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Research Article

Effect of Postsowing Compaction on Cold and Frost Tolerance of North China Plain Winter Wheat

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Improper postsowing compaction negatively affects soil temperature and thereby cold and frost tolerance, particularly in extreme cold weather. In North China Plain, the temperature falls to 5 degrees below zero, even lower in winter, which is period for winter wheat growing. Thus improving temperature to promote wheat growth is important in this area. A field experiment from 2013 to 2016 was conducted to evaluate effects of postsowing compaction on soil temperature and plant population of wheat at different stages during wintering period. The effect of three postsowing compaction methods—(1) compacting wheel (CW), (2) crosskill roller (CR), and (3) V-shaped compacting roller after crosskill roller (VCRCR)—on winter soil temperatures and relation to wheat shoot growth parameters were measured. Results showed that the highest soil midwinter temperature was in the CW treatment. In the 20 cm and 40 cm soil layer, soil temperatures were ranked in the following order of CW > VCRCR > CR. Shoot numbers under CW, CR, and VCRCR treatments were statistically 12.40% and 8.18% higher under CW treatment compared to CR or VCRCR treatments at the end of wintering period. The higher soil temperature under CW treatment resulted in higher shoot number at the end of wintering period, apparently due to reduced shoot death by cold and frost damage.

1. Introduction

Autumn-sown field crops trend to higher yields than spring varieties due to their early spring development [1], an advantage over spring-germinating weeds when competing for limited moisture [2, 3]. In addition, overwintering crops confer some advantages, including reduced soil erosion and nutrient leaching. However, overwintering crops are vulnerable to unfavourable weather for a longer period, potentially reducing winter survival rate, crop vigour, and thereby ultimate yield [4–7].

In North China Plain, the temperature falls to 5 degrees below zero, even lower in winter with a frost-free period of around 190 days. Winter wheat may suffer low-temperature damage from both prolonged exposure to relatively mild but suboptimal temperatures and short exposure to extremely low temperature [8]. Cold and frost damage occur occasionally, and large declines in temperature reduce wheat growth ultimately [9]. Thus improving temperature to resist damage is necessary in this area.

Soil properties are usually influenced by tillage, compaction, and other soil management factors [10–15]. Moderate seedbed compaction is required for optimal soil-seed contact and to reduce soil moisture loss following planting [16]. Several studies have demonstrated that compaction significantly affected soil temperature [17–20]; however, previous research has generally focused on wheel traffic compaction and its effect on soil temperature only a few days after compaction. There is little knowledge about effect of postsowing compaction on soil temperature during winter several months after postsowing compaction, which is more important for cold and frost tolerance. Therefore, the objective of this research is to explore the effects of three postsowing compaction methods (compacting wheel, crosskill roller, and V-shaped compacting roller after crosskill roller) on cold and frost tolerance capacity of North China

(a) Compacting wheel (CW) (b) Crosskill roller (CR) (c) V-shaped compacting roller after crosskill roller (VCRCR)

Figure 1: Postsowing compaction methods.

Plain winter wheat. The cold and frost tolerance capacity is measured by soil temperature variation in 0–60 mm soil depth and winter wheat growth parameters (shoot number, length, and fresh and dry weight) during wintering period. The research will provide a basis for improving cold and frost tolerance capacity of winter wheat.

2. Materials and Methods

2.1. Site Description. The study was conducted from 2013 to 2016 near Beijing, China, in an area with a temperate continental climate and four distinct seasons. Mean annual temperature in the region is 11°C, with a frost-free period of around 190 days. Average annual rainfall is 600 mm, 75% of which occurs during summer. To ensure the same conditions, only winter wheat is sown in October and harvested in June in each year. Soil at the site was a loam with an average soil organic matter content of 18.7 g/kg, total nitrogen of 0.115%, 16.7 mg/kg available phosphorus, and 96 mg/kg available potassium.

