AI translation · View original & related papers at
chinarxiv.org/items/chinaxiv-201711.02167

# Effects of Straw Return on Soil Respiration and Its Temperature Sensitivity Under Two Crop Rotation Patterns: Postprint

**Authors:** Ding Ruixia, Wang Weiyu, Zhang Qing

**Date:** 2017-11-10T00:00:00+00:00

## Abstract

By analyzing the effects of straw return on soil respiration and its temperature sensitivity under different crop rotation patterns, this study provides a theoretical basis for in-depth investigation of carbon cycling in agroecosystems in the Guanzhong region. The experiment was conducted in Yangling, Shaanxi Province, from October 2012 to September 2014, using winter wheat-summer maize rotation and winter wheat-summer soybean rotation as study objects. Two treatments were established: straw return (SM) and no straw (NS). Soil respiration, soil temperature, and soil water content were measured and analyzed for their variation trends and differences under different treatments, and the temperature sensitivity of soil respiration (Q10) was estimated. The results showed that soil respiration exhibited obvious seasonal variation. During most of the crop growth period, soil respiration rates under SM treatment were significantly higher than those under NS treatment ($P<0.05$), and the average soil respiration rate during the crop growth period and cumulative soil respiration emissions under SM treatment were also highly significantly higher than those under NS treatment ($P<0.01$). The average soil respiration rates during different crop growth periods followed the order: summer maize > summer soybean > winter wheat, while total soil respiration showed the pattern: winter wheat > summer maize > summer soybean, and winter wheat-summer maize rotation > winter wheat-summer soybean rotation. Soil temperature differed between winter wheat-summer maize rotation and winter wheat-soybean rotation; specifically, during the early growth stage of winter wheat, soil temperature in winter wheat-summer maize rotation was significantly higher than that in winter wheat-soybean rotation. During the second season, soil temperature at 5 cm depth during the summer maize growth period was significantly lower than that of summer soybean in the same season. Compared with NS treatment, SM treatment increased soil temperature in winter and decreased soil temperature in spring and summer. During periods of high temperature and low rainfall, SM treatment could increase the average water content of 0-30 cm soil. Different preceding crops led to significant differences in soil water content of the tillage layer of winter wheat between the two rotation patterns, and soil water content in the tillage layer under summer maize was significantly higher than that under summer soybean. Correlation analysis showed that soil respiration had highly significant positive correlations with soil temperature at both 5 cm and 10 cm, with a better correlation with soil temperature at 5 cm; however, there was no significant correlation between soil respiration and average soil water content at 0-30 cm. Variations in soil temperature at 5 cm and 10 cm could explain 64.6%-67.3% and 51.5%-59.6% of soil respiration variation, respectively. Throughout the entire study period, temperature sensitivity (Q10) ranged from 1.70 to 2.01. Temperature sensitivity in winter wheat-summer maize rotation was significantly higher than that in winter wheat-soybean rotation, and under the same rotation pattern, temperature sensitivity under SM treatment was significantly lower than that under NS treatment. Therefore, straw return can enhance soil respiration in cropland, reduce the temperature sensitivity of soil respiration, and simultaneously regulate soil hydrothermal conditions.

## Full Text

## Effect of Straw Mulching on Soil Respiration and Its Temperature Sensitivity Under Different Crop Rotation Systems

**DING Ruixia[1], WANG Weiyu[2,3], ZHANG Qing[2]**

[1]Institute of Water-saving Agriculture in Arid Areas of China, Northwest A&F University / Key Laboratory of Crop Physiology and Tillage Sciences in Northwestern Loess Plateau, Ministry of Agriculture, Yangling 712100, China; [2]College of Agronomy, Northwest A&F University, Yangling 712100, China; [3]Research Center of Recycle Agricultural Engineering and Technology of Shaanxi Province, Yangling 712100, China

*This work was funded by the Science and Technology Overall Planning Project in Shaanxi Province of China (2015KTCL02-07).*

**Corresponding author, DING Ruixia, E-mail: dingruixia@sohu.com**

Received Jan. 21, 2017; accepted Apr. 5, 2017

---

### Abstract

Soil respiration represents the second largest carbon flux between terrestrial ecosystems and the atmosphere, playing a critical role in regulating global soil carbon dynamics. As soil temperature and moisture are projected to exert stronger effects on soil respiration in the future, understanding the response of soil microbes to temperature change provides a novel approach for studying drought effects on soil respiration and predicting drought-induced changes in the terrestrial carbon cycle. Temperature sensitivity of soil respiration ($Q$ ) explains the relationship between soil respiration and temperature. This study investigated how straw mulching affects the linkages between soil respiration and temperature in agro-ecosystems in Yangling, Shaanxi Province.

A two-year field experiment (October 2012 to September 2014) was conducted under two crop rotation systems: winter wheat–summer maize and winter wheat–summer soybean. Two treatments—no straw (NS) and straw mulch (SM)—were established to analyze variations in soil respiration rate, temperature, and moisture, and to estimate temperature sensitivity ($Q$ ). Results showed that soil respiration exhibited clear seasonal variation. During most of the crop growth period, SM treatment significantly increased soil respiration rate compared with NS treatment ($P < 0.05$), with mean soil respiration rate and cumulative emissions during the crop growth period being extremely significantly higher under SM ($P < 0.01$). The mean soil respiration rate across crop growth periods followed the order: summer maize (3.401–4.810 $mol \cdot m^{2} \cdot s^{1}$) > summer soybean (3.390–3.762 $mol \cdot m^{2} \cdot s^{1}$) > winter wheat (2.673–3.141 $mol \cdot m^{2} \cdot s^{1}$). Cumulative soil respiration differed among rotations: wheat-maize [34.68–40.81 $t(CO) \cdot hm^{2}$] > wheat-soybean [30.04–33.86 $t(CO) \cdot hm^{2}$].

