Short-Term Effects of Different Straw Return Methods on Soil Structure and Water: Postprint

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Abstract

Through field experiments and evaporation barrel simulation experiments, the effects of different short-term straw return methods on soil structure and water evaporation were analyzed. Four treatments were established: control (CK), chopped straw return (T1), chopped straw return + whole straw mulching (T2), and whole straw mulching (T3). The study found: (1) In the 0~20 cm soil layer, T1, T2, and T3 could all reduce soil bulk density and increase soil capillary porosity, but their effects on aggregates differed significantly. The macro-aggregate contents of T1 and T2 increased by 36.90% and 63.06% compared with CK ($P<0.05$), respectively, while T3 decreased by 9.89% compared with CK. (2) T1, T2, and T3 could all increase the average soil water content in the 0~60 cm soil layer and reduce the cumulative soil water evaporation. T3 had the minimum cumulative evaporation, with no significant difference between T2 and T3. Compared with CK, their water evaporation inhibition rates were 3.65% and 4.13%, respectively. (3) Chopped straw return + whole straw mulching achieved the best effect on improving soil structure and inhibiting soil water evaporation.

Full Text

Effects of Different Short-Term Straw Returning Methods on Soil Structure and Water Content

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Abstract

Through field experiments and evaporation bucket simulations, this study analyzed the effects of different short-term straw returning methods on soil structure and water evaporation. Four treatments were established: control (CK), broken straw returning (T1), broken straw returning plus whole straw cover (T2), and whole straw cover (T3). The results revealed: (1) In the 0–20 cm soil layer, T1, T2, and T3 all reduced soil bulk density and increased capillary porosity, but their effects on aggregates differed significantly. The large aggregate contents in T1 and T2 increased by 36.90% and 63.06% compared with CK ($P<0.05$), respectively, while T3 decreased large aggregate content by 9.89% compared with CK ($P<0.05$). (2) T1, T2, and T3 increased the average soil water content in the 0–60 cm layer and decreased cumulative soil water evaporation. T3 showed the smallest cumulative evaporation, with no significant difference between T2 and T3. Compared with CK, the evaporation inhibition rates were 3.65% and 4.13% for T2 and T3, respectively. (3) Broken straw returning combined with whole straw cover demonstrated the best effect on improving soil structure and inhibiting soil water evaporation.

Keywords: straw crushing and returning; whole straw mulching; soil physical structure; soil water evaporation

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Soil water is a primary limiting factor for agricultural production. Soil water infiltration and retention capacity are influenced by physical properties including bulk density, porosity, and soil aggregates. Straw returning significantly affects soil structure and water content. Most research on straw returning has focused on long-term experiments, which demonstrate that straw returning improves soil structure, reduces water evaporation, and enhances water use efficiency. Short-term studies also indicate significant impacts on soil water and structure, with the returning method being a critical factor affecting soil structure. In northwestern semi-arid and arid regions, natural and anthropogenic factors have degraded some soils, weakening their structure and water storage capacity. Developing effective methods to reduce evaporation, improve physical structure, and promote efficient agricultural resource utilization is urgently needed. Appropriate straw returning methods and quantities are important pathways for improving soil physical structure and water retention capacity. Moderate straw returning facilitates decomposition, simplifies subsequent tillage, and enables continuous straw utilization, thereby achieving efficient straw resource use in the short term.

Previous studies show that whole straw deep incorporation, whole straw mulching, broken straw incorporation, and broken straw mulching all significantly reduce bulk density and increase porosity, promoting the transformation of micro-aggregates into macro-aggregates, enhancing water-stable aggregate stability, and improving water-holding capacity. Both whole and broken straw mulching create a surface barrier that significantly reduces evaporation, slows water fluctuation, and improves water use efficiency. Shallow straw returning most significantly affects water content in the 0–20 cm layer, while deep incorporation provides better soil and water conservation. However, in some arid regions, straw incorporation and crushing may actually promote evaporation and reduce water content. Although straw mulching improves soil physical structure and optimizes the soil solid-liquid-gas ratio, excessive mulching can hinder water infiltration, reduce soil temperature, affect sowing and germination, and even lead to burning when decomposition is incomplete. As agricultural resources are increasingly recycled, straw returning practices are gradually being promoted, making it essential to investigate appropriate returning amounts and methods for improving soil structure and reducing evaporation.

This study combined field and evaporation bucket experiments to examine the effects of different straw returning methods on soil physical structure, evaporation characteristics, and profile water content, aiming to clarify the impacts of short-term straw returning via different methods and provide theoretical support for straw utilization in improving soil structure and reducing evaporation in northwestern semi-arid and arid regions.