2.2. Experimental Design. For each wheat season, the site was uniformly rotary tilled and laser-levelled, and then fertilizer was applied at the rate of 150 kg/ha N, 140 kg/ha P, and 85 kg/ha K before sowing. Winter wheat (Jingdong 8) was then sown at the rate of 187.5 kg/ha. This study assessed three types of postsowing compaction: (1) compacting wheel (CW), (2) crosskill roller (CR), and (3) V-shaped compacting roller after crosskill roller (VCRCR). The compacting wheel and rollers were installed on the planter behind disc openers (Figure 1). CW only compressed the intrarow soil surface just behind the opener; both CR and VCRCR compressed both the intra- and interrow soil surface. The urea fertilizer was applied at rate of 225 kg/ha at jointing stage.

2.3. Measured Parameters. Soil temperature and shoot growth parameters were obtained from November, 2015, to March, 2016, to determine the effect of postsowing compaction on cold and frost tolerance. Winter rainfall and air temperature are shown in Figure 2.

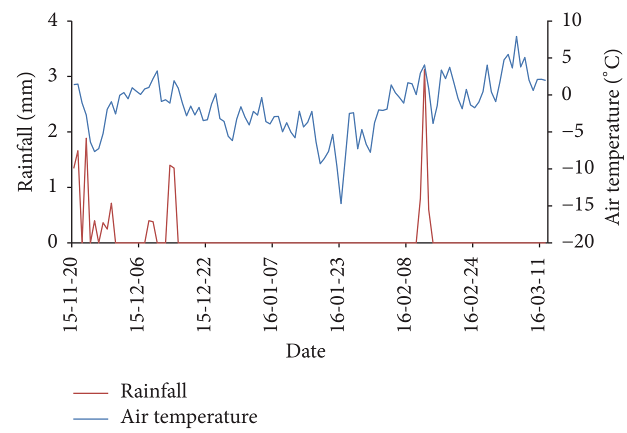
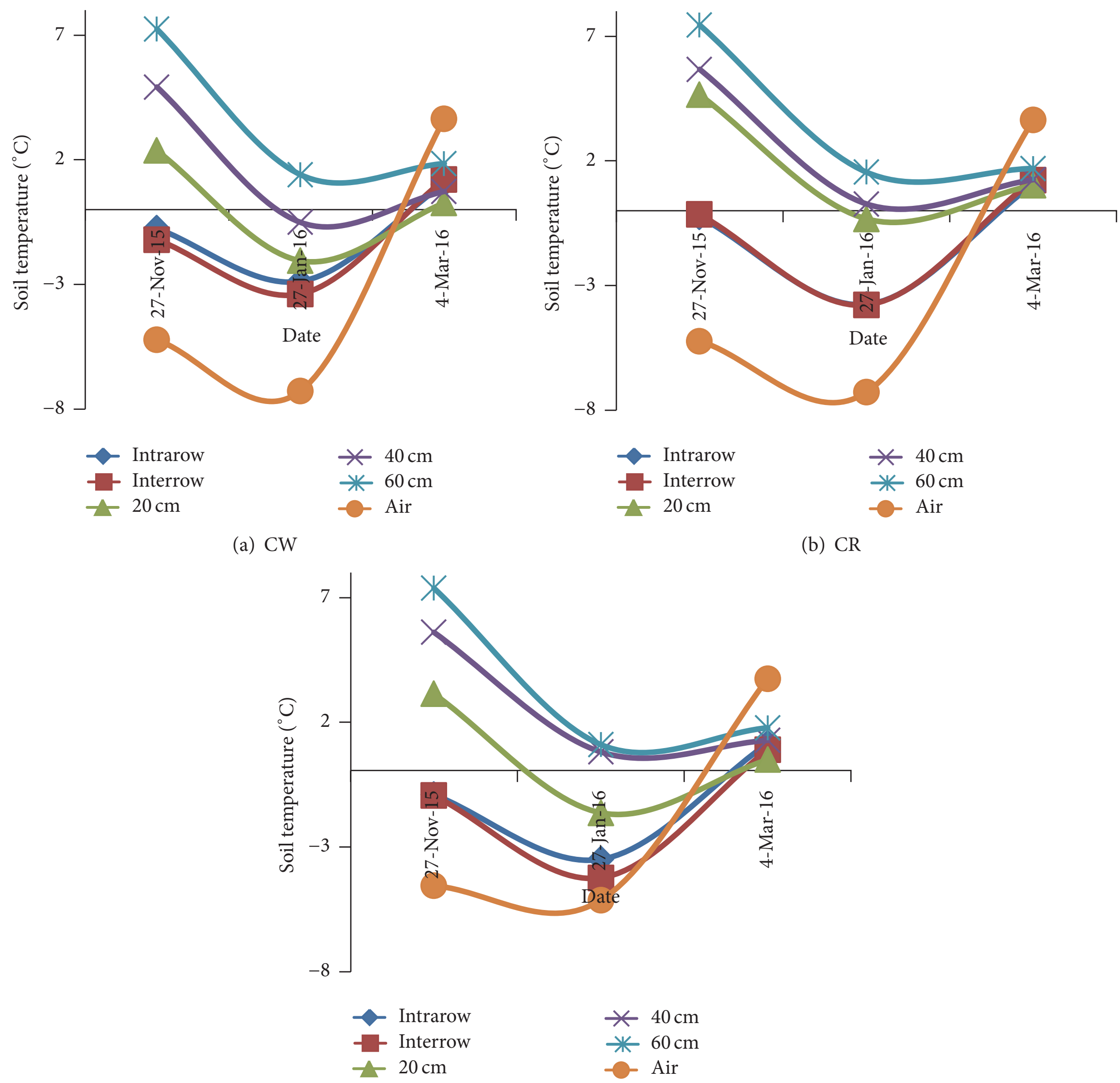


