

Hydrothermal Characteristics and Yield Effects of Winter Wheat Fields under Full Film Mulching with Soil Covering and Hole Sowing in Coastal Low Plain Arid Areas: Postprint

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Abstract

To investigate the effects of whole plastic film mulching with soil-covered dibbling cultivation technology on soil moisture, salinity, temperature, thermal regime, and winter wheat yield in the low plain region of the Bohai Rim, a field experiment was conducted during 2014–2015 at the Nanpi Eco-Agricultural Experimental Station, Chinese Academy of Sciences. Winter wheat experiments with whole plastic film mulching with soil-covered dibbling (PM) and conventional rotary tillage sowing (CK) were established, and the dynamics of soil temperature, moisture, salinity, and heat flux in the tillage layer were monitored at fixed points, with winter wheat yield analyzed. The results indicated that PM could effectively conserve soil moisture during the overwintering and regreening periods, with average soil moisture content being 16.4% higher than that of CK, reaching a significant difference ($P < 0.05$); however, film mulching also blocked the replenishment of soil moisture by later-stage precipitation, with the maximum moisture content difference reaching 10.0%. The daily average soil temperature at 10 cm depth under PM treatment was consistently higher than that under CK treatment, with an average increase of 3.8%, though the difference was not significant ($P > 0.05$); simultaneously, PM reduced the diurnal temperature range of soil by 0.5 °C. PM was beneficial for soil heat absorption and storage, with higher downward ground heat flux during daytime, and the daily average soil heat flux increased significantly by several times compared with CK. Both temperature and heat flux changes indicated that mulching enhanced the soil's ability to resist external temperature variations. The soil electrical conductivity under PM was significantly lower than that of CK by 24.2% ($P < 0.05$), especially during the spring salt-returning period, when the soil electrical conductivity under PM decreased by 39.7% compared with CK. PM increased the grains per spike and thousand-grain weight of winter wheat

compared with CK, with a yield increase of 10.4%, but neither reached significant levels. Therefore, the whole plastic film mulching with soil-covered dibbling winter wheat cultivation technology can improve soil hydrothermal conditions and reduce the harm of soil salinity to wheat, providing theoretical and technical support for the application of this technology in agricultural production in the arid low plain area of the Bohai Rim region.

Full Text

Preamble

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Soil Thermal-Moisture Characteristics and Yield Effects of Whole Field Plastic Mulching with Bunch Planting for Winter Wheat in Arid Coastal Lowland Plains

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Abstract

To investigate the effects of whole field plastic mulching with soil covering and bunch planting on soil moisture, salinity, temperature, thermal regime, and winter wheat yield in the Bohai Rim low plain region, a field experiment was conducted during the 2014–2015 growing season at the Nanpi Eco-agricultural Experimental Station of the Chinese Academy of Sciences. Two treatments were established: whole field plastic mulching with bunch planting (PM) and conventional rotary tillage sowing as the control (CK). Soil temperature, moisture, salinity, and heat flux in the cultivated layer were continuously monitored, and winter wheat yield was analyzed. The results showed that PM effectively conserved soil moisture during the wintering and re-greening stages, with average soil water content 16.4% higher than CK ($P < 0.05$). However, the plastic film also blocked precipitation infiltration later in the season, resulting in a maximum water content difference of 10.0% compared with CK. The daily average soil temperature at 10 cm depth under PM was consistently higher than CK throughout the growing season, with an average increase of 3.8%, though the difference was not statistically significant ($P > 0.05$). PM also reduced the diurnal temperature range by 0.5 °C. PM enhanced soil heat absorption and storage, exhibiting higher downward ground heat flux during daytime, with daily average soil heat flux increasing several-fold compared with CK. Both temperature and heat flux dynamics demonstrated that mulching enhanced soil capacity to resist external temperature fluctuations. Soil electrical conductivity under PM was significantly lower than CK by 24.2% ($P < 0.05$), particularly during the spring salt-return period when PM reduced soil electrical conductivity by 39.7%

compared with CK. PM increased kernels per spike and 1000-kernel weight of winter wheat, resulting in a 10.4% yield increase, though these differences were not statistically significant. Therefore, whole field plastic mulching with bunch planting for winter wheat can improve soil hydrothermal conditions and reduce salt damage, providing theoretical and technical support for applying this technology in the arid coastal low plain region of the Bohai Rim.