1.1 Study Area Description

The experiment was conducted at the Agricultural Information Science Popularization Courtyard (36°37 N, 104°29 E) in Shuichuan Town, Baiyin District, Baiyin City, Gansu Province, at an elevation of 1509 m. The region has a temperate continental climate with an annual average temperature of 7.9 °C, characterized by cold winters, hot summers, and large diurnal temperature variations. With abundant sunshine (2534 h annually) and a frost-free period of 161 days, the area experiences high evaporation (2004 mm) and low precipitation (204 mm). The soil is sandy loam with a bulk density of 1.39 $g \cdot cm^{-3}$.

1.2 Experimental Design

Four treatments were established: (1) CK (control, no straw), (2) T1 (broken straw returning: corn straw crushed to 2–3 cm and incorporated into soil at 9000 $kg \cdot hm^{-2}$, representing total corn straw yield per hectare on an air-dry basis), (3) T2 (broken straw returning plus whole straw cover: same straw amount as T1, crushed to 2–3 cm and incorporated, plus whole straw mulched on surface), and (4) T3 (whole straw cover: whole corn straw mulched on surface at 9000 $kg \cdot hm^{-2}$). Each treatment had three replications. Field plots (3 m × 2.5 m) were arranged in a completely randomized design. Evaporation buckets were interspersed with field plots, and a rain shelter was constructed to prevent precipitation interference. Temperature during the experiment ranged from 5.5 to 28.5 °C.

For the evaporation bucket test, buckets (22 cm diameter, 31 cm height) were perforated uniformly at the bottom, lined with gauze, and filled with soil. Water was added until leakage occurred from the bottom. After 15 cm of water infiltration, the bottom was sealed to prevent further drainage. Straw was applied as in the field experiment, and initial weight was recorded. The test ran from [date] to [date].

1.3 Measurement Indicators and Calculation Methods

Soil profile water content was measured using a TPGSQ-4 moisture meter at 0–5, 5–15, 15–20, 20–40, 40–50, 50–60, 60–80 cm depths on days 1, 3, 5, 7, 10, 15, 20, 25, and 30.

Soil bulk density and porosity were determined on day 30. Three sampling points per treatment were selected, and undisturbed soil cores (0–20 cm) were collected using rings. Bulk density was calculated after oven-drying. Total porosity = (1 -bulk density/soil particle density) × 100% (soil particle density = 2.65 $g \cdot cm^{-3}$). Capillary porosity = field capacity -wilting point. Non-capillary porosity = total porosity -capillary porosity.

Water-stable aggregates were collected on day 30. Three sampling points per treatment were selected, and undisturbed soil (0–20 cm) was collected in plastic boxes. After removing debris and breaking into 2–5 mm pieces, samples were air-dried. The wet-sieving method was used to determine water-stable aggregates of >2 mm, 1-2 mm, 0.5-1 mm, 0.25-0.5 mm, and <0.25 mm. Mean weight diameter (MWD), geometric mean diameter (GMD), and unstable aggregate index (ELT) were calculated:

$$MWD = \sum_{i=1}^{n} w_i \bar{x}_i$$

$$GMD = \exp\left(\frac{\sum_{i=1}^{n} w_i \ln \bar{x}_i}{\sum_{i=1}^{n} w_i}\right)$$

$$ELT = \frac{M_Z - M_{>0.25}}{M_Z} \times 100\%$$

where $\bar{x}_i$ is the mean diameter of aggregate fraction i, w_i is the mass fraction, M_Z is total aggregate mass, and $M_{>0.25}$ is mass of aggregates >0.25 mm.

Daily evaporation in bucket tests was measured by weighing at 18:00 daily using a 0.01 g precision balance.

Cumulative evaporation versus time relationship was fitted using the Gardner model:

$$E = at^b$$

where t is time, E is cumulative evaporation, and a and b are fitting parameters. The evaporation rate v is derived from this relationship.

1.4 Data Processing

Data were analyzed using Excel and SPSS 20.0. One-way ANOVA was performed with significance level at $P < 0.05$. Figures were prepared using Excel.

2.1.1 Effects on Soil Bulk Density and Porosity

All straw returning methods reduced bulk density and increased total and capillary porosity in the 0–20 cm layer. As shown in Table 1, bulk density followed the order CK > T3 > T2 > T1, with no significant difference between T1 and T2. Total porosity of T1, T2, and T3 increased by 6.1%, 5.0%, and 3.6% compared with CK, respectively, with T1 showing significant increase. Capillary porosity increased by 34.3% in T1, 22.7% in T2, and 8.1% in T3, with no significant difference between T2 and T3. Non-capillary porosity decreased significantly in the 0–20 cm layer under straw returning treatments.

