Postprint: Soil Moisture Dynamics in Mountain Apple Orchards of the Loess Hilly Region, Northern Shaanxi

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Abstract

Mastering soil moisture characteristics is key to achieving scientific orchard management, rational and efficient utilization of limited rainwater resources, and ensuring high yield and quality of fruit trees. Taking a 6-year-old Red Fuji apple orchard in the mountainous area of Mizhi, northern Shaanxi as the research object, and using a soil moisture monitoring method combining FDR, neutron moisture meter, and oven-drying method from April 2015 to June 2016, we analyzed the overall soil moisture characteristics of the mountainous apple orchard, water dynamics at different positions of individual trees, and the soil moisture environmental effects of different dryland farming measures (straw mulching, ridge-furrow rainwater harvesting with plastic film mulching, organic fertilizer mulching). The results showed that: drought in mountainous orchards of northern Shaanxi was severe during certain periods, most severely during the apple tree's new shoot growth and young fruit development stage; the degree of spring soil drought depended on the level of soil water storage before the previous winter. Soil water in the 0–60 cm layer (the concentrated root distribution layer) of the orchard varied with rainfall, showing relatively consistent seasonal variation characteristics; soil moisture changes lagged behind rainfall changes, and the influence of rainfall on soil moisture decreased with soil depth, the effect weakening at 100 cm depth, while soil water content below 200 cm in the soil profile remained relatively stable. The soil in the 6-year-old mountainous apple orchard had already exhibited desiccation, with a distinct low-moisture layer present at 90–300 cm, where soil volumetric water content remained below 12% throughout the year. At the individual tree scale, soil water content increased monotonically with distance from the trunk; the average value of soil moisture occurred at 105 cm from the trunk; soil water content at positions along the row direction at different distances from the trunk was significantly higher than that at positions along the plant direction at equal distances from the trunk ($P<0.05$). Straw mulching, ridge-furrow rainwater harvesting with plastic film mulching, and organic fertilizer mulching measures all effectively improved the soil moisture environment and alleviated the water supply-demand contradiction during the fruit tree growing period compared with the blank control (no mulching, no irrigation), with ridge-furrow rainwater harvesting with plastic film mulching showing the best moisture conservation effect; it is recommended that rain-fed apple orchards in the loess hilly region of northern Shaanxi adopt ridge-furrow rainwater harvesting with plastic film mulching as a moisture conservation measure.

Full Text

Soil Moisture Dynamics of Apple Orchards in the Loess Hilly Area of Northern Shaanxi Province

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Abstract: Understanding soil moisture characteristics is critical for scientific orchard management, efficient utilization of limited rainfall resources, and ensuring high fruit yield and quality. This study investigated a 6-year-old 'Fuji' apple orchard in Mizhi County, northern Shaanxi, from April 2015 to June 2016 using a comprehensive soil moisture monitoring approach combining FDR (Frequency Domain Reflectometry), neutron moisture meter, and oven-drying methods. The research analyzed the overall soil moisture characteristics of the hillside orchard, moisture dynamics at different positions around individual trees, and the environmental effects of different dryland farming practices (straw mulching, ridge-film mulching with furrow rainwater harvesting, and organic fertilizer mulching). Results showed that seasonal drought was severe in the hillside orchard, particularly during shoot growth and young fruit development stages. Spring drought severity depended on soil water storage before winter dormancy. Soil moisture in the 0–60 cm layer (the main root distribution zone) varied with rainfall, showing consistent seasonal patterns; however, soil moisture changes lagged behind rainfall, and rainfall effects diminished with soil depth. The 100 cm depth layer was less affected by rainfall, while soil moisture below 200 cm remained relatively stable. The 6-year-old hillside orchard already exhibited soil desiccation, with a distinct low-moisture layer at 90–300 cm where volumetric water content remained below 12% year-round. At the single-tree scale, soil moisture increased monotonically with distance from the trunk, with the average moisture value occurring at approximately 105 cm from the trunk. Soil moisture at sites along the row direction was significantly higher than at equivalent distances along the plant direction ($P < 0.05$). All three mulching treatments effectively improved the soil moisture environment and alleviated water supply-demand conflicts during the growing season compared to the control (no mulching, no irrigation), with ridge-film mulching and furrow rainwater harvesting showing the best moisture conservation effects. This practice is recommended for rainfed apple orchards in the loess hilly areas of northern Shaanxi Province.