Keywords: Whole field plastic mulching; Bunch planting; Soil water content; Soil salinity; Soil heat flux; Winter wheat

The Bohai Rim low plain region enjoys abundant light and heat resources and possesses rich land reserves, serving as a frontier zone for coastal development strategies and a potential area for grain production increases in Hebei Province. Winter wheat is the main grain crop in this region, with a planting area of 734,000 hectares. However, the region suffers from severe freshwater scarcity, uneven precipitation distribution leading to seasonal drought, and poor alignment between natural rainfall and winter wheat water demand patterns [1-2]. Additionally, winter wheat is frequently affected by spring soil salt return and low temperature stress, resulting in chronically low and unstable yields [3-5]. Therefore, identifying effective measures to conserve and utilize precipitation, improve spring soil thermal conditions, suppress soil salt return, and increase crop yield has become critical for wheat production in this region.

Numerous studies have demonstrated that plastic mulching in arid regions can reduce soil evaporation losses [6-8], improve crop water and nutrient use efficiency [9-11], and increase yields [12-14], while also raising soil temperature and alleviating salinity damage [7,9]. However, some research indicates that mulched wheat may suffer from heat stress during late growth stages, leading to premature senescence and yield reduction [15-17]. Other studies show that mulching can intensify soil water consumption, with yield improvements built upon higher water use [17-20], and that mulching effects on crop water consumption vary regionally [21-23].

In recent years, whole field plastic mulching with soil covering and bunch planting has emerged as an integrated water-harvesting and evaporation-suppressing technology that efficiently utilizes light and heat resources. This technique has demonstrated significant effects on moisture conservation, water use efficiency improvement, and yield increase, and has been widely adopted in northwestern China [9,12,14,17,21]. Current research on this technology has primarily focused on moisture retention and temperature enhancement, crop water consumption patterns, and yield effects. However, few studies have examined its impacts on soil moisture and salinity in winter wheat fields in the Bohai Rim low plain region, or how it influences soil temperature and thermal regimes. The adaptability of this technology in the Bohai Rim low plain region requires further investigation. Therefore, this study was conducted at the Nanpi Eco-agricultural Experimental Station to analyze how whole field plastic mulching with bunch

planting affects soil temperature and thermal conditions in winter wheat fields, providing a theoretical basis for observing and evaluating hydrothermal effects. Additionally, this research offers insights for developing high-yield cultivation patterns and unlocking grain production potential in the Bohai Rim low plain region.

1.1 Study Area Description

The experiment was conducted during the 2014–2015 growing season at the Nanpi Eco-agricultural Experimental Station of the Chinese Academy of Sciences, located at 38°06' N, 116°40' E, at an elevation below 20 m. The region has a mean annual temperature of 13.4 °C, \$ 10 °C accumulated temperature of 4,600 °C, annual sunshine duration of 2,318 h, and water surface evaporation of 1,500–1,800 mm. The experimental area is a coastal, arid, water-deficient, and salinized region, with multi-year average precipitation of 572.5 mm, concentrated in June–August (421.5 mm, accounting for 73.6% of annual precipitation). No surface irrigation is available, but shallow brackish groundwater resources are abundant with a water table depth of 5–7 m.

The cultivated soil is light loamy fluvo-aquic soil, with topsoil salt content of 1.08–1.15 g · kg⁻¹, classifying it as lightly salinized soil with distinct seasonal salt accumulation or leaching. Soil bulk density is 1.42 g · cm⁻³, average field capacity is 34.2%, topsoil organic matter is 10–12 g · kg⁻¹, and available nitrogen, phosphorus, and potassium are 98 mg · kg⁻¹, 15 mg · kg⁻¹, and 100 mg · kg⁻¹, respectively.

