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Effects of Liquid Film Mulching on Soil Structural Characteristics and Infiltration Performance in Dryland: Postprint

Authors: Bai Xiumei, Zhang Yao

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Abstract

To investigate the effects of long-term liquid film mulching on soil structure and infiltration performance in dryland soils, a randomized block field experiment was conducted from 2015 to 2018 at the Forestry Experiment Station of Shanxi Agricultural University. The experiment employed two tillage methods (ridge-furrow tillage and flat planting) combined with two mulching materials (liquid film and plastic film), with flat planting without mulching as the control (CK). The results showed that: (1) Compared with CK, the treatments of ridge-furrow tillage with liquid film mulching (PY), flat planting with liquid film mulching (LY), ridge-furrow tillage with plastic film mulching (PS), and flat planting with plastic film mulching (LS) all significantly increased soil organic matter content and capillary porosity, while significantly reducing soil bulk density. Among these, the PY treatment showed the most pronounced effect, with increases of 30.6% and 17.1% in organic matter content and capillary porosity, respectively, and a 7.9% decrease in bulk density. (2) All mulching treatments significantly improved soil structural characteristics, as evidenced by increased contents of >0.25 mm aggregates in both dry and wet sieving, reduced soil aggregate structure destruction rate, and enhanced aggregate water stability index. The PY treatment demonstrated the greatest improvement in aggregate stability. (3) The stable infiltration performance of the soil was significantly enhanced under mulching treatments, with the stable infiltration rate, average infiltration rate, and initial infiltration rate all showing significant increases. The PY treatment achieved the highest values, with increases of 76.9%, 65.3%, and 54.3% compared to CK, respectively. (4) Correlation analysis revealed that soil infiltration rates were significantly or extremely significantly correlated with organic matter content, capillary porosity, bulk density, and aggregate stability indicators. (5) In summary, long-term liquid film mulching, particularly when combined with ridge-furrow tillage, can effectively improve soil physicochemical properties, enhance soil aggregate structure, and increase

infiltration capacity, thereby representing an effective soil management practice for dryland agricultural production.

Full Text

Effects of Liquid Film Mulching on Soil Structure Characteristics and Infiltration Performance of Drylands

BAI Xiumei[1], **ZHANG Yao**[1], **ZHANG Yong**[2], **DU Yi**[3]
[1]College of Forestry, Shanxi Agricultural University, Taigu, Shanxi 030801, China
[2]Shanxi Institute of Soil and Water Conservation Science, Taiyuan, Shanxi 030013, China
[3]College of Resources and Environment, Shanxi Agricultural University, Taigu, Shanxi 030801, China

Abstract

To investigate the effects of long-term liquid film mulching on soil structure and infiltration characteristics in drylands, a randomized block field experiment was conducted at the Forestry Test Station of Shanxi Agricultural University from 2015 to 2018. The experimental design included liquid film and plastic film mulching under both ridge-furrow tillage and conventional flat planting conditions, with flat planting without mulching as the control. The results showed that: (1) Liquid film mulching improved soil physicochemical properties. Compared with other treatments, liquid film mulching significantly increased soil organic matter content and capillary porosity. (2) Liquid film mulching improved soil structural characteristics. Compared with other treatments, liquid film mulching significantly increased the content of >0.25 mm aggregates under both dry and wet sieving, significantly reduced soil aggregate structure breakdown rate, and significantly improved aggregate water stability index. (3) Liquid film mulching enhanced soil stable infiltration performance. The stable infiltration rate and average infiltration rate under liquid film mulching were significantly higher than those under other treatments. (4) Under the same mulching method, ridge-furrow tillage was more conducive to improving soil structural characteristics than flat planting, but there was no significant difference in stable infiltration rate between the two tillage methods. (5) Correlation analysis indicated that the initial infiltration rate had no significant correlation with soil physicochemical indicators, while stable infiltration rate and average infiltration rate showed significant or extremely significant correlations with capillary porosity, >0.25 mm water-stable aggregate content, aggregate breakdown rate, and aggregate water stability index.