Keywords: Apple orchard; Soil moisture; Mulching; Soil moisture conservation; Loess Hilly Area

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Introduction

The Loess Hilly Area of northern Shaanxi represents the most severely eroded region of the Loess Plateau. Economic forests, which provide both economic and ecological benefits, have been extensively studied in this region, with research focusing on water consumption depth of fruit trees [1-2], soil moisture characteristics of orchards of different ages [3-4], and soil moisture under irrigation conditions [5-6]. With the expansion of apple cultivation in Shaanxi Province, hillside apple orchards have developed rapidly in this region, covering 40,000 hectares and becoming a significant regional specialty industry [7]. The establishment of hillside apple orchards represents a successful case of implementing the Grain-for-Green Program, deepening soil and water conservation, and developing modern agriculture and forestry, effectively addressing long-standing conflicts between low vegetation establishment success, poor water conservation benefits, and slow rural economic development [8].

However, the region experiences low rainfall with uneven spatiotemporal distribution, coupled with strong transpiration water consumption by apple trees, resulting in severe soil water deficits in hillside orchards that significantly affect apple yield and quality [7]. Clarifying soil moisture environmental characteristics is essential for scientific orchard management, rational and efficient utilization of limited rainfall resources, and ensuring high fruit yield and quality. While many scholars have analyzed soil moisture conditions in apple orchards on the Loess Plateau [7,9-12], showing that soil moisture content gradually decreases from south to north in Shaanxi Province and varies with region, stand age, and site type, most existing research has focused on soil moisture regulation management and differences in local areas and orchard types. Studies specifically targeting soil moisture environments in rainfed hillside apple orchards in the loess mound-hilly gully region of northern Shaanxi remain scarce.

This study addresses this gap by examining a 6-year-old 'Fuji' apple orchard in Mizhi, northern Shaanxi, using a combined monitoring approach with FDR, neutron moisture meter, and oven-drying methods. The objectives were to analyze soil moisture dynamics in hillside apple orchards, moisture variations at different positions around individual trees, and the environmental effects of different dryland farming measures, thereby providing a scientific basis for strengthening water management in hillside orchards, improving water use efficiency, and enhancing quality and productivity in rainfed apple orchards.

1.1 Study Area Description

The experiment was conducted at the Mizhi Dangta Hillside Apple Science and Technology Demonstration Base of the Yulin Hillside Apple Test Station, Shaanxi Provincial Fruit Industry Administration. The site features typical loess mound-hilly gully landforms at 986–1,012 m elevation, representing the most severely eroded area with a semi-arid temperate climate. Spring temperatures rise rapidly with strong winds, low rainfall, and occasional frost and spring drought. Summer is warm with periodic droughts, heavy rainstorms, hail, and gusty winds. Autumn is cool with rapid temperature drops and frost events. Winter is cold and dry.

Annual average precipitation is 451.6 mm, with a maximum of 704.8 mm and minimum of 186.1 mm. Rainfall distribution is highly seasonal: April–June receives little precipitation, mostly ineffective events below 5 mm, while June–September accounts for over 60% of annual rainfall, often occurring as high-intensity storms that generate substantial runoff. The annual average temperature is 8.9 °C, with extreme maximum and minimum temperatures of 38.2 °C and -25.5 °C, respectively, and a frost-free period of 162 days. The terrain consists of terraces with loess soil (loessal soil) having a bulk density of 1.20–1.35 g · cm ³, field capacity of 22.4%, and organic matter content of 4.2 g · kg ¹. The orchard covered 13.5 hectares with 6-year-old apple trees at 4 m × 5 m spacing, with ‘Fuji’ as the main cultivar and ‘Gala’ and ‘Qinguan’ as pollinizers. Precipitation during the experimental period (April 2015–June 2016) is shown in [Figure 1: see original paper].

1.2 Research Methods

Continuous Monitoring: Five CS616 soil moisture probes (Campbell Scientific Inc., measurement error ±3%) were installed at the center point of diagonal connections among four apple trees in the orchard center, connected to a CR1000 data logger (Campbell Scientific, USA). Volumetric water content was continuously monitored at 30-minute intervals in 20, 40, 60, 100, and 200 cm soil layers to analyze soil drought conditions and moisture dynamics in the root-concentrated and rhizosphere layers.