1.2 Experimental Design

A field experiment was conducted with two treatments: whole field plastic mulching with bunch planting (PM) and conventional rotary tillage sowing as the control (CK). Each treatment plot was 240 m² without replication. For the PM treatment, after summer maize harvest, a specialized wheat mulching and planting machine (2MXF-120 type) performed all operations in one pass, including rotary tillage, compaction, film laying, soil covering, and planting. The seeding rate was 112.5 kg · hm⁻², with hole spacing of 12 cm, row spacing of 20 cm, and 1 cm of soil covering on the film surface. For the CK treatment, the seeding rate was 225 kg · hm⁻² with row spacing of 15 cm. Both treatments received 25 kg of diammonium phosphate (N-P₂O₅-K₂O: 18-46-0) as base fertilizer applied before winter wheat planting. Winter wheat (variety 'Xiaoyan 81') was sown on October 20, 2014, and harvested on June 10, 2015.

Data were analyzed using SPSS 16.0 software, and LSD tests were used for significance comparison of yield and its components.

1.3 Measurement Methods

Soil moisture, temperature, and electrical conductivity: After winter wheat emergence in October 2014, soil temperature-salinity-moisture sensors (CS650 Soil Water Content Reflectometers, Campbell Inc., USA) were installed at 5 cm and 10 cm depths in the center of wheat rows. These sensors simultaneously measured soil water content, temperature, and apparent electrical conductivity, controlled and recorded by a data logger (CR1000, Campbell Inc., USA) at 2-hour intervals.

Soil heat flux: Soil heat flux plates (HFP01, Hukseflux, Netherlands) were installed at 7.5 cm depth adjacent to the soil sensors, connected to the same CR1000 data logger with a 30-minute recording interval.

Winter wheat yield: At maturity, a 2 m² sampling area was randomly selected in the center of each treatment plot with four replications for harvest and threshing; the average represented actual yield. Spike number was surveyed in 1 m double rows per treatment. Twenty spikes were randomly selected from each treatment to determine kernels per spike and 1000-kernel weight.

Data processing: Microsoft Excel 2003 was used for data processing.

2.1 Effects of Whole Field Plastic Mulching on Soil Moisture in Winter Wheat Fields

[Figure 1: see original paper] shows the temporal variation of soil water content at 10 cm depth in winter wheat rows along with precipitation. The trends of surface soil water content were generally consistent between treatments, but differed across growth stages. During the wintering and re-greening stages, average soil water content under PM was 14.8%, significantly higher than CK at 12.7% ($P < 0.05$), indicating effective moisture conservation. After re-greening, precipitation caused rapid increases in soil water content followed by gradual declines, with CK showing greater amplitude of increase and decrease than PM. CK had significantly higher soil water content than PM, especially after rainfall when the difference reached 10.0%, demonstrating that mulching blocked precipitation infiltration. However, during later growth stages (booting to harvest), the difference between treatments became insignificant, likely due to reduced water consumption by mature wheat and decreased evaporation from canopy shading.

2.2 Effects of Whole Field Plastic Mulching on Soil Temperature and Heat Flux in Winter Wheat Fields

[Figure 2: see original paper] illustrates the dynamic changes in soil temperature at 10 cm depth in winter wheat rows. The daily average soil temperature trends were similar between treatments. PM consistently maintained higher daily average temperature at 10 cm depth than CK, with an average increase

of 1.5 °C across the entire growth period ($P > 0.05$), particularly during the wintering stage (December 2014–mid-February 2015). However, during later growth stages (after mid-March), the temperature difference narrowed, with PM only 0.3 °C higher than CK, indicating that mulching moderately increased soil temperature during early growth, benefiting wheat development.

Throughout the growing season, PM reduced daily maximum temperature by 0.8 °C and increased daily minimum temperature by 0.3 °C compared with CK. Combined, these effects significantly reduced the diurnal temperature range under PM, though this difference diminished as the season progressed.