2.1.2 Effects on Water-Stable Aggregate Composition and Stability

Straw returning methods significantly promoted macro-aggregate formation, with broken straw treatments more effective than whole straw cover. As shown in Figure 1, water-stable macro-aggregate contents (>2 mm) in T1 and T2 were 23.08% and 23.30%, respectively, significantly higher than CK (13.40%). All methods improved aggregate stability (Table 2). MWD and GMD in T1, T2, and T3 increased by 122.35%, 123.53%, and 55.29%, respectively, compared with CK (P<0.05), while ELT decreased by 31.66%, 34.15%, and 15.38%, respectively. T2 showed the greatest improvement in water-stable aggregate stability, though not significantly different from T1.

2.2.1 Effects on Soil Evaporation Intensity

All straw returning methods inhibited daily evaporation, with whole straw cover most effective. Evaporation bucket tests (Figure 2) showed daily evaporation decreased over time. During the first 10 days, all treatments had higher evaporation than CK, but T3 showed the smallest increase. After day 10, evaporation decreased rapidly with declining water content, but T3 maintained lower rates. On day 21, high humidity reduced evaporation in all treatments, but T3 remained lowest. Throughout the experiment, T3 reduced evaporation by 21.2–58.8% compared with CK, T2 by 10.5–51.5%, and T1 by 3.65–4.13%, demonstrating significant inhibition effects.

2.2.2 Effects on Cumulative Evaporation

Cumulative evaporation increased rapidly then gradually stabilized. All straw treatments reduced evaporation compared with CK (Figure 3). Final cumulative evaporation values were 21.28 mm (T3), 21.88 mm (T2), 23.30 mm (T1), and 24.20 mm (CK). The Gardner model fitted the cumulative evaporation versus time relationship well ($R^2 > 0.98$, $P<0.01$) (Table 3). Based on parameter values, evaporation rates ranked CK > T1 > T2 > T3, consistent with observed trends.

2.3 Effects on Soil Profile Water Content

Straw returning methods primarily affected water content in the 0-60 cm profile, with the most significant impact in the 0–20 cm layer (Figure 4). On day 1, water content in the 0–20 cm layer followed the order T2 > T1 > T3 > CK. Throughout the experiment, average water content in the 0–20 cm layer was highest in T2 (21.22%) and T3 (21.18%), significantly higher than CK (16.8%). In the 0–60 cm layer, T2, T3, and T1 increased average water content by 1.64%, 0.98%, and 2.20%, respectively, compared with CK.

3 Discussion

Previous research has primarily confirmed from long-term perspectives that straw returning improves soil physical structure by increasing organic matter, enlarging pores, and optimizing soil solid-liquid-gas phases. Short-term studies also demonstrate significant effects on soil structure. Our short-term experiment showed that broken straw returning, broken straw returning plus whole straw cover, and whole straw cover effectively reduced bulk density and increased porosity, with greater effects at higher application rates. These treatments also reduced micro-aggregate content (<0.25 mm) in the 0–20 cm layer and improved water-stable aggregate stability, with T2 showing the most significant effect. This occurs because incorporated straw acts as a "wedge," improving the soil-atmosphere interface microenvironment and promoting aggregate formation while enhancing water storage capacity.

Straw returning most significantly affects water content in the 0–20 cm layer. Our simulation experiments explored tillage layer water dynamics. T2 and T3 were more effective at inhibiting evaporation than T1, with no significant difference between T2 and T3. Surface straw mulch creates a soil-atmosphere barrier that hinders evaporation and delays water loss, substantially preserving soil moisture. T1, T2, and T3 all maintained higher average water content in the 0–60 cm layer, consistent with findings by Chen et al. However, our results differ slightly from Yuan et al., who found straw mulching primarily affected the 0–50 cm layer, possibly due to differences in soil type and climate.

This short-term experiment provides preliminary insights, but longer observation periods and additional treatments are needed to determine optimal straw returning methods and rates for improving soil properties and reducing evaporation. Future research should also investigate deeper soil water dynamics.

4 Conclusions

This study investigated the effects of different short-term straw returning methods on soil structure and water evaporation using mathematical modeling, revealing significant differences among methods:

1) Broken straw returning and broken straw returning plus whole straw cover significantly reduced bulk density, increased porosity, and improved water-stable aggregate stability in the 0–20 cm layer, promoting macro-aggregate formation.

2) Straw returning increased average water content in the 0–60 cm layer and reduced cumulative evaporation, with whole straw cover showing the most significant evaporation inhibition.

3) Broken straw returning effectively improved soil physical structure, while whole straw cover best reduced evaporation. Broken straw returning plus whole straw cover combined these advantages, making it the optimal choice when both soil structure improvement and evaporation inhibition are desired.

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