Soil temperature varied significantly between rotation systems. During early winter wheat growth, soil temperature under wheat-maize rotation was significantly higher than under wheat-soybean rotation. At 5 cm depth during the second summer crop season, soil temperature in maize plots was significantly lower than in soybean plots. Compared with NS treatment, SM treatment increased soil temperature in winter but decreased it in spring and summer. During hot, dry periods, SM treatment significantly increased mean soil moisture content in the 0–30 cm layer. Differences in preceding crops created significant differences in topsoil moisture between the two rotations, with moisture content under summer maize being significantly higher than under summer soybean.

Correlation analysis revealed that soil respiration was extremely significantly positively correlated with soil temperature at both 5 cm and 10 cm depths, with a stronger correlation at 5 cm. However, no significant correlation was found between soil respiration and mean soil moisture content in the 0–30 cm layer. Soil temperature at 5 cm and 10 cm depths explained 64.6%–67.3% and 51.5%–59.6% of soil respiration variation, respectively. Across the entire study period, $Q$ values ranged from 1.70 to 2.01, being significantly higher under wheat-maize than wheat-soybean rotation. Within each rotation system, $Q$ was significantly lower under SM treatment than NS treatment.

Therefore, straw mulching enhances soil respiration, reduces its temperature sensitivity, and regulates soil hydrothermal conditions in farmland ecosystems.

**Keywords:** Crop rotation system; Straw mulch; Soil respiration; Temperature sensitivity; Soil moisture and heat condition

## Introduction

Since the Industrial Revolution, rapid human development has posed unprecedented challenges to the natural environment, with climate change and its impacts representing one of the most critical environmental issues facing humanity today. As environmental conditions deteriorate, the carbon cycle—closely linked to climate change—has become a major research focus worldwide. Soil carbon pools constitute the largest carbon reservoir in terrestrial ecosystems. As the primary form of CO exchange between soil and atmospheric carbon pools, soil respiration accounts for more than two-thirds of total emissions from terrestrial ecosystems. Globally, over 75 Pg of carbon (1 Pg = $1\times10^{1}$ g) is released annually to the atmosphere through soil respiration. Even minor changes in soil respiration will inevitably alter atmospheric carbon concentrations, thereby exacerbating global warming and threatening human survival and environmental sustainability. Agricultural production is estimated to contribute 21%–25% of anthropogenic greenhouse gas emissions, and in China—a major agricultural nation—carbon emissions from farmland increased by 93.9% between 1999 and 2009. Therefore, studying carbon emissions from agricultural production holds significant practical importance.

Compared with other terrestrial ecosystems, farmland ecosystems experience the greatest human disturbance. Variations in tillage, fertilization, and irrigation practices create differences in soil environments that subsequently affect soil respiration rates. Soil respiration flux measured at the soil surface generally represents the sum of root respiration and microbial respiration. Soil respiration intensity is closely linked to soil organic matter content and mineralization rates, as well as to microbial community composition and activity. Straw mulching, a widely adopted agricultural practice, is believed to improve soil hydrothermal conditions and enhance soil aeration. Previous studies have also demonstrated that straw mulching significantly affects soil organic matter content and microbial biomass. Extensive research has examined soil respiration responses to straw mulching, with mixed results. Some studies indicate that no-tillage with straw mulching increases soil organic matter content, promoting organic matter decomposition and CO release, thereby enhancing soil respiration rates. Conversely, other research suggests that no-tillage with stubble retention significantly reduces soil respiration rates, with the magnitude of reduction increasing with stubble amount.

Soil respiration is closely associated with temperature, typically showing increased CO flux with rising temperatures. However, soil respiration also exhibits thermal adaptation, which can weaken the relationship between respiration and temperature changes. The strength of this adaptation depends primarily on the temperature sensitivity of soil respiration, making Q (the factor by which respiration increases with a 10°C temperature rise) a critical parameter for understanding global carbon cycle responses to climate change.

Researchers have developed various temperature response functions, with Q being the most widely used. Among the many factors influencing soil respiration temperature sensitivity, temperature and moisture dominate, affecting both microbial communities and substrate availability. Synthesized Q values across ecosystems range from 1.28 to 4.75. Recent studies on agricultural ecosystems have increased, focusing primarily on how tillage and fertilization practices alter hydrothermal conditions, nutrient content, and microbial status, thereby changing temperature sensitivity. However, research specifically addressing straw mulching effects remains limited, often treating it as one of several tillage practices or examining single crops rather than rotation systems.

This study analyzes two common rotation systems in Shaanxi Province to compare how straw mulching affects soil respiration temperature sensitivity across different rotations, providing theoretical insights for carbon cycling research in the Guanzhong region' s farmland ecosystems.

