one freeze-thaw cycle each year, and the agricultural soil usually begins to freeze in early Nov., and starts to thaw in late February or early March, it is usually late Mar. that agricultural soil frost will disappear completely. And farmers usually start planting in early May when soil temperature is suitable for germination of corn seeds. Munsell soil color charts (Beijing New Landmark Soil Equipment Co., Ltd.) were used to determine the soil classification, according to the USDA soil taxonomy, the soil at the Agricultural Testing Farm of Jilin University belongs to Mollisols. An experiment was conducted and the following results were gotten, the Mollisols at the study site has an organic matter content of 33.91 g kg^{-1}, total nitrogen content of 1.92 g kg^{-1}, available phosphorus content of 24.73 mg kg^{-1}, available potassium content of 159.73 mg kg^{-1} within the surface soil (0–30 cm depth) and soil pH values ranging from 6.5 to 7.1. And the percentages of sand, silt and clay are 57%, 13% and 30%, respectively.

There usually a lot of snow in winter, and a portion of them are snowstorm, it is a very common phenomenon that the wind always redistribute the snow. In the experimental location, the weather data of last 30 years showed that the first snow always occurred in late Oct. or early Nov. The snow would begin to melt by the end of Feb. or early Mar, and the snow would disappear completely by the mid of Mar.

The field experiment was started in early winter of 2012, before this experiment was conducted, natural fallow-type vegetation was grown for 5 years, and the major vegetation species were *Echinochloa crusgalli* (L.) Beauv, *Setaria viridis* (L.) Beauv, *Amaranthus retroflexus* L., *Artemisia lavandulaefolia* DC., *Polygonum bungeanum* Turez and the percentages of them are 20%, 3%, 5%, 47% and 23%, respectively.

2.2. Experimental design

The experimental period included 3 winters which from 2012 to 2015. Two treatments were established in this experiment. Both of them were zero tillage, each treatment was planted with continuous corn (*Zea Mays* L.), and the difference was the management of corn stalk. One treatment was CCR, the other one was SCR, and the standing corn residue was 50-cm high.

Each treatment consisted of 4 replications every year, 8 fully randomized plots which were all 100-m in length and 50-m in width were chosen to carry out SCR treatment (4 plots) and CCR treatment (4 plots), respectively.

2.3. Measurement of soil frost depth, snow depth and soil heat flux

The measurement of soil frost depth was carried out for 3 winters from 2012 to 2015. Two o'clock in the morning is the coldest time every day in Northeast China by referring