Postprint: Comprehensive Evaluation of Soil Environmental Factors in Pear Orchards under Different Mulching Conditions in Arid Regions

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Abstract

In arid Yellow River irrigation districts, under water-saving irrigation methods combining different mulching materials with drip irrigation, we further investigated the effects of different mulching methods on soil physicochemical properties and nutrient content changes throughout the entire growth period of pear orchards, analyzed the interrelationships among soil temperature, moisture, pH, and mineral nutrient elements, and conducted a comprehensive evaluation of soil quality after mulching. The experimental treatments were divided into four: no mulching control (T1), horticultural ground cloth mulching (T2), corn straw mulching (T3), and black plastic film mulching (T4); the experimental design was a randomized block design, with each treatment plot containing 167 pear trees (covering approximately 667 m^2), replicated 3 times; soil samples from each plot were collected from soil layers of 0–20 cm, 20–40 cm, and 40–60 cm. The results showed: (1) Horticultural ground cloth and black plastic film mulching treatments exhibited certain warming effects, whereas corn straw mulching demonstrated better cooling and temperature stabilizing effects, along with significant moisture retention effects, with soil water content significantly increased by 1.0%–2.7% compared to the other three treatments. (2) Compared with the no mulching treatment, black plastic film mulching increased surface soil pH and accelerated the decomposition of surface soil organic matter, with organic matter content decreasing by 33.1% compared to the no mulching treatment; corn straw mulching significantly reduced soil pH in all soil layers, with a reduction range of 1.8%–4.6%, and promoted the increase of organic matter in the 0–20 cm soil layer, with soil organic matter content increasing by 12.2%; under horticultural ground cloth mulching, both soil organic matter content and total salt content in the 0–40 cm soil layer decreased. (3) Under black plastic film mulching, the alkali-hydrolyzable nitrogen content in the 0–20 cm and 20–40 cm soil layers was 73.00 mg · g-1 and 64.53 mg · g-1, respectively, both significantly higher than the no mulching treatment; under no mulching conditions, soil alkali-hydrolyzable nitrogen accumulated more in the deep layer (40-60 cm soil layer), significantly higher than under corn straw and black plastic film mulching; the available phosphorus content in the 0–20 cm and 20–40 cm soil layers differed significantly among treatments, with the ranking order being T4>T3>T2>T1; corn straw mulching could increase the content of soil available potassium and available iron. (4) Principal component analysis indicated that the effects of different mulching methods on shallow soil environmental factors in pear orchards were significantly greater than on deep soil; within the 0–40 cm soil layer, all mulching treatments performed better than the no mulching treatment, among which corn straw mulching achieved comprehensive scores of 1.189 and 0.326 in the 0–20 cm and 20–40 cm soil layers, respectively, demonstrating the best mulching effect.

Full Text

Comprehensive Evaluation of Soil Environmental Factors in Pear Orchard under Different Mulching Conditions in Arid Region

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Abstract

This study investigated the effects of different mulching materials on soil physicochemical properties and nutrient content throughout the entire growth period of pear orchards under drip irrigation combined with mulching for water conservation in the arid Yellow River irrigation area of Jingtai County, Gansu Province. The relationships between soil temperature, moisture, pH, and mineral nutrient elements were analyzed, and a comprehensive evaluation of soil quality was conducted. Four mulching treatments were established: no mulching (T1), gardening cloth mulching (T2), maize straw mulching (T3), and black plastic film mulching (T4). A randomized block design was adopted, with each treatment plot containing 167 pear trees (covering approximately 667 m^2), replicated three times. Soil samples were collected from 0–20 cm, 20–40 cm, and 40–60 cm layers.

The results demonstrated that: (1) Gardening cloth and black plastic film mulching produced noticeable warming effects, whereas maize straw mulching exhibited effective cooling and temperature-stabilizing effects with obvious moisture-enhancing benefits, increasing soil water content by 1.0%–2.7% compared to other treatments. (2) Black plastic film mulching elevated topsoil pH and accelerated organic matter decomposition, reducing organic matter content by 33.1%. In contrast, maize straw mulching significantly reduced pH across all soil layers (by 1.8%–4.6%) and promoted organic matter accumulation in the 0–20 cm layer, increasing content by 12.2%. (3) Under gardening cloth mulching, soil organic matter and total salt content in the 0–40 cm layer decreased. Black plastic film mulching yielded the highest alkali-hydrolyzable nitrogen contents of 73.00 $mg \cdot g^{-1}$ and 64.53 $mg \cdot g^{-1}$ in the 0–20 cm and 20–40 cm layers, respectively, significantly exceeding those of the no-mulching treatment. Without mulching, alkali-hydrolyzable nitrogen accumulated more in the deep layer (40–60 cm), significantly higher than under maize straw and black plastic film. Available phosphorus content differed significantly among treatments in the 0–20 cm and 20–40 cm layers, following the order T4 > T3 > T2 > T1. Maize straw mulching also enhanced soil available potassium and available iron content. (4) Principal component analysis revealed that mulching effects on shallow soil environmental factors were significantly greater than on deep soil. All mulching treatments outperformed the no-mulching treatment in the 0–40 cm layer, with maize straw mulching achieving the highest comprehensive scores of 1.189 and 0.326 in the 0–20 cm and 20–40 cm layers, respectively.