Keywords: liquid film; ridge-furrow tillage; soil structure; infiltration; dryland

Soil structure forms the foundation of soil fertility. Only with good soil structure can the contradictions between water and air and between water and nutrients be regulated to continuously meet crop requirements for nutrients and water, thereby establishing a solid foundation for high and stable crop yields. Soil water infiltration is the process by which surface water enters the soil and represents an important indicator reflecting soil water infiltration and retention capacity [1]. Previous studies have shown that soil organic matter content [2-3], mechanical composition [4], pore conditions, soil aggregate content, and stability indicators serve as fundamental reflections of soil structural characteristics and exert important influences on water infiltration [5-8]. Liquid film mulching can not only reduce "white pollution" but also suppress soil surface evaporation, increase soil organic matter content, improve precipitation resource utilization efficiency, and increase crop yields [9-13]. Previous research on liquid film application effects has primarily focused on its ability to increase temperature, conserve water, prevent erosion, improve soil ecological environments, and regulate crop growth and development [14-15], while studies on the effects of liquid film application on soil structure stability and water infiltration performance remain limited. This paper analyzes the effects of continuous liquid film spraying on soil structural characteristics and infiltration performance through field plot experiments, aiming to provide a theoretical basis for the selection of mulching materials in dryland farming and for the storage and efficient utilization of farmland water.

1.1 Study Area Description

The experiment was conducted in dryland at the Forestry Test Station of Shanxi Agricultural University. The study area features a typical warm temperate continental monsoon climate, with an average annual sunshine duration of 2639 h, average annual precipitation of 450-500 mm, average annual temperature of 9.8 °C, average annual evaporation of 1649 mm, and average annual frost-free period of 154 d. Precipitation is concentrated from July to September, accounting for 70% of the annual total. The test field soil is cinnamon soil with a sandy loam texture and flat terrain. The preceding crop was soybean before the 2015 experiment. Pre-sowing soil samples from the 0-20 cm layer showed a bulk density of 1.34 $g \cdot cm^{-3}$, weight water content of 8.75%, field capacity of 25.6%, wilting humidity of 5.80%, total nitrogen content of 0.93 $g \cdot kg^{-1}$, available nitrogen of 24.4 $mg \cdot kg^{-1}$, available phosphorus of 8.0 $mg \cdot kg^{-1}$, and available potassium of 86.0 $mg \cdot kg^{-1}$.

1.2 Experimental Design

The experiment included five treatments: (1) flat planting with liquid film mulching on planting rows ( ), (2) flat planting with plastic film mulching on planting rows ( ), (3) flat planting without mulching as control ( ), (4) ridge-furrow planting with full liquid film mulching ( ), and (5) ridge-furrow planting with plastic film mulching on ridges only and furrow seeding beside the film ( ). In the ridge-furrow planting treatments, ridge and furrow widths were each approximately 50 cm, with a plot area of 3 m × 6 m. Plastic film was 80 cm wide with a thickness of 0.008 mm. Liquid film was the "Lüye Liquid Film" product from Yangling Mingrui Ecological Technology Co., Ltd. in Shaanxi Province. For application, the liquid film concentrate was first diluted with 7-8 times clean water, stirred until fully dispersed, then filtered through a screen and sprayed evenly on the ground using a sprayer. For the final mixture, 1.5-2 times clean water was added and stirred evenly (i.e., 7-8 kg of concentrate per plot). The test crop was the Xianyu 335 corn hybrid bred by Pioneer Company. Flat plastic film mulching involved film application followed by spot seeding; ridge-furrow plastic film mulching involved manual ridge formation followed by film application on ridges and furrow seeding beside the film; liquid film plots were sprayed after seeding; and the control treatment without mulching received an equal amount of clean water. Planting density was 60,000 plants $\cdot$ hm^{-2}. Sowing occurred in early May according to soil moisture conditions. Organic fertilizer and compound fertilizer were applied once before sowing at rates equivalent to 250 kg $\cdot$ hm^{-2} and 80 kg $\cdot$ hm^{-2}, respectively. Other management measures were the same as in conventional corn fields.