Deep Profile Monitoring: Nine 6-m deep neutron access tubes were uniformly arranged in a 3×3 grid in the central and peripheral orchard areas, each positioned at the center of diagonal connections among four apple trees. Soil moisture content was measured every 10–15 days using a CNC503B(DR) intelligent neutron moisture meter, recording every 10 cm in 0–100 cm and every 20 cm in 100–580 cm layers. Mean values were calculated to examine vertical variation characteristics.

Single-Tree Scale Monitoring: Three representative, moderately growing, pest-free trees were selected in the orchard center. At each tree, 2-m deep neutron access tubes were installed along both row and plant directions at distances of 30, 60, 90, 120, 150, and 180 cm from the trunk. Measurements were taken every 10-15 days using the CNC503B(DR) meter with calibration equation y = 59.006x + 0.2705, recording every 10 cm in 0–100 cm and every 20 cm in 100-160 cm layers. Mean values from the three trees were calculated to characterize soil moisture at the single-tree scale.

Mulching Treatments: A randomized block design was implemented with nine trees per plot (3×3 arrangement) and three replications. Three dryland farming practices currently used in northern Shaanxi hillside orchards were applied: straw mulching (Treatment I), ridge-film mulching with furrow rainwater harvesting (Treatment II), and organic fertilizer mulching (Treatment III), with no mulching as control (CK). Treatment I used chopped corn straw at ~15 cm thickness across the entire plot. Treatment II created two ridges (80–100 cm wide, 0.01 mm high) on both sides of the trunk along the row direction, covered with 1.6–2 m wide black plastic film, with 10 cm deep/wide collection ditches along film edges. Treatment III used chicken manure at ~15 cm thickness. Soil moisture was measured monthly using the oven-drying method (105 °C) at 2 m depth with samples every 20 cm. For Treatments I, III, and CK, one sample each was taken between plants and between rows; for Treatment II, samples were taken on ridges, in furrows, and between rows.

Calculations: Soil water storage (SWS) was calculated as:

$$SWS = 0.1 \times \theta_m \times \rho \times H$$

where SWS is soil water storage (mm), is mass water content (%), is soil bulk density (g · cm ³), and H is soil layer depth (cm).

Precipitation was monitored using a Campbell Scientific weather station installed in the orchard. Data processing and graphing used Microsoft Excel 2013 and SigmaPlot 12.5, with statistical analysis performed using DPS 6.0.

2.1.1 Seasonal Dynamics of Soil Moisture in Hillside Orchards

Soil moisture variation in northern Shaanxi hillside apple orchards is closely related to precipitation, evaporation, and tree water consumption. Approximately 80% of apple tree roots are distributed in the 0–60 cm soil layer [13]. [Figure 2: see original paper] shows soil moisture dynamics measured by FDR at the center point of diagonal connections among four apple trees in the orchard center. During the growing season, soil moisture in the root-concentrated layer (0–60 cm) was significantly affected by rainfall, showing seasonal patterns consistent with precipitation but with a temporal lag. Rainfall effects diminished with soil depth. In winter, soil moisture reached its annual minimum due to freezing.

From early April to late June, low rainfall (mostly ineffective events <5 mm), frequent strong winds, and intense solar radiation caused substantial evaporative loss, while increasing water consumption by shoot growth and young fruit development led to continuously declining soil moisture. A 14.4 mm rainfall event on June 29 increased moisture in 20 and 40 cm layers but not in 60 cm. During the hot, rainy period from July to September, soil moisture increased with rainfall. A continuous 77.4 mm rainfall from July 17-22 increased moisture by 43.0%, 56.3%, and 18.9% in 20, 40, and 60 cm layers, respectively. From August 28 to September 10, cumulative rainfall of 68.6 mm increased moisture by 48.9%, 49.2%, and 72.1% in the respective layers. Despite lower rainfall than in July, the greater moisture increase resulted from July' s high-intensity, short-duration rainfall generating more runoff and less infiltration.

From September 22 to late October, despite lower temperatures, reduced rainfall and high fruit development water consumption caused sharp moisture declines across all layers. A 53.6 mm rainfall on November 5-6 substantially increased moisture in all layers. From late November to mid-December, low temperatures and minimal tree water consumption maintained high moisture levels. By late December, temperatures below 0 °C caused soil freezing, converting liquid water to solid and resulting in extremely low readings from moisture probes. In the following March, temperatures above 0 °C caused thawing, rapidly increasing shallow soil moisture despite scarce rainfall. By late March, when the frozen layer completely thawed, moisture returned to pre-freezing levels, indicating that soil moisture at the start of a new growing season depends on water storage accumulated during the previous rainy season.