---

## 1. Materials and Methods

**1.1 Study Site** The experiment was conducted in the Yangling Agricultural Demonstration Zone in Shaanxi Province (108°07 E, 34°12 N). The region has a continental warm temperate monsoon climate with a mean annual temperature of 12.9°C. Precipitation occurs mainly from July to September, with an average annual rainfall of approximately 660 mm. The cropping system is double-cropping per year. The experimental soil is [soil type], with basic physicochemical properties shown in .

** Soil chemical properties of the tested field**

| Soil depth (cm) | Organic matter (g · kg 1) | Available phosphorus (mg · kg 1) | Available potassium (mg · kg 1) | Alkali-hydrolysable nitrogen (mg · kg 1) |
|---|---|---|---|---|
| 0-10 | 8.78±0.34A | 13.00±0.14A | 158.12±1.87A | 37.32±0.53A |
| 10–20 | 6.76±0.46B | 11.16±0.44B | 133.17±1.81B | 28.11±0.93B |
| 20–30 | 4.94±0.39C | 9.02±0.04C | 123.81±1.81C | 22.16±2.13C |

*Note: Soil chemical properties were measured before the experiment in 2011.*

**1.2 Experimental Design** The experiment ran from 2012 to 2014, focusing on two rotation systems: winter wheat (*Triticum aestivum* L.)–summer maize (*Zea mays* L.) and winter wheat–summer soybean (*Glycine max* L.). Winter wheat was sown in early October 2012 and 2013, and harvested in June 2013 and 2014. Summer maize and soybean were sown immediately after winter wheat harvest and harvested in early October 2013 and 2014. Wheat variety was 'Xinong 889' , maize was 'Luodan 9' , and soybean was 'Dongdou 339' .

To avoid irrigation-induced stimulation of soil respiration that could affect measurement accuracy, irrigation was minimized. Each winter wheat season received only one winter irrigation in mid-January (during overwintering), while summer crops received one irrigation in mid-July to alleviate drought stress, with rainfall providing remaining water needs. All irrigation was flood irrigation.

The entire experimental area was under no-tillage. Each rotation system had two treatments: straw mulch (SM) and no straw (NS, control). In the wheat-maize rotation, treatments were designated SM1 and NS1; in the wheat-soybean rotation, SM2 and NS2. Each plot measured 8.6 m × 8 m, with 0.5 m spacing between plots and three replicates per treatment. For SM treatment, crop residues were returned directly after harvest; for NS treatment, all residues were removed. Fertilizer application rates were: winter wheat—urea 375 kg · hm ² + diammonium phosphate 375 kg · hm ²; summer maize—urea 375 kg · hm ²; summer soybean—diammonium phosphate 150 kg · hm ². All fertilizers were applied as basal dressings. Straw incorporation amounts and nitrogen application rates are detailed in .

** Amounts of straw incorporation and nitrogen fertilizer application for different crops**

| Crop | Straw incorporation (kg · hm ²) | Nitrogen fertilizer [kg(N) · hm ²] |
|---|---|---|
| Winter wheat | [value] | [value] |
| Summer maize | [value] | [value] |
| Summer soybean | [value] | [value] |

*Note: Nitrogen amounts were calculated based on 46% N in urea and 17.4% N in diammonium phosphate.*

### 1.3 Measurements

**1.3.1 Gas Measurement** Soil respiration rate was measured using a GXH-3010E1 portable infrared analyzer. After sowing, PVC chambers (10 cm height, 16 cm diameter) were installed in each plot at 5 cm depth, with three chambers per plot arranged in a triangular pattern 1 m apart. During measurement, a small fan was placed on top of each chamber and run for 3 minutes to homogenize internal gas before sampling. All measurements were conducted between 9:00–11:00.

Soil respiration rate was calculated as:

$$R = k \cdot \frac{(X_2 - X_1) \cdot H}{\Delta t}$$

where $R$ is soil respiration rate ( mol · m $^{2}$ · s $^{1}$), $k$ is a conversion coefficient (1.80 at 25°C and 1 standard atmosphere), $X_1$ and $X_2$ are initial and final CO concentrations (%), $H$ is chamber height (m), and $\Delta t$ is measurement duration (s).

Measurements began after the first winter wheat sowing (October 2012). Due to slow growth before regreening, measurements were taken at seedling (15 days after sowing, DAS), tillering (50 DAS), overwintering (95 DAS), and regreening stages (155 DAS), then every 15 days thereafter, totaling 9 measurements per wheat season. Summer crops were measured every 15 days after sowing (7 measurements total). After rainfall events, measurements were delayed 3–5 days to minimize precipitation effects.

**1.3.2 Soil Temperature Measurement** Right-angle soil thermometers at multiple depths were installed 10 cm from PVC chambers, with three sets per treatment. Soil temperatures at 5, 10, and 15 cm depths were recorded simultaneously with CO measurements.

**1.3.3 Soil Moisture Measurement** Soil moisture was determined by oven-drying method. On each measurement day, soil samples were collected from 0-30 cm depth in 10-cm increments, with three replicates per plot.

**1.3.4 Cumulative Soil Respiration** Cumulative soil respiration was calculated using the formula from Zhai et al.:

$$R_a = \frac{(R_i + R_{i+1})}{2} \times 3600 \times 24 \times 44 \times 10^{-8} \times n$$

where $R_a$ is cumulative soil respiration [t(CO ) · hm $^{2}$], $R_i$ and $R_{i+1}$ are successive respiration rate measurements, and $n$ is the interval days between measurements.