1.3 Measurement Methods and Related Index Calculations

Field infiltration tests were conducted after corn harvest in September. Plastic film was removed from the plastic film mulching plots before infiltration testing. After more than four months of natural degradation and field management, the liquid film did not form surface crusts that would affect water infiltration. Before infiltration experiments, undisturbed soil samples were collected from each plot using a ring sampler to determine soil porosity and bulk density in the laboratory; mixed soil samples from the 0-20 cm layer were collected to determine soil mechanical composition using the hydrometer method. Soil infiltration was measured using the double-ring infiltrometer method. The double rings (inner ring diameter 35 cm, outer ring diameter 50 cm, both 17 cm high) were placed between corn planting rows without any surface treatment. Both rings were inserted 15 cm into the soil. During testing, a minimum water depth of 15 cm was maintained in both rings, controlled by water level markers. A stopwatch was used for timing. At the start of measurement, water was quickly supplied to bring the water level to 1.5-2 cm above the soil surface. When the water level dropped below the marked position, water was added promptly to maintain a constant water level while recording the amount of water added and infiltration time. During the experiment, the outer ring was also supplied with water promptly to maintain a 15 cm water depth. Water addition amounts were recorded at time intervals of 1, 5, 10, 20, 30, 40, 50, 60, 80, 100, 120, 140, and 160 min. The initial infiltration rate was calculated based on the infiltration amount in the first 5 min; the infiltration rate when soil infiltration reached a stable value was recorded as the stable infiltration rate; and the ratio of total soil water infiltration to time within a certain period was recorded as the average infiltration rate. Soil organic matter content was determined using the potassium dichromate external heating method; water content was determined using the oven-drying method; air-dried aggregates were determined using the dry sieving method; water-stable aggregates were determined using the Savinov method [16], and based on these results, the >0.25 mm water-stable aggregate content and aggregate breakdown rate were calculated. The aggregate structure breakdown rate = (1 - water-stable aggregate content of >0.25 mm / mechanical composition content of >0.25 mm) × 100%. The mean weight diameter (MWD) of aggregates was calculated using the formula derived by Qiu Liping et al. [17]: MWD = XiWi (i = 1, 2, ···, n), where Xi is the average diameter of each aggregate fraction and Wi is the weight percentage of each aggregate fraction. Soil aggregate water stability index was determined using the water immersion disintegration method [16] on 3-5 mm air-dried aggregates from the 0-20 cm layer.

1.4 Data Analysis

SPSS 17.0 and Excel 2007 software were used for statistical analysis.

2.1 Effects of Liquid Film Mulching on Soil Organic Matter Content and Structural Indicators

As shown in Table 1 , liquid film mulching significantly increased soil organic matter content. The organic matter contents of and treatments were relatively low, being 16.24% and 24.36% lower than that of treatment, respectively. The organic matter contents of and treatments were relatively high, being 19.64% and 11.64% higher than that of treatment, respectively. Liquid film application significantly increased soil organic matter content, while plastic film mulching promoted organic matter decomposition and transformation, which was not conducive to organic matter accumulation. Both liquid film and plastic film treatments significantly reduced soil bulk density compared with the control, with reduction ranges of 5.93%-9.63%. Total porosity and capillary porosity also increased significantly compared with the control. The capillary porosity of treatment increased by 15.10% and 9.99% compared with and treatments, respectively, and was significantly higher than that of plastic film mulching. Analysis showed that both ridge-furrow tillage and flat planting with liquid film mulching significantly increased the content of >0.25 mm aggregates under dry sieving. Under wet sieving, treatment had the highest macro-aggregate content, with significant differences from other treatments, while there was no significant difference between liquid film and plastic film mulching. Both total porosity and capillary porosity increased significantly compared with the control. The water-stable aggregate contents of and treatments were significantly higher than that of treatment, with treatment having the second-highest content and no significant difference between the two. This indicated that liquid film mulching under ridge-furrow tillage was more conducive to increasing the content of >0.25 mm aggregates under both dry and wet sieving. Liquid film application significantly reduced aggregate structure breakdown rate ($P < 0.05$) and significantly improved aggregate water stability index. The breakdown rates of and treatments were also significantly lower than that of treatment. The water stability indices from high to low were: > > > > . The water stability of treatment was the highest (33.71%), followed by treatment (31.76%), with no significant difference between them, while treatment had the lowest water stability (8.54%), significantly different from other treatments ($P < 0.05$). This demonstrated that spraying liquid film was more effective than plastic film mulching in improving soil aggregate water stability, while the effects of flat planting and ridge-furrow tillage were not significant. Under the same mulching method, compared with flat planting, ridge-furrow tillage slightly increased soil organic matter content, soil bulk density, and capillary porosity, while total porosity was slightly lower than that of flat planting. In terms of soil particle size, ridge-furrow tillage increased soil clay content while correspondingly reducing silt content. Except for these changes, the contents of sand fraction (1-0.05 mm), silt fraction (0.05-0.001 mm), and clay fraction (<0.001 mm) showed no obvious patterns compared with the control.