Figure 2: Distribution of rainfall and temperature at experiment site.

2.3.1. Soil Temperature. Soil temperature was continuously recorded to a depth of 60 cm from sowing to green stage. In each plot, five soil temperature sensors were inserted into the intrarow and interrow soil surface and random position at depths of 20 cm, 40 cm, and 60 cm. The sensors were connected to a solar-powered automatic weather station that recorded data hourly. A 24-hour period at the beginning (November 27, 2015), middle (January 27, 2016), and end (March 4, 2016) of wintering period was selected for statistical comparison of the effect of postsowing compaction on soil temperature.

2.3.2. Shoot Growth Parameters. Shoot length and fresh and dry weight were measured at the end (March 4, 2016) of the wintering period. Shoot number was measured at the beginning (November 27, 2015) and the end (March 4, 2016) of wintering period. Shoot dry weights were determined after



(a) CW (b) CR (c) VCRCR

FIGURE 3: Mean soil and air temperature during wintering period.

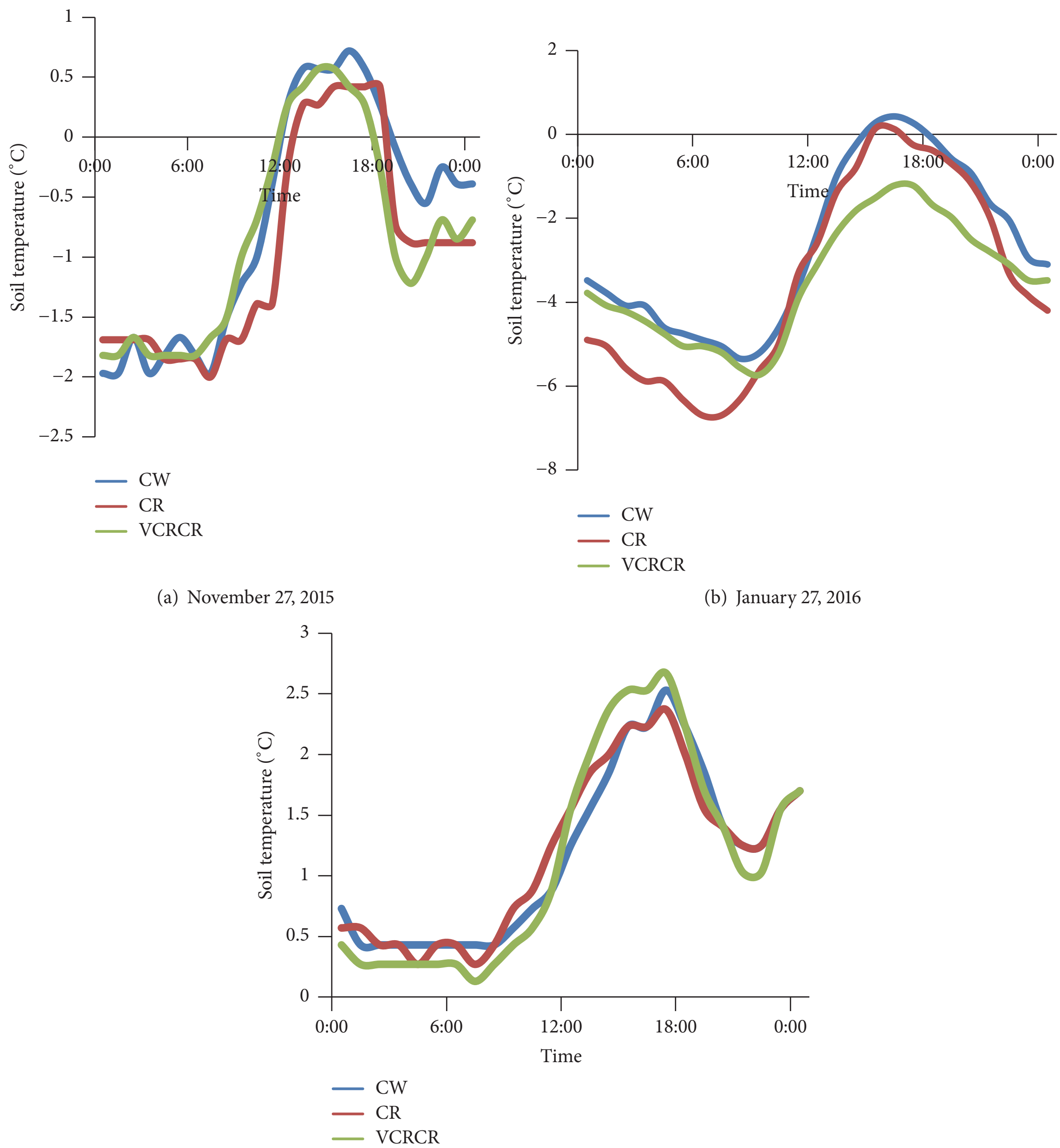
heating at 105°C for 15 min, followed by incubation at 80°C for 24 h [21–24]. All measurements were performed in triplicate and the data thus obtained was averaged.

2.4. Statistical Analysis. Mean values were calculated for each of the measured variables, and ANOVA was used to assess the treatment effects. When ANOVA indicated a significant F-value, multiple comparisons of mean values were performed by the least significant difference test at $\alpha = 0.05$.