Soil heat flux is fundamental for studying land-atmosphere energy exchange and simulating land surface energy processes [24–25]. Positive values indicate downward heat transfer, while negative values indicate upward transfer. Daily average soil heat flux under PM was significantly higher than CK ([Figure 3: see original paper]), with a seasonal average of $13.4 \text{ W} \cdot \text{m}^{-2}$, $14.8 \text{ W} \cdot \text{m}^{-2}$ higher than CK, indicating that mulching facilitated soil heat absorption and storage. The inset in Figure 3 shows soil heat flux at 7.5 cm depth on April 13. The difference between treatments was significant ($P < 0.05$): during peak heat transfer hours (11:00–14:00), CK heat flux was only 45–60% of PM. Temporally, CK reached peak heat flux approximately 0.5 hours later than PM. This demonstrates that PM had higher downward heat flux during daytime and lower upward heat flux at night, enhancing soil capacity to resist external temperature variations.

2.3 Effects of Whole Field Plastic Mulching on Soil Salinity in Winter Wheat Fields

[Figure 4: see original paper] shows the temporal variation of electrical conductivity at 10 cm depth in winter wheat rows. The dynamic trends of apparent soil electrical conductivity were generally consistent between treatments, but CK had 31.9% higher conductivity than PM throughout the growing season ($P < 0.05$), reaching 65.8% higher during the spring salt-return period (mid-February–late March 2015). After re-greening (mid-February 2015), PM maintained the lowest soil electrical conductivity without showing salt-return phenomena as temperature increased. Thus, mulching effectively suppressed soil salt return and prevented salt damage to winter wheat.

2.4 Effects of Whole Field Plastic Mulching on Winter Wheat Yield

Yield and yield components of winter wheat under PM and CK are presented in Table 1. PM increased kernels per spike and 1000-kernel weight by 9.8% and 4.4%, respectively, though differences were not significant. Spike number under PM was 3.4% lower than CK (not significant). PM increased winter wheat yield by 10.4% compared with CK. These results indicate that PM primarily improved kernels per spike and 1000-kernel weight to achieve yield increases.

Table 1 Comparison of winter wheat yield and its components between whole field plastic mulching with bunch planting (PM) and conventional rotary tillage sowing (CK)

Treatment	Spike number ($10^4 \cdot \text{hm}^{-2}$)	Kernels per spike	1000-kernel weight (g)	Yield (kg · hm^{-2})
PM	534.90±33.20a	29.0±1.0a	37.8±0.6a	5,869.69±611.32a
CK	553.95±37.96a	26.4±3.1a	36.2±1.3a	5,869.69±611.32a

3 Discussion and Conclusions

Plastic mulching cultivation effectively harvests rainwater and conserves soil moisture by reducing ineffective evaporation between plants, significantly improving soil water conditions during crop growth [12,19–20]. Consequently, regulating soil moisture through mulching to create more favorable environments for crop growth has become an important approach for high-yield cultivation in arid regions. Mulching can increase soil water storage by 30% and reduce evapotranspiration by 50%, directing limited water resources primarily to crop transpiration [25–27]. Plastic-mulched winter wheat can maintain 9.4–11.9% higher water content in the cultivated layer from wintering to jointing stages compared with bare land [14]. Additionally, plastic mulching effectively regulates the temporal and spatial redistribution of soil moisture, promoting a virtuous cycle of soil-plant water relations [18].

In this study, whole field plastic mulching effectively protected soil moisture and reduced large fluctuations in water content. Particularly during wintering and re-greening stages, soil water content was 16.4% higher than CK, avoiding drought stress damage during the critical re-greening period and providing favorable moisture conditions for later growth. These results align with previous findings [18]. However, this study also revealed that due to the barrier effect of plastic film, soil could not receive adequate rainwater supplementation after re-greening, causing PM soil water content to fall below CK and resulting in inefficient use of rainfall. After precipitation in mid-February, CK soil could promptly and fully receive infiltration, achieving maximum water content 28.0% higher than PM. During later growth stages (after April), differences between treatments became insignificant due to canopy interception and film degradation, with PM averaging only 9.7% lower than CK. Precipitation amount and timing in the experimental region may be the main reasons for differences between this study and results from northwestern China. Higher water content in CK during early seedling stages may result from soil compaction by agricultural machinery during planting.