**1.3.5 Data Analysis** Soil respiration temperature response was modeled using the exponential function:

$$R = a \cdot e^{bT}$$

where $R$ is soil respiration rate ( mol · m $^{2}$ · s $^{1}$), $T$ is soil temperature (°C), and $a$ and $b$ are regression coefficients.

Temperature sensitivity (Q ) was calculated as:

$$Q_{10} = e^{10b}$$

Data analysis and graphing were performed using Microsoft Excel 2010, SPSS 20.0, and Origin 2016, with Duncan' s multiple range test for ANOVA.

---

## 2. Results

**2.1 Dynamics of Soil Temperature Under Different Treatments** As shown in [Figure 1: see original paper], monthly mean air temperature ranged from -1.6°C (January 2013) to 23.1°C (August 2013) during 2012-2013, and from -1.3°C (December 2013) to 28.2°C (June 2014) during 2013-2014. In both years, June–August temperatures exceeded 21°C. Most monthly rainfall was below 230 mm, except in April 2013, February 2014, April 2014, and September 2014 when it exceeded 300 mm.

In both rotation systems, soil temperature during winter wheat growth showed a decreasing then increasing trend, with the turning point at 95 DAS. At 95 DAS in both wheat seasons, SM treatment had higher temperatures than NS at both 5 cm and 10 cm depths (0.1-0.8°C higher). During 95-230 DAS, SM treatment had lower temperatures than NS: in wheat-maize rotation, decreases of 4.4%-10.7% (5 cm) and 1.3%-5.3% (10 cm) in 2012-2013, and 2.5%-10% (5 cm) and 0.5%-4.2% (10 cm) in 2013-2014; similar patterns occurred in wheat-soybean rotation.

During summer crop seasons, soil temperature in 2013 soybean decreased continuously, while maize temperature remained stable until 60 DAS then declined. In 2014, both crops showed an increase then decrease pattern with the peak at 45 DAS. In 2013, SM treatment reduced soil temperature by 0.3%-7.7% (5 cm) and 0.3%-7.4% (10 cm) in maize, and by 0.3%-4.4% (5 cm) and 0.7%-6.1% (10 cm) in soybean. In 2014, temperature reductions were 1.7%-9.8% (5 cm) and 0.35%-0.4% (10 cm) in maize, and 0.7%-4.6% (5 cm) and 0.7%-3.7% (10 cm) in soybean.

Throughout the study period, wheat-maize rotation had significantly higher soil temperature than wheat-soybean rotation during early wheat growth stages. In the second summer crop season, 5 cm soil temperature under maize was significantly lower than under soybean. Within each rotation, SM and NS treatments differed significantly, and soil temperature generally decreased with depth, except during 50-95 DAS in winter wheat.

**2.2 Dynamics of Soil Moisture Under Different Treatments** Mean soil moisture in the 0-30 cm layer varied significantly between rotation systems ([Figure 3: see original paper]). During 2012-2013 wheat season at 185, 200, and 230 DAS, SM treatment increased moisture by 9.58%, 1.77%, and 7.46% compared with NS in wheat-maize rotation, and by 0.08%, 6.21%, and 3.53% in wheat-soybean rotation. During 2013–2014 wheat season at 215 and 230 DAS, SM increased moisture by 6.62% and 2.92% in wheat-maize rotation, and by 3.08% and 5.39% in wheat-soybean rotation.

During both summer maize seasons (30-90 DAS), SM treatment increased moisture by 0.5%–3.18% in 2013 and 0.06%–4.17% in 2014 compared with NS. In 2012–2013 summer soybean season, SM increased moisture by 0.78%–3.50% throughout the growth period. In 2013–2014, SM increased moisture by 0.44%–13.85% at all times except 90 DAS.

**2.3 Effects of Soil Hydrothermal Factors on Soil Respiration** Pearson correlation analysis showed extremely significant positive correlations between soil respiration and soil temperature at both 5 cm and 10 cm depths in both rotation systems (). Correlation coefficients ranged from 0.611 to 0.687 in wheat-maize rotation and 0.227 to 0.397 in wheat-soybean rotation. SM treatment showed stronger correlations than NS, and correlations were stronger at 5 cm than at 10 cm depth. No significant correlations were found between soil respiration and mean soil moisture in the 0–30 cm layer.

Exponential functions explained the relationship between soil respiration and temperature (). Soil temperature at 5 cm depth explained 64.6%–67.3% of soil respiration variation, while temperature at 10 cm depth explained 51.5%–59.6%.

** Correlation analysis of soil respiration and soil hydrothermal factors**

| Rotation system | Treatment | 5 cm soil temperature | 10 cm soil temperature | 0–30 cm soil moisture |
|---|---|---|---|---|
| Wheat-maize | NS | 0.631** | 0.611** | ns |
| | SM | 0.687** | 0.670** | ns |
| Wheat-soybean | NS | 0.286** | 0.227** | ns |
| | SM | 0.397** | 0.374** | ns |

*Note: NS = no straw incorporation, SM = straw incorporation. ** indicates significant correlation at P < 0.01 level.*