Below 60 cm, rainfall infiltration decreased while root absorption and evaporation also weakened, though moisture content in this layer remained crucial for tree development [7]. [Figure 2: see original paper] shows that the 100 cm layer was significantly less affected by rainfall, with most precipitation unable to replenish this layer. During the growing season, tree water consumption exceeded rainfall infiltration, causing overall moisture decline. The substantial, sustained rainfall on November 5-6 sharply increased moisture in this layer. Winter freezing in this layer was shorter than in 0-60 cm, with weaker moisture variation. The 200 cm layer showed relatively stable moisture, with a coefficient of variation of only 12.7% during the study period, due to minimal environmental influence, low root water consumption, and deep groundwater tables in the Loess Plateau that only slowly migrated upward.

2.1.2 Drought Conditions in Hillside Orchards

Since apple tree development depends on water absorbed directly from soil, relative soil water content (percentage of soil water content to field capacity) was used as an agricultural drought index. Drought severity was classified as: extremely severe (<30%), severe (30-40%), moderate (40-50%), mild (50-60%), and no drought (>60%) [14].

[Figure 3: see original paper] reveals severe seasonal drought in the experimental orchard. From April to mid-June 2015, the orchard experienced moderate drought (0-60 cm soil water storage of 84.0-100.8 cm), with continuously decreasing storage. This period requires appropriate water supplementation. Xu et al. [15] indicated that the optimal relative soil water content during bud break, flowering, shoot growth, and young fruit development (late March–early June) is 50-60%, recommending three irrigation events during these stages.

From mid-June to mid-July, soil storage decreased to only 66.8 mm, indicating severe drought. Only two effective rainfall events exceeding 10 mm on June 29 and July 17 slightly alleviated the severe conditions. This period (shoot growth and young fruit development) is a critical season for irrigation, with one supplemental irrigation recommended. From late July to early October (fruit expansion period), the orchard generally experienced mild drought, except for moderate drought from late August to early September. The optimal relative soil water content during fruit expansion is 70-80% [15], suggesting one irrigation event. From mid-October to early November, moderate drought occurred, but irrigation was unnecessary as fruit had been harvested. From late March to mid-May 2016, high soil moisture resulted in no drought, but mild drought developed from mid-May to late June due to low precipitation and increasing tree water consumption.

2.1.3 Vertical Variation of Soil Moisture in Hillside Orchards

Averaging data from nine neutron access tubes revealed a distinct "high-low-high" moisture pattern with depth in the 0-580 cm profile [Figure 4: see original paper]. Soil moisture variation primarily occurred above 200 cm, with variability decreasing with depth (CV = 9.56-22.71%). Below 200 cm, moisture remained relatively stable (CV = 2.9-5.3%), indicating that natural precipitation rarely infiltrates below 200 cm.

Soil desiccation is widespread in perennial vegetation on the Loess Plateau due to long-term water deficits [7,16-18]. Apple trees require higher soil moisture than typical drought-tolerant plants, with optimal relative water content of 50-60% during bud break, flowering, and shoot growth, and 70-80% during fruit expansion [15]. Using 50% of field capacity as the desiccation threshold [7], the 6-year-old hillside orchard showed severe desiccation below 60 cm, with a distinct low-moisture layer at 90-300 cm where volumetric water content remained below 12% year-round, posing a serious threat to sustainable orchard health.

2.2 Soil Moisture Characteristics at the Single-Tree Scale

[Figure 5: see original paper] demonstrates significant spatial variability in soil moisture around individual trees, with moisture increasing monotonically with distance from the trunk in both row and plant directions. Fine roots concentrate radially within 0-90 cm and vertically within 0-120 cm, particularly at 40-60 cm depth, with the most extensive distribution at 60 cm from the trunk [19]. Root density and water uptake intensity decrease with distance from the trunk.

Averaging moisture measurements at each horizontal position and fitting them to distance from the trunk revealed linear positive relationships : $y = 0.0105x + 6.8702$ (between plants) and $y = 0.014x + 7.6912$ (between rows), where y is soil moisture (%) and x is distance from trunk (cm). Solving these equations for the average moisture values yielded optimal sampling distances of 105.0 cm (between plants) and 104.6 cm (between rows). Therefore, sampling at approximately 105 cm from the trunk best represents average orchard soil moisture.