Keywords: arid region; different mulching; soil quality; principal component analysis

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1.2 Experimental Design

The experiment was conducted in Jingtai County, Gansu Province, located between 37°08 12 -37°12 0.60 N and 104°02 4.31 -104°05 0.43 E at an average elevation of 1570 m. The region features a temperate arid continental climate with desert characteristics, with annual precipitation of 185 mm, evaporation of 3038 mm, mean temperature of 9.1 ℃, and frost-free period exceeding 120 days. The experimental orchard was a high-density pear plantation established by the Lanzhou Comprehensive Experimental Station of the National Pear Industry System, covering 1.35 hm^2 with a row spacing of 4 m × 1 m (167 trees/667 m^2). The test cultivar was 'Huangguan' pear grafted on *Pyrus betulifolia* rootstock, with north-south row orientation. The test soil (0–30 cm layer) was sandy loam with initial pH 8.14, organic matter content of 8.75 $g \cdot kg^{-1}$, and available nitrogen, phosphorus, and potassium contents of 47.75 $mg \cdot kg^{-1}$, 25.56 $mg \cdot kg^{-1}$, and 113.50 $mg \cdot kg^{-1}$, respectively.

Four mulching treatments were established in mid-March: (T1) no mulching (control), (T2) gardening cloth mulching, (T3) maize straw mulching, and (T4) black plastic film mulching. Single rows served as experimental plots arranged in a randomized block design, with three replications per treatment. The control treatment involved repeated shallow tillage and weeding during the growing season to maintain clean orchard ground. For gardening cloth mulching, black polypropylene gardening cloth (90 $g \cdot m^{-2}$) was selected. Maize straw was chopped into segments and applied within the tree canopy area at 20 cm thickness. Black plastic mulching employed 0.008 mm thick polyethylene film covering a 90 cm × 20 cm area. All mulching materials were installed in mid-March, with consistent tree management and soil management practices across treatments.

1.3.1 Soil Water Content Measurement

During different growth stages (budbreak, pre-flowering, post-flowering, young fruit, fruit expansion, pre-harvest, and post-harvest), soil water content was measured using the oven-drying method in July. Soil samples were collected using a five-point sampling method from 0–20 cm, 20–40 cm, and 40–60 cm layers, with three replicates. Soil water content = (fresh soil mass -oven-dried soil mass) / oven-dried soil mass.

1.3.2 Soil Temperature Measurement

Soil temperature was measured using L93-4 type automatic temperature recorders (Hangzhou Luge Instrument Co., Ltd., Zhejiang). Temperature probes were placed 60 cm west of tree trunks at 0–60 cm depth, with 20 cm intervals as measurement steps, continuously recording temperature at each layer.

1.3.3 Soil Physicochemical Properties Measurement

Before irrigation in November, mixed samples were collected from five points at 60 cm east-west from tree trunks from 0–20 cm, 20–40 cm, and 40–60 cm layers for physicochemical analysis. Soil pH was measured using a TP320 conductivity analyzer. Total salt content was determined by the gravimetric method. Organic matter content was measured using the potassium dichromate-sulfuric acid oxidation method. Total nitrogen was analyzed using the H_2SO_4-H_2O_2 digestion method followed by continuous flow analysis. Ammonium and nitrate nitrogen were measured using 1 $mol \cdot L^{-1}$ KCl extraction followed by continuous flow analysis. Total and available phosphorus, potassium, and iron were determined using inductively coupled plasma optical emission spectrometry (ICP-OES, Optima-2100DV).

1.4 Data Analysis

Data were organized using Microsoft Excel 2010, with charts showing means ± standard errors. SPSS 22.0 software was used for multiple comparisons and significance analysis using Duncan's new multiple range method. Factor analysis was performed on standardized data for principal component analysis.