2.2 Effects of Liquid Film Mulching on Soil Structure Stability Indicators

Soil aggregates constitute the basic units of soil structure. The higher the content of >0.25 mm macro-aggregates, the stronger the soil structural stability. As shown in Table 2 , the content of >0.25 mm aggregates under dry sieving showed the following pattern: > > > > , with no significant difference between and treatments, but both significantly higher than treatment ($P < 0.05$). The mean weight diameter (MWD) of wet-sieved aggregates, which serves as a comprehensive indicator reflecting the distribution of soil aggregate sizes, showed higher values for and treatments with no significant difference between them. The MWD of treatment was significantly lower than other treatments ($P < 0.05$). Analysis indicated that both ridge-furrow tillage and liquid film mulching were the main factors affecting MWD values. The water-stable aggregate content of >0.25 mm, capillary porosity, aggregate breakdown rate, aggregate water stability index, and organic matter content were used for correlation analysis with soil infiltration rates.

2.3 Effects of Liquid Film Mulching on Soil Infiltration Performance

Initial infiltration rate, stable infiltration rate, and average infiltration rate are the three most commonly used indicators for evaluating soil infiltration. The initial infiltration rate characterizes whether surface water can rapidly infiltrate into soil, representing an important indicator for evaluating the ease of surface runoff formation from rainfall. As shown in Table 3 , under the same tillage method, there was no significant difference in initial infiltration rate between liquid film and plastic film mulching treatments. The reason may be that although a thin film formed on the surface initially, similar to surface crusting, the liquid film gradually degraded over time. By the time of infiltration testing after corn harvest, the liquid film and plastic film treatments did not produce significant effects on initial infiltration rate. There was also no significant difference in initial soil water content among treatments, which would not cause differences in initial infiltration rates. However, under the same mulching method, ridge-furrow tillage significantly reduced the initial infiltration rate compared with flat planting, indicating that tillage method caused significant changes in initial infiltration rate. Additionally, since there was no significant difference in initial water content among treatments in this experiment, it was not the cause of soil infiltration differences. Infiltration gradually entered the stable stage after approximately 120 min, beginning about 30-55 min after infiltration started.

The stable infiltration rate and average infiltration rate of treatment were significantly higher than those of other treatments. The stable infiltration rate and average infiltration rate of treatment were the lowest ($P < 0.05$). This demonstrated that continuous liquid film mulching for four years was more effective than plastic film mulching in improving soil stable infiltration performance. There was no significant difference in initial infiltration rate between ridge-furrow tillage and flat planting under the same mulching method, and the effects of these two tillage methods on stable infiltration rate were not significantly different. The experiment also showed that tillage method did not significantly affect soil stable infiltration rate.

2.4 Correlations Between Soil Infiltration Performance and Structural Characteristics After Liquid Film Mulching

Soil infiltration performance is influenced by soil physicochemical properties [19]. Correlation analysis was conducted between soil infiltration rates and selected physicochemical property indicators. The analysis showed that initial infiltration rate had relatively small correlations with physicochemical property indicators, likely because when water supply contacts the surface, it directly enters the soil through surface non-capillary pores, with minimal response to soil physicochemical properties.

Stable infiltration rate showed significant positive correlations with capillary porosity and >0.25 mm water-stable aggregate content ($P < 0.05$), significant negative correlation with aggregate breakdown rate, and extremely significant positive correlation with aggregate water stability index ($P < 0.01$). This is because stable infiltration rate represents the infiltration rate after infiltration trends toward stability, which is related not only to surface soil non-capillary porosity but also to subsurface soil structure; thus, soil structural indicators significantly affect soil stable infiltration rate.

Average infiltration rate showed significant positive correlations with organic matter content, capillary porosity, and >0.25 mm water-stable aggregate content, extremely significant negative correlation with aggregate breakdown rate, and extremely significant positive correlation with aggregate water stability index ($P < 0.01$). This is because average infiltration rate runs through the entire infiltration process, and infiltration rate is closely related to soil physicochemical properties. Higher soil organic matter content and better soil structure are more conducive to water infiltration. The study showed that long-term liquid film mulching can significantly increase soil organic matter content, improve soil structural conditions, and enhance soil aggregate stability, thereby improving soil infiltration performance.