Soil moisture at sites along the row direction was significantly higher than at equivalent distances along the plant direction ($P < 0.05$), due to greater competition for soil water between adjacent trees (4 m spacing) than between rows (5 m spacing).

2.3.1 Soil Moisture in the Root Concentrated Layer (0-60 cm)

Different mulching treatments affected soil moisture retention and loss differently. [Figure 6: see original paper] shows seasonal moisture variation was primarily rainfall-driven. From April–June, low rainfall and strong evaporation with increasing tree water consumption caused gradual moisture decline. From July–September, increased rainfall replenished soil moisture. From October, reduced rainfall caused moisture to decrease again. April 2016 began with relatively high moisture levels.

In the 0–20 cm layer, moisture from April–June ranked: Treatment II > III > I > CK, with significant differences between all treatments and CK ($P < 0.05$), and between Treatments I and II ($P < 0.05$), but not between III and I or II ($P > 0.05$). Film mulching most effectively suppressed evaporation, making ridge-film mulching superior to straw and organic fertilizer mulching. From July–October, moisture ranked: III > I > II > CK, with all treatments significantly different from CK ($P < 0.05$) but not from each other ($P > 0.05$). During the rainy season, precipitation penetrated straw and organic fertilizer layers to effectively recharge soil moisture, while film mulching prevented infiltration and unmulched between-row areas experienced relatively high evaporation.

In 20–40 cm and 40–60 cm layers, moisture consistently ranked: II > III > I > CK, with all treatments significantly different from CK ($P < 0.05$) but not from each other ($P > 0.05$). During spring drought, Treatments I, II, and III increased 0–60 cm moisture by 14.7%, 22.5%, and 17.9% compared to CK, respectively. During the rainy season, they increased moisture by 16.9%, 21.2%, and 20.9%, respectively. Thus, minimizing evaporation during spring drought and enhancing infiltration during the hot, rainy summer is key for water management in northern Shaanxi’ s arid hillside apple orchards.

2.3.2 Soil Moisture Environment in the Rhizosphere Layer (60-200 cm)

Mulching treatments also significantly affected 60–200 cm soil moisture. [Figure 6: see original paper] shows that during the growing season, water storage ranked: II > III > I > CK, with all treatments significantly different from CK

(P < 0.05), and Treatment I significantly different from II (P < 0.05), but III not significantly different from I or II (P > 0.05). From April–June, minimal rainfall reached below 60 cm while tree water consumption increased, causing storage to decline in all treatments. During this dry period, Treatments I, II, and III increased storage by 9.3%, 15.4%, and 12.3% compared to CK, respectively. After mid-July, heavy rainfall recharged the 60–200 cm layer, but fruit development consumed substantial water, slowing recovery. When rainfall decreased in October, storage declined again. During the rainy season, Treatments I, II, and III increased storage by 8.9%, 13.6%, and 10.3% compared to CK, respectively. Mulching measures thus significantly improved rhizosphere moisture accumulation and environment.

2.3.3 Soil Profile Moisture Differences During Critical Periods

[Figure 7: see original paper] shows that 0–200 cm soil moisture decreased with depth until stabilizing, with all treatments ranking: II > III > I > CK, and all mulched treatments significantly higher than CK (P < 0.05). During the water critical period, 0–100 cm moisture followed the same ranking, with all treatments significantly different from CK (P < 0.05) and Treatment I significantly different from II (P < 0.05), but III not significantly different from I or II (P > 0.05). Below 100 cm, no significant differences existed among mulched treatments (P > 0.05). Treatments I, II, and III increased average 0–200 cm moisture by 16.1%, 23.8%, and 18.7% compared to CK, respectively.

During flower bud differentiation, reduced rainfall and continuous tree water consumption decreased moisture, though the ranking II > III > I > CK persisted with no significant differences among mulched treatments (P > 0.05). Moisture increases were 18.4%, 23.2%, and 20.5% for Treatments I, II, and III, respectively. During fruit expansion, fruit development consumed substantial water. Although heavy rainfall recharged 0–60 cm moisture, infiltration was insufficient to increase moisture below 60 cm. The ranking remained II > III > I > CK with no significant differences among mulched treatments (P > 0.05), and moisture increases of 23.0%, 29.8%, and 26.8%, respectively.