3. Results

3.1. The Relationship between Soil Temperature and Air Temperature. Midwinter was the coldest of the three sampling stages (Figure 3). All sampling depths followed a similar pattern of temperature change with air temperature. There was less temperature differences between sampling dates at the deeper sampling depths, and temperature generally increased with sampling depth during entire winter period. At the beginning and middle of wintering period, soil temperature for each depth was significantly higher than air temperature; however, at the end of wintering period, air temperature was greater than soil temperature at any depth.

The compaction treatments affected soil temperature. Under CW treatment, there were significant differences in soil temperatures at the beginning and middle of wintering period, with 60 cm > 40 cm > 20 cm > intrarow > interrow. Soil temperatures in the 60 cm soil layer were 2.33°C, 4.88°C, 8.45°C, and 8.00°C higher at the beginning and 1.91°C, 3.45°C, 4.78°C, and 4.28°C higher at the middle of wintering period than 40 cm, 20 cm, interrow, and intrarow soil surface layer, respectively. Under CR treatment, soil temperature in 60 cm soil layer was significantly 1.78°C, 2.80°C, 7.60°C, and 7.70°C



(a) November 27, 2015

(b) January 27, 2016

(c) March 4, 2016

Figure 4: Temporal soil temperature changes on intrarow soil surface under different postsowing compaction treatments.