3 Discussion

Previous studies have shown that liquid film mulching in farmland can achieve effects similar to plastic film mulching while reducing "white pollution" [20-21], and that liquid film mulching saves time and labor, is not limited by terrain, and can inject new vitality into farmland mulching cultivation techniques. In this study, the effects of continuous four-year liquid film mulching on soil bulk density, structural characteristics, and organic matter content were similar to the research results of Zhang Jie [10], Yang Qinghua [22], and Zhang Guoquan [23]. Organic matter is an important binding agent for soil aggregate formation. Liquid film mulching can increase soil organic matter content, improve soil pore conditions, and increase aggregate structure stability.

Soil structural characteristics are closely related to soil infiltration performance [19]. Mo Bin et al. [24] showed that under different land uses in purple soil areas, soil initial infiltration rate was negatively correlated with initial water content, capillary porosity, and organic matter content, with a significant negative correlation with capillary porosity. Chen Wenyuan et al. [4] found significant positive correlations between soil initial infiltration rate and organic matter content and >0.25 mm water-stable aggregate content during forest and grassland restoration in the loess hilly region. This study found no significant correlation between soil initial infiltration rate and selected physicochemical indicators. However, this study determined that soil stable infiltration rate and average infiltration rate were significantly positively correlated with soil capillary porosity, similar to the research results of Guo Tianlei et al. [6]. This is because larger soil effective porosity results in smaller resistance to fluid movement, correspondingly increasing soil infiltration capacity.

This study found that soil stable infiltration rate and average infiltration rate were significantly or extremely significantly positively correlated with water-stable aggregate content and water stability index, and significantly or extremely significantly negatively correlated with aggregate breakdown rate. This is mainly because the formation of water-stable aggregates improves soil pore conditions, which not only enhances soil aeration and water permeability but also improves soil hydraulic structural stability, keeping soil stable infiltration rate constant and facilitating soil water infiltration.

The study also showed that under the same mulching method, ridge-furrow tillage reduced soil initial infiltration rate compared with flat planting. Analysis revealed that infiltration tests were conducted between corn planting rows. Under ridge-furrow tillage conditions, rainfall collected on ridges and accumulated in furrows, and after water infiltration and evaporation losses, partial crusting formed on the furrow surface, affecting initial infiltration rate. Ridge-furrow tillage did not significantly affect stable infiltration rate and average infiltration rate.

4 Conclusions

(1) Spraying liquid film improved soil physicochemical properties. Liquid film mulching significantly increased soil organic matter content and capillary porosity. Although there was no significant difference in soil bulk density between liquid film and plastic film mulching treatments, both were significantly reduced compared with the control. Under the same mulching method, there were no significant differences in soil organic matter content, soil bulk density, and capillary porosity between ridge-furrow tillage and flat planting. Ridge-furrow tillage increased soil clay content while correspondingly reducing silt content.

(2) Liquid film mulching improved soil structural characteristics. Compared with other treatments, liquid film mulching significantly increased >0.25 mm aggregate content under both dry and wet sieving, significantly increased mean weight diameter of wet-sieved soil aggregates, significantly reduced soil aggregate breakdown rate, and significantly improved aggregate water stability index. Under the same mulching method, ridge-furrow tillage was more conducive to improving soil structural characteristics than flat planting, but the effect of tillage method on soil structural stability was not obvious.

(3) Liquid film mulching improved soil stable infiltration performance. The stable infiltration rate and average infiltration rate under liquid film mulching were significantly higher than those under other treatments. There was no significant difference in initial infiltration rate between liquid film and plastic film mulching under the same tillage method. Under the same mulching method, ridge-furrow tillage and flat planting had no significant difference in their effects on stable infiltration rate.

(4) Soil physicochemical properties affected soil infiltration performance. Correlation analysis showed that soil organic matter content was positively correlated with infiltration indicators, with a significant positive correlation with average infiltration rate. Capillary porosity significantly affected soil stable infiltration rate and average infiltration rate. Aggregate stability indicators significantly or extremely significantly affected soil stable infiltration rate and average infiltration rate.

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