Discussion

Soil moisture conditions play a crucial role in plant ecosystems. This orchard exhibited seasonal variation in 0–60 cm moisture consistent with rainfall patterns, with moisture changes lagging behind rainfall and rainfall effects diminishing with depth. The 100 cm layer was less affected by rainfall, with only intense events infiltrating to this depth. The 200 cm layer showed stable moisture (CV = 5.01%) with minimal external influence. These findings align with Wang et al. [7,9] and Zou et al. [12], who reported high water consumption in 0–60 cm layers, rainwater infiltration depths above 1 m but rarely reaching 2 m, and greater water consumption by apple trees than rainfall supplementation. This study achieved continuous dynamic monitoring, including during winter dormancy. Atmospheric precipitation was the sole water source, with sudden winter moisture declines and spring increases likely resulting from soil freezing and thawing, as solid water cannot be detected by moisture probes. While soil desiccation is common in mature apple orchards on the Loess Plateau, this study found desiccation already present in a 6-year-old orchard, with a distinct low-moisture layer at 90–300 cm (volumetric water content <12%). This differs from Cao et al. [21] and Guo et al. [22], possibly due to differences in climate, rainfall, and soil texture. Characterizing overall orchard soil moisture environments can effectively guide rational water management in rainfed orchards and support theoretical foundations for improving apple quality and productivity.

At the single-tree scale, soil moisture increased monotonically with distance from the trunk in both row and plant directions, consistent with Zhang et al. [23] and Li et al. [24]. This pattern reflects more extensive and dense root systems near the trunk, causing greater water consumption and lower moisture content. The linear relationships ($y = 0.0105x + 6.8702$ between plants; $y = 0.014x + 7.6912$ between rows) indicate that average moisture occurs at approximately 105 cm from the trunk, providing an optimal sampling location. Moisture along the row direction was significantly higher than at equivalent distances along the plant direction, suggesting that reducing competition between adjacent trees through appropriate planting density can effectively improve orchard water environments and increase yields.

Ground mulching effectively reduces soil evaporation, conserves water, enhances water retention capacity, increases orchard soil moisture, and alleviates water supply-demand conflicts during the growing season. All three mulching methods improved soil moisture environments in dryland orchards, consistent with previous studies [25-29]. Ridge-film mulching with furrow rainwater harvesting showed superior overall effects compared to straw and organic fertilizer mulching. Organic fertilizer mulching effectively conserved water, maintained temperature, reduced evaporation, and improved soil enzyme activity and fertility, but large-scale application can cause odor issues. Straw mulching intercepted rainfall, conserved water, slowed evaporation, and maintained soil fertility, but limited cropland area constrains straw availability for large-scale orchard application and may induce pest problems. Ridge-film mulching provided excellent moisture conservation in inter-plant areas due to film coverage, while unmulched furrows and between-row areas experienced strong evaporation, reducing overall effectiveness. However, during spring and summer drought, minimal rainfall could be harvested in furrows to improve local water supply, which still played an important role in tree development. Therefore, ridge-film mulching with furrow rainwater harvesting is recommended for rainfed apple orchards in loess mound-hilly gully regions.

Conclusions

1. Seasonal drought is severe in northern Shaanxi hillside apple orchards, with spring drought severity depending on soil water storage before winter dormancy. Soil moisture in 0–60 cm layers varies with rainfall, showing

consistent seasonal patterns that lag behind rainfall events, with rainfall effects diminishing with depth. The 100 cm layer is less affected by rainfall, while moisture below 200 cm remains relatively stable. Six-year-old hillside orchards already exhibit soil desiccation with a distinct low-moisture layer at 90–300 cm.

2. At the single-tree scale, soil moisture increases monotonically with distance from the trunk in both row and plant directions, with moisture along the row direction significantly higher than at equivalent distances along the plant direction ($P < 0.05$).

3. All three mulching treatments effectively improved soil moisture environments in dryland orchards. In the 0–60 cm layer, straw mulching, ridge-film mulching, and organic fertilizer mulching increased moisture by 14.7–16.9%, 21.2–22.5%, and 17.9–20.9%, respectively. In the 60–200 cm layer, these treatments increased moisture by 8.9–9.3%, 13.6–15.4%, and 10.3–12.3%, respectively.

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Note: Figure translations are in progress. See original paper for figures.