higher at the beginning and 1.28°C, 1.88°C, 5.33°C, and 5.31°C higher at the middle of wintering period than 40 cm, 20 cm, interrow, and intrarow soil surface layer, respectively. Soil temperature on the intrarow soil surface was equivalent to the interrow soil surface. However, surface soil temperatures were remarkably lower than deeper soil layers. Under VCRCR treatment, soil temperature in 60 cm soil layer was separately 1.75°C, 4.20°C, 8.24°C, and 8.21°C higher than 40 cm, 20 cm, interrow, and intrarow soil surface layer at the beginning of wintering period. And significant differences only occurred between 60 cm soil layer and 20 cm layer or on the soil surface. Soil temperature on the intrarow soil surface was 20.84% higher than that on interrow soil surface layer in the middle of wintering period and remarkably lower on the surface soil than deeper soil layers. At the end of wintering period, soil temperature had no remarkable distinction between soil layers for all treatments.

3.2. Temporal Soil Temperature Changes on Intrarow Soil Surface. Soil surface temperatures on the intrarow followed the typical sinusoidal pattern (Figure 4), with minimum temperatures at 6:00–8:00 and maximum soil temperature at 15:00–17:00. At the beginning of wintering period, the maximum soil temperature under CW was 0.3°C and 0.15°C higher than CR and VCRCR treatments, and the minimum soil temperature under the CW treatment was 0.03°C higher than

CR treatment but 0.15°C lower than VCRCR treatment. In the middle of wintering period, the maximum soil temperature under CW treatment was 0.3°C and 1.65°C higher than CR and VCRCR treatments, and the minimum soil temperature under CW treatment was 1.35°C and 0.38°C higher than CR treatment and VCRCR treatment, respectively. At the end of wintering period, the maximum soil temperature under CW treatment was 0.16°C higher than CR treatment and 0.14°C lower than VCRCR treatment, and the minimum soil temperature under CW treatment was 0.16°C and 0.3°C higher than CR treatment and VCRCR treatment, respectively. At the beginning and end of the wintering period, soil temperature was unaffected by compaction. However, treatment differences were significant in midwinter. CR had the lowest soil temperatures throughout the midwinter sampling period and CW the highest.

3.3. Temporal Soil Temperature Changes on Interrow Soil Surface. Temporal soil temperature changes on interrow soil surface during wintering period were showed at Figure 5. The trend of temporal soil temperature changes on interrow soil surface was similar to those on intrarow surface. At the beginning of wintering period, CR and VCRCR treatments had the highest maximum soil temperatures, 0.15°C higher than CW treatment. The lowest minimum soil temperature occurred in the CW treatment, 0.26°C and 0.53°C lower than CR and VCRCR treatments, respectively. In the middle of wintering period, CR had the highest maximum soil temperature, 0.53°C higher than CW or VCRCR treatments. The highest minimum soil temperature occurred under the CW treatment, which was 0.97°C and 1.27°C higher than CR and VCRCR treatments, respectively. At the end of wintering period, the highest maximum soil temperature was under CR treatment, 0.46°C and 1.13°C higher than CW and VCRCR. CW treatment had the same minimum soil temperature with CR, which was 0.16°C higher than VCRCR treatment.

3.4. Temporal Soil Temperature Changes in Different Soil Depth. Temporal soil temperature in the 20–60 cm soil layer increased with increasing soil depth (Figure 6). Only the 20 cm soil layer in the middle of wintering period displayed significant diurnal temperature variation and also the greatest differences between treatments. In the 20 cm and 40 cm soil layer, soil temperatures were ranked in the following order of CW > VCRCR > CR during the entire wintering period. Soil temperature under CW treatment was significantly higher than that under CR treatment at the beginning and middle of wintering period and remarkably higher than that under VCRCR treatment in the middle of wintering period in the 20 cm soil layer. CW treatment had remarkably higher soil temperature than CR during the entire wintering period and higher than VCRCR in the middle of wintering period; soil temperature under VCRCR treatment was notably higher than that under CR treatment at all stages in the 40 cm soil layer. There were no significant differences in the 60 cm soil layer.