** Fitted equations of soil respiration with soil temperature**

| Rotation system | Treatment | Soil depth (cm) | Fitted equation | P-value |
|---|---|---|---|---|
| Wheat-maize | NS | 5 | R=0.838e · | <0.001 |
| | SM | 5 | R=0.868e · | <0.001 |
| | NS | 10 | R=1.048e · | <0.001 |
| | SM | 10 | R=0.882e · 3 | <0.001 |

| Rotation system | Treatment | Soil depth (cm) | Fitted equation | P-value |
|---|---|---|---|---|
| Wheat-soybean | NS | 5 | R=0.805e · | <0.001 |
| | SM | 5 | R=1.063e · | <0.001 |
| | NS | 10 | R=0.787e · | <0.001 |
| | SM | 10 | R=0.787e · | <0.001 |

**2.4 Dynamics of Soil Respiration Rate Under Different Treatments**

Soil respiration rates under different treatments are shown in [Figure 4: see original paper]. After winter wheat sowing, respiration rates decreased gradually to a minimum at 95 DAS. During 155–230 DAS, patterns varied among treatments. In 2012–2013, only SM treatment in wheat-soybean rotation showed continuously increasing respiration, while other treatments peaked then declined. In 2013–2014, all treatments increased during 95–200 DAS then decreased during 215–230 DAS.

During summer crop seasons, respiration rates generally increased then decreased. In 2013, peak respiration occurred at 45 DAS in soybean and 60 DAS in maize. In 2014, wheat-maize rotation maintained higher respiration rates than wheat-soybean during 30–105 DAS, with all treatments peaking at 60 DAS.

In wheat-maize rotation, SM treatment significantly increased respiration rates by 1.08%–36.53% compared with NS at most measurement times (except 230 DAS in 2012–2013 and 200 DAS in 2013–2014). In wheat-soybean rotation, SM increased respiration by 1.51%–99.43% at all times except 95–155 DAS. During summer maize seasons, SM increased respiration by 0.70%–56.24% at most times (except 30 and 75 DAS in 2014). During summer soybean seasons, SM increased respiration by 0.73%–11.64% throughout both seasons.

Mean soil respiration rates were 2.673–3.141 mol·m ²·s ¹ for winter wheat, 3.401–4.810 mol·m ²·s ¹ for summer maize, and 3.390–3.762 mol·m ²·s ¹ for summer soybean (). SM treatment significantly increased mean respiration rates ($P < 0.01$) across all crops and seasons: by 14.13% and 9.35% in wheat-maize wheat seasons, 12.61% and 7.29% in wheat-soybean wheat seasons, 16.55% and 16.70% in maize seasons, and 4.01% and 2.33% in soybean seasons.

** Mean soil respiration rates in crop growth periods ( mol·m ²·s ¹)**

| Treatment | Winter wheat 2012–2013 | Winter wheat 2013–2014 | Summer maize 2013 | Summer maize 2014 | Summer soybean 2013 | Summer soybean 2014 |
|---|---|---|---|---|---|---|
| NS | 2.673±0.028C | 2.801±0.016B | 3.401±0.017B | 4.731±0.030B | 3.113±0.029A | 3.090±0.023A |
| SM | 3.113±0.029A | 3.090±0.023A | 3.964±0.017A | 4.810±0.020A | 2.745±0.004B | 2.774±0.006B |

*Note: Different letters indicate significant differences among treatments within the same growth period at P < 0.01.*

**2.5 Dynamics of Cumulative Soil Respiration Under Different Treatments** Cumulative soil respiration represents total CO released during the entire crop growth period. As shown in , cumulative respiration differed significantly among crops: winter wheat > summer maize > summer soybean. Consequently, wheat-maize rotation had higher total respiration [34.68–40.81 t(CO ) · hm$^{2}$] than wheat-soybean rotation [30.04–33.86 t(CO ) · hm$^{2}$]. Within each crop, cumulative respiration was significantly higher under SM than NS treatment ($P < 0.01$), consistent with mean respiration rate patterns.

** Cumulative soil respiration in crop growth periods [t(CO ) · hm$^{2}$]**

| Treatment | Winter wheat 2012–2013 | Winter wheat 2013–2014 | Summer maize 2013 | Summer maize 2014 | Summer soybean 2013 | Summer soybean 2014 |
|---|---|---|---|---|---|---|
| NS | 19.80±0.39B | 20.29±0.014B | 15.80±0.11B | 18.17±0.15B | 21.89±0.33A | 21.94±0.39A |
| SM | 21.89±0.33A | 21.94±0.39A | 17.46±0.17A | 18.80±0.14A | 19.85±0.21C | 18.88±0.29C |

**2.6 Variation in Soil Respiration Temperature Sensitivity (Q )** The exponential function $R = ae^{bT}$ was used to model the response of soil respiration to 5 cm soil temperature across two rotation cycles, from which Q values were estimated ([Figure 5: see original paper]). Across the entire study period, Q ranged from 1.70 to 2.01. Q was significantly higher in wheat-maize rotation than in wheat-soybean rotation ($P < 0.05$). Within each rotation, SM treatment had significantly lower Q than NS treatment ($P < 0.01$). Specifically, SM reduced Q by 0.20 in wheat-maize rotation and by 0.16 in wheat-soybean rotation.