Soil thermal regime affects seed germination, root growth, and microbial activity, representing a critical environmental factor that directly or indirectly influences crop growth [8,11,18]. Plastic film can eliminate soil latent heat exchange, reduce sensible heat exchange, and suppress nighttime effective radiation emission, resulting in higher soil temperatures under mulch [7,13]. Low

temperatures during seedling stage can affect winter wheat germination and morphological establishment, and the warming effect of mulching effectively addresses this issue [9]. In this study, PM increased soil temperature by an average of 3.8% and increased daily downward soil heat flux several-fold compared with CK, improving surface soil thermal conditions and benefiting germination and early growth, consistent with previous research [7,9]. During later growth stages, wheat canopy shading and soil covering by the film reduced surface air movement and evaporation intensity, hindering water-heat transfer at the soil-atmosphere interface and gradually narrowing temperature and heat flux differences between treatments, thereby avoiding heat stress and premature senescence [7,9]. Additionally, PM reduced diurnal temperature variation and moderated temperature change trends compared with CK, decreasing the risk of freezing damage from excessive temperature fluctuations. The fact that PM absorbed more heat energy during daytime and released less at night further demonstrates its enhanced capacity to resist external temperature changes.

Spring soil salt return easily causes salt stress damage to winter wheat in the Bohai Rim low plain region [3]. Soil salinity in the 0-20 cm layer is the primary factor affecting early growth and yield, and plastic mulching suppresses surface salt accumulation, reduces salinity hazards, improves root growth environments, and enhances ecological adaptability to salt stress [15]. Throughout the growing season, PM maintained lower soil electrical conductivity than CK, with particularly significant differences during spring re-greening when salt reduction effects reached approximately twofold, effectively suppressing salt return and preventing salt damage. Salt migration occurs with water movement, as water is the primary carrier. Although precipitation increases soil water content, adsorbed salt ions are released as water content rises, increasing soil solution concentration and electrical conductivity. Plastic mulching suppresses soil evaporation, reduces water loss, prevents upward movement of deep soil salts with water, and weakens surface salt accumulation [28]. Additionally, freshwater condensing on the underside of the film from soil evaporation and subsequently dripping back onto the soil surface provides some leaching effect on soil salts [29].

Whole field plastic mulching improved soil hydrothermal conditions and reduced spring salt return damage, thereby promoting winter wheat root water utilization capacity [18-19]. Mulching can enhance source-sink capacity and material translocation during later stages, achieving efficient water use and yield increases [15]. In this study, PM promoted early vegetative growth by improving soil water, temperature, and salinity conditions, and facilitated kernel formation and filling during later stages without heat stress or water deficit, increasing kernels per spike and 1000-kernel weight compared with CK. Therefore, whole field plastic mulching technology can improve yield components and increase winter wheat yield by modifying population structure and fully exploiting individual plant potential.

Overall, whole field plastic mulching with bunch planting improves soil hydrothermal conditions, reduces salt damage, and can improve yield components

and increase yield at lower seeding rates. This has positive significance for enhancing winter wheat field productivity, increasing crop yields, and improving sustainable farmland utilization in the Hebei low plain region. However, plastic film should be promptly removed after harvest to allow soil to receive abundant summer rainfall and store sufficient water for subsequent summer maize growth and the next winter wheat planting. Since this study was based on one-year hydrothermal data and did not address soil fertility conditions, future research should investigate the coupled effects of water-heat and nutrient supply capacity on field productivity. Additionally, studies on negative impacts of whole field plastic mulching in the Bohai Rim low plain region should be strengthened to propose reasonable countermeasures, ensuring safe and appropriate technology application and providing stronger support for grain production improvement and water-saving model development in this region.

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