3.5. Shoot Growth Parameters at the Beginning and End of Wintering Period. Shoot number at the beginning of the wintering period (November 27, 2015) had no significant difference between every two treatments (Table 1). At the end of wintering period (March 4, 2016), shoot number was 12.40% and 8.18% higher under CW compared to CR and VCRCR treatments, and only CW and CR treatments were significantly different.

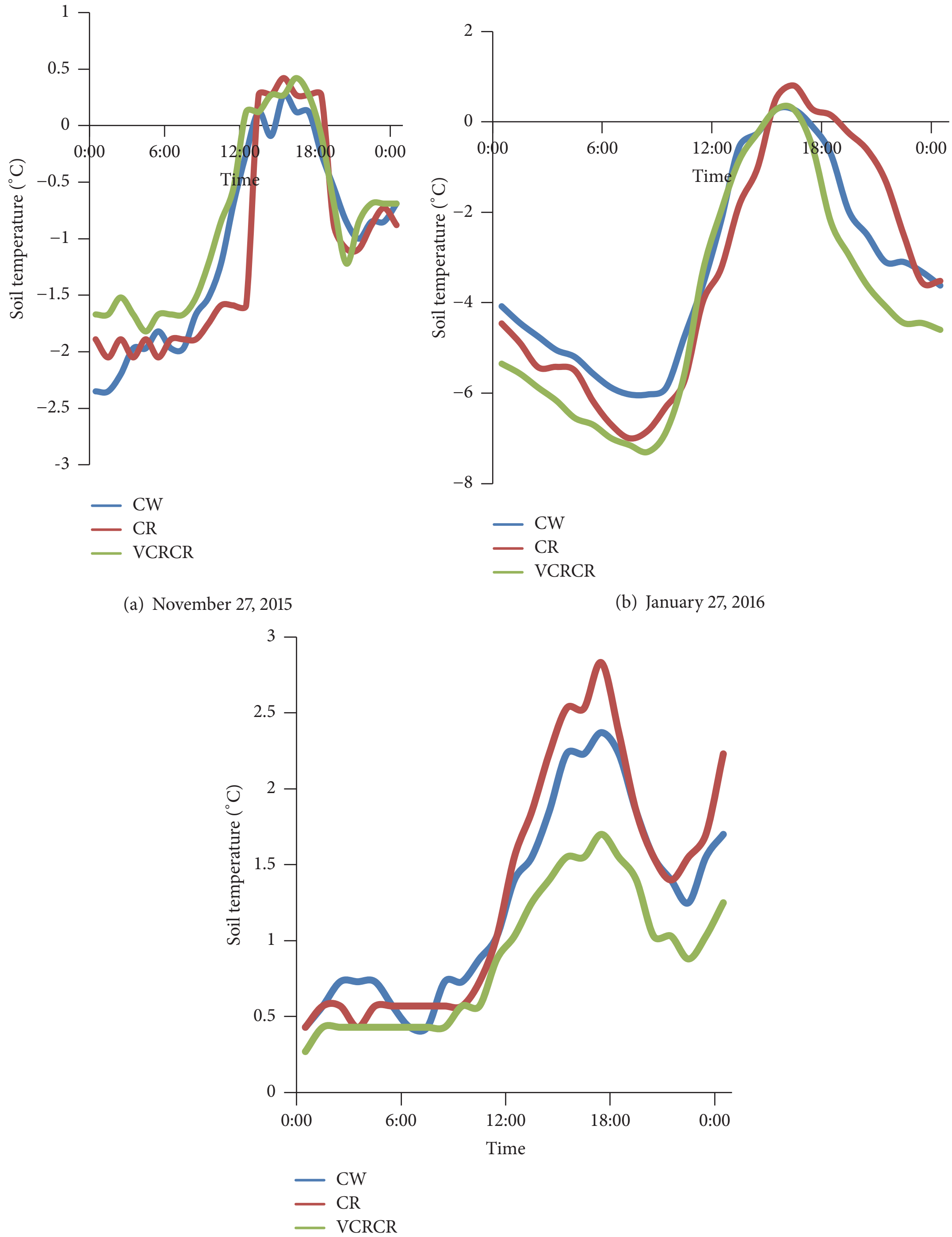
Shoot length was 8.68% and 4.78% taller under the CW treatment than CR and VCRCR treatments (Table 2). Fresh weight of 10 shoots was 9.57% and 7.66% lower under CR treatment than CW and VCRCR treatments; shoot dry weight was 14.30% and 13.79% lower under CR treatment than CW and VCRCR treatments, respectively. The difference between CW and VCRCR treatments was not significant both for shoot fresh and for dry weight.