**[Figure 5: see original paper] Variations of temperature sensitivity (Q ) values under different treatments**

*Note: Different uppercase letters indicate significant differences between treatments within the same rotation system at P < 0.01.*

---

## 3. Discussion and Conclusion

Soil temperature dynamics respond to air temperature changes and solar radiation receipt. In this study, seasonal soil temperature patterns matched air temperature trends, but depth-specific patterns differed: at 10 cm depth, temperature was higher than at 5 cm in winter, but lower in spring and summer. This occurs because heat transfers from deep to shallow layers when air temperature is low, and from shallow to deep layers when air temperature is high. Previous studies have confirmed that straw mulching regulates topsoil temperature, which our results support: SM treatment increased soil temperature when external temperatures were low, but decreased it when temperatures rose.

During winter wheat growth, different straw amounts from preceding crops (maize vs. soybean) caused differential heat loss to the atmosphere, leading to significant temperature differences between rotations during early wheat growth. For summer crops, canopy differences affected soil temperature: larger maize leaves reduced solar radiation reaching the soil surface, lowering temperature compared with soybean.

Previous research indicates straw mulching increases soil moisture during crop growth, though our results show this effect was not universal. During hot, dry months with high evapotranspiration, low rainfall, and long intervals between events, SM treatment increased topsoil moisture by reducing ineffective evaporation. Additionally, maize plots had higher moisture than soybean plots, likely because larger maize leaves reduced direct solar radiation and slowed evaporation. Differences in winter wheat topsoil moisture between rotations may be attributed to varying root systems altering infiltration rates under rotation systems.

Some studies suggest no-tillage with straw mulching reduces soil respiration, but our no-tillage experiment showed SM significantly increased respiration, consistent with Blanco-Canqui et al. Straw decomposition is a slow process; unconverted carbon is released as CO or CH . Additionally, high nitrogen application rates altered soil C/N ratios, favoring microbial decomposition and increasing carbon release. The higher mean respiration rates under SM align with previous findings.

Differences in respiration rates between rotations stem from altered microbial community distribution, diversity, and nutrient cycling due to different crop growth characteristics. Variations in soil temperature and moisture under different rotations, along with differing nitrogen application and straw amounts, contribute to these differences. Soil temperature and moisture are key environmental factors affecting respiration. Our study found significant positive correlations between respiration and temperature at 5 cm and 10 cm depths, with stronger correlations at 5 cm, consistent with Li et al. Temperature at 5 cm explained 64.6%–67.3% of respiration variation, slightly lower than the 62.31%–78.66% reported by Zhang et al. No significant correlation between respiration and 0–30 cm soil moisture was observed, agreeing with several previous studies.

Q values (1.70–2.01) were slightly lower than the reported Chinese range (2.25±0.28). Wheat-maize rotation had higher Q than wheat-soybean rotation, possibly because lower temperatures in wheat-maize rotation during later growth stages enriched microbial diversity, potentially increasing Q . SM treatment reduced Q compared with NS, consistent with previous research. This may be attributed to climatic conditions: high summer temperatures and single irrigation events may have caused drought stress, reducing temperature sensitivity.

As part of a long-term experiment, our two-year study requires further validation. Future research will continue investigating long-term effects of straw mulching on soil respiration temperature sensitivity.

In conclusion, during 2012–2014, straw mulching under different rotations significantly affected soil respiration and its temperature sensitivity. Soil respiration showed clear seasonal variation, with SM treatment significantly increasing respiration rates, mean respiration rates, and cumulative emissions compared with NS. Cumulative respiration was higher in wheat-maize than wheat-soybean rotation. Straw mulching regulated soil temperature (increasing in winter, decreasing in spring/summer) and improved soil moisture during hot, dry periods. Soil temperature was significantly positively correlated with respiration, explaining 64.6%–67.3% and 51.5%–59.6% of variation at 5 cm and 10 cm depths, respectively, while moisture showed no significant correlation. Straw mulching reduced temperature sensitivity of soil respiration, providing practical implications for studying farmland ecosystem carbon cycling responses to global climate change.

---

**References**

[1] Keeling C D. Climate change and carbon dioxide: An introduction[J]. Proceedings of the National Academy of Sciences of the United States of America, 1997, 94(16): 8273–8274

[2] Bond-Lamberty B, Thomson A. A global database of soil respiration data[J]. Biogeosciences, 2010, 7(6): 1915–1926

[3] Hibbard K A, Law B E, Reichstein M, et al. An analysis of soil respiration across northern hemisphere temperate ecosystems[J]. Biogeochemistry, 2005, 73(1): 29–70

[4] Schlesinger W H, Andrews J A. Soil respiration and the global carbon cycle[J]. Biogeochemistry, 2000, 48(1): 7–20

[5] Li H, Qiu J J, Wang L G, et al. Modelling impacts of alternative farming management practices on greenhouse gas emissions from a winter wheat-maize rotation system in China[J]. Agriculture, Ecosystems & Environment, 2010, 135(1/2): [pages]

[6] Duan H P, Zhang Y, Zhao J B, et al. Carbon footprint analysis of farmland ecosystem in China[J]. Journal of Soil and Water Conservation, 2011, 25(5): 203–208

[7] Raich J W, Tufekciogul A. Vegetation and soil respiration: Correlations and controls[J]. Biogeochemistry, 2000, 48(1): [pages]

[8] Lal R. Soil carbon sequestration impacts on global climate change and food security[J]. Science, 2004, 304(5677): [pages]

[9] Luo Y Q, Zhou X H. Soil Respiration and Environment[M]. Jiang L F, Qu L Y, Zhou Y M, et al., trans. Beijing: Higher Education Press, 2007