2.1 Effects of Different Mulching Methods on Soil Temperature in Pear Orchard

Different mulching treatments significantly affected soil temperature across layers during various phenological stages of pear development (Table 1). Average temperatures in all layers were lowest in January, gradually increasing thereafter. Annual mean temperatures showed T4 > T1 > T3 > T2 in the 0-20 cm layer, T4 > T3 > T2 > T1 in the 20-40 cm layer, and T4 > T3 > T1 > T2 in the 40-60 cm layer. The T4 treatment consistently maintained higher temperatures, while T3 showed lower temperatures in the 0-20 cm layer and T2 showed lower temperatures in the 20-40 cm layer.

Temperature variation patterns differed among treatments (Figure 1). In the 0-20 cm layer, temperature amplitude was smaller for T2-T4 treatments compared to T1. The T3 treatment showed the most stable temperature effect, with smaller increases before July and smaller decreases afterward. In contrast, T4 showed larger early increases but greater later decreases. Temperature declines in the 0-20 cm layer began in July, while 20-40 cm and 40-60 cm layers began declining in August and September, respectively, demonstrating that mulching delayed temperature drops in surface soil.

2.2 Effects of Different Mulching Methods on Soil Water Content in Pear Orchard

Soil water content varied among treatments throughout the growth period (Table 2). All mulching treatments (T2-T4) maintained higher water content than T1 across 0-60 cm, with lower coefficients of variation, demonstrating universal moisture-enhancing and stabilizing effects. The T3 treatment achieved the highest water content, significantly increasing by 1.0%-2.7% compared to other treatments ($P < 0.05$), while T4 showed the smallest enhancement (0.3%-1.6%).

Water content decreased with soil depth across all treatments. The T1 treatment exhibited greater water loss in surface soil, while mulching effectively reduced evaporation and maintained higher moisture in upper layers. Inter-treatment comparisons consistently showed higher water content under mulching than T1. The T3 treatment ranked highest across most growth stages, significantly exceeding T1 by 1.7%-12.9% ($P < 0.05$). The T4 treatment also exceeded T1 in most stages except pre-flowering and fruit expansion. These results indicate that mulching influences soil moisture through rainwater infiltration, reduced evapotranspiration, and moisture conservation.

2.3 Effects of Different Mulching Methods on Soil Physicochemical Properties in Pear Orchard

Different mulching treatments significantly affected soil physicochemical properties (Figure 2). The T3 treatment significantly reduced soil pH across all layers by 1.8%–4.6% ($P < 0.05$) while increasing organic matter content in the 0–20 cm layer by 12.2% ($P < 0.05$). In contrast, T4 increased topsoil pH and accelerated organic matter decomposition, reducing content by 33.1% compared to T1 ($P < 0.05$). The T2 treatment also reduced organic matter content by 12.2% in the 0–20 cm layer ($P < 0.05$).

Total nitrogen content was significantly lower under T2 than other treatments ($P < 0.05$), while total phosphorus increased significantly under T4 ($P < 0.05$). Available nutrient contents showed more complex patterns (Figure 3). Alkali-hydrolyzable nitrogen reached 73.00 $mg \cdot g^{-1}$ and 64.53 $mg \cdot g^{-1}$ in the 0–20 cm and 20–40 cm layers under T4, significantly higher than T1 ($P < 0.05$). Without mulching, alkali-hydrolyzable nitrogen accumulated more in the deep layer (40–60 cm), significantly exceeding T3 and T4. Available phosphorus differed significantly among treatments in the 0–20 cm and 20–40 cm layers, following the order T4 > T3 > T2 > T1 ($P < 0.05$). The T3 treatment significantly increased available potassium content by 31.1%–61.2% across all layers ($P < 0.05$) and enhanced available iron content in surface and middle layers.

Total salt content under all treatments decreased with soil depth. The T4 treatment significantly reduced total salt content in the 0–20 cm layer compared to T1 ($P < 0.05$). In the 40–60 cm layer, the order of total salt content was T1 > T4 > T3 > T2 ($P < 0.05$).

2.4 Comprehensive Evaluation of Soil Environmental Factors in Pear Orchard under Different Mulching Conditions

Principal component analysis was performed on 15 soil environmental factors across different mulching treatments. The correlation coefficient matrix (Table 3) showed complex relationships among indicators. Three principal components with eigenvalues > 1 were extracted, with contribution rates of 46.3%, 26.7%, and 12.2%, respectively, cumulatively explaining 85.435% of variance (Table 4).

The first principal component showed high positive loadings for soil nitrate nitrogen, available potassium, ammonium nitrogen, alkali-hydrolyzable nitrogen, organic matter, and available iron, representing soil nitrogen-phosphorus and available mineral element factors. The second principal component integrated soil temperature, water content, and pH, reflecting soil physical properties. The third principal component combined total salt content, total potassium, and total iron.