4. Discussion

Consistent with previous studies [25–27], we found that the hourly change in soil temperature followed that of daily air temperature, although the amplitude was smaller than air temperature. Temporal soil temperature on the intra- and interrow surface soil layer had a similar diurnal pattern as with air temperature, but also with a smaller fluctuation; this same pattern has been reported by several previous authors [28–30]. However, temporal soil temperature in the 20–60 cm depths was stable in a 24-hour cycle; however, it had an analogical change rule with the surface soil temperature and air temperature in the whole wintering period, which manifested that temperature in deeper soil layers had a hysteresis compared to surface soil and air temperature. This may be because soil temperature change is the result of energy absorption from solar radiation and air temperature and the subsequent release, which results in smaller soil temperature fluctuations as soil depth increased. These results were in agreement with Liao et al. [31], who reported that variation in soil temperature was lower at deeper soil as compared to that in the surface soil, indicative of thermal insulation provided by vegetation, water, and surface soil layers.

There is limited information on the effects of postsowing compaction on soil temperature variation.

In this study, we observed that soil temperature on the intrarow soil surface under CW treatment was higher than CR and VCRCR treatments, especially at the coldest stage in the middle of wintering period. This indicated that CW had the ability to increase soil temperature, particularly at colder weather. Our study demonstrated that soil temperature on the intrarow soil surface was similar to that on the interrow soil surface under CR treatment; however, it was 20.84% higher on the intrarow soil surface than interrow soil surface layer in the middle of wintering period under VCRCR treatment. This indicated that different levels of compaction (CR treatment compacted planted soil once, and VCRCR treatment compacted planted soil twice) resulted in differences between intrarow and interrow soil surface, with heavier compaction causing higher soil temperature on the intrarow soil surface. In addition, soil temperature on the intrarow soil surface was significantly higher than that on the interrow soil surface during wintering period, especially in the middle of the period under the CW treatment, which



(a) November 27, 2015

(b) January 27, 2016

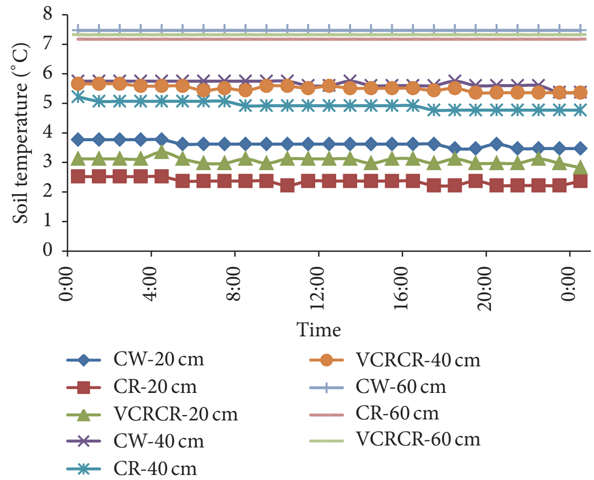
(c) March 4, 2016

Figure 5: Temporal soil temperature changes on interrow soil surface under different postsowing compaction treatments.