[10] Li H F, Xia H P, Xiong Y M, et al. Mechanism of greenhouse gases fluxes from soil and its controlling factors: A review[J]. Ecology and Environment, 2007, 16(6): 1781-1788

[11] Nan X X, You D H, Tian X H, et al. Effect of returning cropland straw to field on soil organic carbon and grain yield in Guanzhong plain[J]. Acta Agriculturae Boreali-Sinica, 2011, 26(5): 222-229

[12] Buman R A, Alesii B A, Hatfield J L, et al. Profit, yield, and soil quality effects of tillage systems in corn-soybean rotations[J]. Journal of Soil and Water Conservation, 2004, 59(6): [pages]

[13] Yu A Z, Huang G B, Chai Q. Effect of different tillage treatments on soil respiration of winter-wheat farmland in oasis irrigated area Northwest China[J]. Acta Prataculturae Sinica, 2012, 21(1): 273-278

[14] Cui F J, Li L J, Liu J H, et al. No-tillage stubble with residues influence on soil respiration and the soil enzyme activity and nutrient[J]. Chinese Agricultural Science Bulletin, 2011, 27(21): 147-153

[15] Irvine J, Law B E. Contrasting soil respiration in young and old-growth ponderosa pine forests[J]. Global Change Biology, 2002, 8(12): 1183-1194

[16] Zhou X H, Sherry R A, An Y, et al. Main and interactive effects of warming, clipping, and doubled precipitation on soil CO efflux in a grassland ecosystem[J]. Global Biogeochemical Cycles, 2006, 20(1): GB1003

[17] Yang Y, Huang M, Liu H S, et al. The interrelation between temperature sensitivity and adaptability of soil respiration[J]. Journal of Natural Resources, 2011, 26(10): 1811-1820

[18] Yang Q P, Xu M, Liu H S, et al. Impact factors and uncertainties of the temperature sensitivity of soil respiration[J]. Acta Ecologica Sinica, 2011, 31(8): 2301-2311

[19] Raich J W, Schlesinger W H. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate[J]. Tellus B: Chemical and Physical Meteorology, 1992, 44(2): 81-99

[20] Davidson E A, Janssens I A, Luo Y Q. On the variability of respiration in terrestrial ecosystems: Moving beyond Q [J]. Global Change Biology, 2006, 12(2): 154-164

[21] Zheng Z M, Yu G R, Fu Y L, et al. Temperature sensitivity of soil respiration is affected by prevailing climatic conditions and soil organic carbon content: A trans-China based case study[J]. Soil Biology and Biochemistry, 2009, 41(7): [pages]

[22] Peng Q, Dong Y S, Qi Y C, et al. Effects of nitrogen fertilization on soil respiration in temperate grassland in Inner Mongolia, China[J]. Environmental Earth Sciences, 2011, 62(6): [pages]

[23] Wang R, Sun Q Q, Wang Y, et al. Temperature sensitivity of soil respiration: Synthetic effects of nitrogen and phosphorus fertilization on Chinese Loess Plateau[J]. Science of the Total Environment, 2017, 574: 1665–1673

[24] Liu S, Yan C R, He W Q, et al. Soil respiration and its affected factors under different tillage systems in dryland production systems[J]. Acta Ecologica Sinica, 2010, 30(11): 2919–2924

[25] Jiang J S, Guo S L, Wang R, et al. Effects of nitrogen fertilization on soil respiration and temperature sensitivity in spring maize field in semi-arid regions on Loess Plateau[J]. Environmental Science, 2015, 36(5): 1802–1809

[26] Dai K, Cai D X, Wang Y, et al. Effects of different tillage on soil respiration rate of spring corn in the dryland of North China—Effects of soil temperature on soil respiration rate[J]. Soils and Fertilizer Sciences in China, 2010, (6): 64–69

[27] Zhang S, Luo H X, Wang L C, et al. Analysis of soil respiration and the influencing factors in soybean fields under conservation tillage[J]. Chinese Journal of Eco-Agriculture, 2013, 21(8): 913–920

[28] Tu C, Wang J, Liu W Z. Variation in soil respiration and its driving factors in rainfed winter wheat fields with different mulching measures[J]. Plant Nutrition and Fertilizer Science, 2012, 18(5): 1107–1114

[29] Zhai L M, Liu H B, Zhang J Z, et al. Long-term application of organic manure and mineral fertilizer on N O and CO emissions in a red soil from cultivated maize-wheat rotation in China[J]. Agricultural Sciences in China, 2011, 10(11): [pages]

[30] Lloyd J, Taylor J A. On the temperature dependence of soil respiration[J]. Functional Ecology, 1994, 8(3): 315–323

[31] Chen J K, Li S J, Zhang Y, et al. Characteristics of soil temperature and response to air temperature under different tillage systems—Diurnal dynamic of soil temperature and its response to air temperature[J]. Scientia Agricultura Sinica, 2009, 42(7): 2592–2600

[32] Fu G Z, Li C H, Wang J Z, et al. Effects of stubble mulch and tillage managements on soil physical properties and water use efficiency of summer maize[J]. Transactions of the CSAE, 2005, 21(1): 52–56

[33] Dai Y X, Zhang X Q, Guo X X, et al. Effects of no tillage with rotation on soil hydrothermal dynamics and available nutrients in dry farming area[J]. Soil and Fertilizer Sciences in China, 2016, (6): 14–20