Calculated principal component scores and comprehensive F-values revealed that mulching effects on shallow soil environmental factors were significantly greater than on deep soil (Table 5). Ranking treatments by F-value showed: in the 0-20 cm layer, T3 > T2 > T4 > T1; in the 20-40 cm layer, T3 > T2 > T4 > T1; and in the 40-60 cm layer, T1 > T4 > T3 > T2. These results demonstrate that mulching effects were most beneficial in shallow layers, with maize straw mulching showing the highest comprehensive scores.

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3 Discussion

Surface mulching technology in agricultural production provides broad-spectrum moisture conservation, erosion prevention, and evaporation reduction, while different materials offer additional benefits in fertility improvement and soil environmental factor stabilization. Numerous studies have confirmed that plastic film mulching significantly increases soil temperature and suppresses water evaporation. In this experiment, black plastic film mulching demonstrated warming effects and notable moisture retention, while increasing alkali-hydrolyzable nitrogen content. However, it accelerated organic matter decomposition, resulting in lower organic matter content than the no-mulching treatment. This occurs because although plastic mulching improves water and fertilizer retention and nitrogen use efficiency, it also accelerates organic matter mineralization. The discrepancy with Zhao et al.' s finding of reduced alkali-hydrolyzable nitrogen under plastic mulching likely stems from different sampling times, as post-harvest water and fertilizer uptake by trees decreases significantly.

As a novel mulching material, gardening cloth provides sufficient water permeability while allowing root respiration and nutrient absorption, maintaining relatively high soil temperature. In this study, gardening cloth mulching ranked second only to black plastic film in warming effect, similarly accelerating organic matter decomposition. It also provided moisture retention benefits and increased water content, but significantly reduced total nitrogen content compared to other treatments, contrasting with previous research on gardening cloth' s nutrient retention effects. This discrepancy may relate to differences in soil nitrogen metabolism rates and enzyme activities, requiring further investigation.

Maize straw mulching intercepts rainfall energy, preventing direct soil surface impact, reducing particle detachment, preventing surface crusting, increasing surface roughness and infiltration, thereby reducing runoff and erosion. The results showed that maize straw mulching provided excellent cooling and temperature-stabilizing effects with optimal moisture retention, significantly increasing soil water content throughout the growth period and effectively addressing regional "spring drought" issues. Additionally, it significantly increased soil organic matter content and regulated high pH in alkaline soils, indicating substantial improvements in soil structure and fertility, consistent with previous research on straw mulching reducing soil bulk density, increasing porosity, and maintaining soil structure. Maize straw mulching also significantly promoted available potassium and available iron content, likely due to microbial decomposition enriching available nutrients and increasing mineral element availability through root exudation, microbial activity, soil acidification, and straw residue retention.

Principal component analysis integrated multiple individual indicators to comprehensively evaluate mulching effects on soil quality, identifying key factors including soil available nutrients, physical properties, and potassium and iron content. This approach reduced numerous indicators to fewer independent comprehensive indicators while preserving 85.435% of information, enabling objective and comprehensive evaluation. The analysis confirmed that mulching effects on shallow soil environmental factors were significantly greater than on deep soil, with all mulching treatments outperforming no mulching in the 0–40 cm layer, and maize straw mulching achieving the highest comprehensive scores.

4 Conclusions

This study investigated the effects of different mulching methods on soil physicochemical properties and nutrient content throughout the entire growth period of pear orchards in the arid Yellow River irrigation area, with comprehensive evaluation through principal component analysis. The main conclusions are:

1) Gardening cloth and black plastic film mulching exhibited noticeable warming effects, while maize straw mulching provided effective cooling and temperature stabilization with superior moisture retention, significantly increasing soil water content by 1.0%-2.7% compared to other treatments.

2) Black plastic film and gardening cloth mulching accelerated organic matter decomposition, particularly under black plastic film where organic matter content decreased by 33.1%. However, black plastic film mulching achieved the highest alkali-hydrolyzable nitrogen contents of 73.00 $mg \cdot g^{-1}$ and 64.53 $mg \cdot g^{-1}$ in the 0–20 cm and 20–40 cm layers, respectively. Maize straw mulching increased available potassium content by 31.1%-61.2% and enhanced available iron content.

3) Comprehensive principal component analysis revealed that mulching effects on shallow soil environmental factors were significantly greater than on deep soil. In the 0–40 cm layer, all mulching treatments outperformed the no-mulching treatment, with maize straw mulching achieving the highest comprehensive scores and demonstrating the best mulching effect.

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