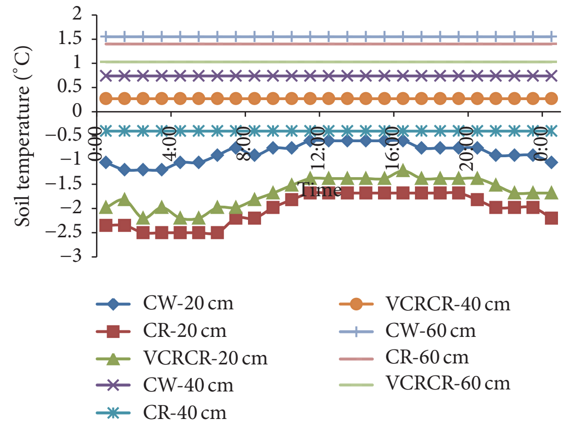
Table 1: Shoot number under different treatments on November 27, 2015, and March 4, 2016 (thousands/ha).

Date	Treatments		
	CW	CR	VCRCR
27-Nov	8688a	8146a	8350a
4-Mar	6893a	6038b	6329ab
Winter survival	0.79a	0.74b	0.76ab

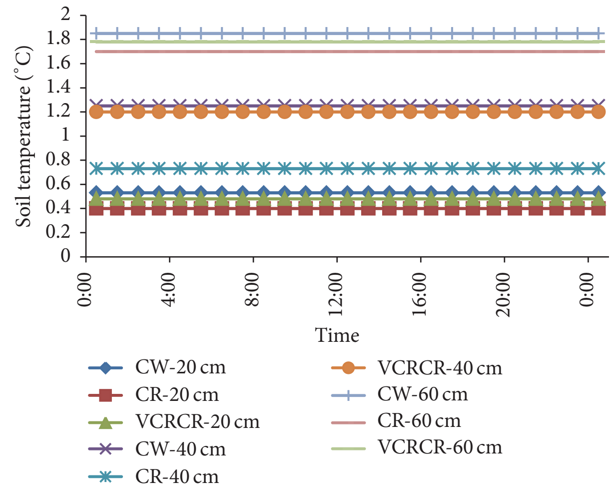
Means in the same rows followed by the same letter are not significantly different.



(a) November 27, 2015



(b) January 27, 2016



(c) March 4, 2016

Figure 6: Temporal soil temperature changes in different soil depth under different postsowing compaction treatments during wintering period.

Table 2: Shoot length and fresh and dry weight per 10 shoots under different treatments on March 4, 2016.

Test item	Treatment		
	CW	CR	VCRCR
Shoot length/mm	366.30a	334.50b	348.80ab
Shoot fresh weight per 10 shoots/g	36.06a	32.91b	35.43a
Shoot dry weight per 10 shoots/g	8.95a	7.83b	8.91a

Means in the same row followed by the same letter are not significantly different.

showed that seedlings and wheel compaction had a function to increase soil temperature (there were no compaction and seedlings on the interrow soil surface under CW treatment). The CW treatment had higher soil temperature and shoot winter survival (Table 1), length, and fresh and dry weight (Table 2) compared to the CR or the VCRCR treatments at the end of wintering period. This indicates that improvement in soil temperature was a factor contributing to the superior cold and frost tolerance capacity during wintering period [32–34]. Our data indicate that postsowing compaction with the CW treatment could improve soil temperature and winter wheat cold and frost tolerance capacity.

5. Conclusions

We measured how soil temperature was affected by different postsowing compaction methods during the wintering period in the North China Plain. To determine the resistance of wheat frost damage response to soil temperature as affected by postsowing compaction during wintering period, shoot growth parameters including shoot number, length, and fresh and dry weight at the beginning and end of wintering period were measured. We found that, during the wintering period, the trend of soil temperature change was similar to air temperature, but the gap between maximum and minimum soil temperature was smaller compared to air temperature. Data indicated that the adoption of CW significantly improved a wide range of soil temperature on the intrarow and deeper depth soil layer and thus contributed to higher shoot number, length, and fresh and dry weight.

The resultant positive changes in soil temperature and shoot growth parameters reduced the shoot death caused by frost damage and improved shoot winter survival under the CW treatment, making it a viable option for improving wheat production in the North China Plain. Since physicochemical presowing seed treatments have been reported to be highly efficient in enhancing the germination, growth, and productively of crops, further experiments for the synthetic action of postsowing compaction and presowing seed treatments are needed to confirm the effects of enhancing crop growth characteristics and productivity.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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