[34] Wang X, Jia Z, Liang L. Effect of straw incorporation on soil moisture, evapotranspiration, and rainfall-use efficiency of maize under dryland farming[J]. Journal of Soil and Water Conservation, 2014, 69(5): 449–455

[35] Wang H, Liu Q R, Zhang S Y, et al. Grain yield and soil water content of super-high-yield summer maize under straw mulching[J]. Journal of Soil and

Water Conservation, 2011, 25(5): 261–264

[36] Kar G, Verma H N, Singh R. Effects of winter crop and supplemental irrigation on crop yield, water use efficiency and profitability in rainfed rice based cropping system of eastern India[J]. Agricultural Water Management, 2006, 79(3): [pages]

[37] Li X S, Wu N, Liu L, et al. Effects of different straw recycling and tillage methods on soil respiration and microbial activity[J]. Chinese Journal of Applied Ecology, 2015, 26(6): 1765–1771

[38] Lu X L, Liao Y C. Effects of tillage on soil respiration and root respiration under rain-fed summer corn field[J]. Environmental Science, 2015, 36(6): 2266–2273

[39] Blanco-Canqui H, Lal R. Soil structure and organic carbon relationships following 10 years of wheat straw management in no-till[J]. Soil and Tillage Research, 2007, 95(1/2): [pages]

[40] Liu X F, Li L J, Yan R Q, et al. Response of soil organic carbon of rain fed cropland to stubble tillage in Inner Mongolia[J]. Chinese Agricultural Science Bulletin, 2015, 31(7): 218–222

[41] Sun Y, Ren G X, Feng Y Z, et al. Comprehensive influence of straw-returning and nitrogen fertilization on hydrothermal factors and soil respiration[J]. Journal of Northwest A&F University: Natural Science Edition, 2015, 43(3): 146–152

[42] Wang W Y, Qiao B, Akhtar K, et al. Effects of straw returning to field on soil respiration and soil water heat in winter wheat-summer maize rotation system under no tillage[J]. Scientia Agricultura Sinica, 2016, 49(11): 2136–2152

[43] McDaniel M D, Grandy A S, Tiemann L K, et al. Crop rotation complexity regulates the decomposition of high and low quality residues[J]. Soil Biology and Biochemistry, 2014, 78: [pages]

[44] Jiang J S, Guo S L, Zhang Y J, et al. Changes in temperature sensitivity of soil respiration in the phases of a three-year crop rotation system[J]. Soil and Tillage Research, 2015, 150: [pages]

[45] Zhang Q Z, Wu W L, Wang M X, et al. Effects of crop residue amendment and N rate on soil respiration[J]. Acta Ecologica Sinica, 2005, 25(11): 2883–2887

[46] Qiang X C, Yuan H L, Gao W S. Effect of crop-residue incorporation on soil CO emission and soil microbial biomass[J]. Chinese Journal of Applied Ecology, 2004, 15(3): 499–502

[47] Li C Z, Zhang T T, Yang G H, et al. Effect of straw mulching and fertilization on soil respiration from summer-maize farmland during later growth period in Guanzhong irrigation district[J]. Ecology and Environmental Sciences, 2013, 22(3): 411–416

[48] Zhang J L, Liao Y C, Zeng A, et al. Effects of different levels of N fertilizer on soil respiration, and its relation to soil moisture and soil temperature under rainfed land of summer maize[J]. Journal of Agro-Environment Science, 2013, 32(7): 1382–1388

[49] Yang L, Liao Y C, Gao M S, et al. Relationship analysis of CO  emission fluxes and soil temperature and moisture in rainfed wheat field with different tillage[J]. Acta Agriculturae Boreali-Occidentalis Sinica, 2011, 20(1): 70–75

[50] Zhang Y, Zhang H L, Chen J K, et al. Effects of different tillage practices on CO  emission fluxes from farmland in North China Plain and the analysis of soil temperature and moisture[J]. Transactions of the CSAE, 2009, 25(4): 47–53

[51] Peng S S, Piao S L, Wang T, et al. Temperature sensitivity of soil respiration in different ecosystems in China[J]. Soil Biology and Biochemistry, 2009, 41(5): 1008–1014

[52] Chen B Y, Liu S R, Ge J P, et al. Annual and seasonal variations of Q  soil respiration in the sub-alpine forests of the Eastern Qinghai-Tibet Plateau, China[J]. Soil Biology and Biochemistry, 2010, 42(10): 1735–1742

[53] He X H, Du Z L, Wang Y D, et al. Sensitivity of soil respiration to soil temperature decreased under deep biochar amended soils in temperate croplands[J]. Applied Soil Ecology, 2016, 108: 204–210

[54] Hu Z H, Ling H, Chen S T, et al. Soil respiration, nitrification, and denitrification in a wheat farmland soil under different managements[J]. Communications in Soil Science and Plant Analysis, 2013, 44(21): 3092–3102

[55] Davidson E A, Janssens I A. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change[J]. Nature, 2006, 440(7081): 165–173

[56] Almagro M, López J, Querejeta J I, et al. Temperature dependence of soil CO  efflux is strongly modulated by seasonal patterns of moisture availability in a Mediterranean ecosystem[J]. Soil Biology and Biochemistry, 2009, 41(3): 594–605

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

*Source: ChinaXiv —Machine translation. Verify with original.*