

## Effects of Straw Incorporation and Rotary Tillage on Soil Physical Properties and Maize Mechanical Sowing Quality in Central Sichuan (Postprint)

**Authors:** Zhu Min, Shi Yunxiang, Sun Zhiyou, Wang Xinglong, Zhang Di, Kong Fanlei, Yuan Jichao

**Date:** 2017-11-09T00:00:00+00:00

### Abstract

To determine suitable straw returning methods and tillage practices for machine-planted maize production under the wheat-maize double cropping system in purple soil regions of the hilly areas of central Sichuan, ameliorate soil problems such as poor fertility and excessive stickiness, improve seedbed conditions and sowing quality in the tillage layer, and achieve high crop yields, four treatments were established: rotary tillage with straw returning (RTS), no-tillage with straw returning (NTS), rotary tillage without straw returning (RT), and no-tillage without straw returning (NT), to investigate the effects of wheat straw returning and rotary tillage on the physical properties of purple clay soil and the sowing quality of machine-planted summer maize in the hilly areas of central Sichuan. The results showed that, compared with no straw returning, wheat straw returning significantly increased soil capillary porosity in the 0-10 cm soil layer at the jointing stage and soil water content in the 0-10 cm layer throughout the entire growth period under no-tillage treatment, while significantly reducing emergence rate, sowing uniformity, and seedling uniformity. Compared with no-tillage, rotary tillage reduced soil bulk density and water content in the 0-10 cm layer, increased capillary porosity, increased emergence rate by 9.9%, and significantly improved seedling plant height, stem diameter, leaf area, and dry weight. Under wheat straw returning conditions, rotary tillage reduced soil bulk density in the 0-10 cm layer by 2.0%-12.1% compared with no-tillage, and significantly increased emergence rate, sowing uniformity, seedlings per hole, and seedling uniformity, with emergence rate increasing by 17.9%. Maize emergence rate was significantly positively correlated with soil water content in the 0-10 cm layer, while both sowing uniformity and seedling uniformity were significantly negatively correlated with soil bulk density in the 0-10 cm layer. It can be concluded that rotary tillage under wheat straw returning improved soil structure, increased soil water content, and was more conducive to improving the sowing

quality and seedling vigor of machine-planted maize in the wheat-summer maize cropping system in the hilly areas of central Sichuan.

## Full Text

### Effect of Straw Return and Rotary Tillage on Soil Physical Properties and Mechanical Sowing Quality of Maize in Central Sichuan

ZHU Min<sup>1</sup>, SHI Yunxiang<sup>2</sup>, SUN Zhiyou<sup>2</sup>, WANG Xinglong<sup>1</sup>, ZHANG Di<sup>1</sup>, KONG Fanlei<sup>1</sup>, YUAN Jichao<sup>1</sup> (1. College of Agriculture, Sichuan Agricultural University, Wenjiang 611130, China; 2. Beijing Shunxin Agricultural Seed Technology Co., Ltd, Beijing 100097, China)

#### Abstract

To identify suitable straw return and tillage methods for mechanically sown maize production under the wheat-maize double-cropping system in the hilly purple soil region of Central Sichuan, and to address problems of soil barrenness and excessive viscosity while improving sowing conditions and quality for high crop yields, we conducted an experiment with four treatments: rotary tillage with straw return (RTS), no-tillage with straw return (NTS), rotary tillage without straw return (RT), and no-tillage without straw return (NT). The study investigated the effects of wheat straw return combined with tillage practices on the physical properties of purple clay soil and the sowing quality of mechanically sown summer maize in hilly areas of Central Sichuan.

The results showed that compared with no straw return, wheat straw return significantly increased capillary porosity in the 0-10 cm soil layer at the jointing stage and soil water content throughout the entire growth period under no-tillage conditions, but significantly reduced emergence rate, sowing uniformity, and seedling uniformity. Compared with no-tillage, rotary tillage decreased soil bulk density and water content in the 0-10 cm layer while increasing capillary porosity, with emergence rate increasing by 9.9% and significant improvements in seedling height, stem diameter, leaf area, and dry weight.

Under wheat straw return conditions, rotary tillage reduced soil bulk density in the 0-10 cm layer by 2.0%-12.1% compared with no-tillage, significantly improving emergence rate (by 17.9%), plants per hill, mechanical sowing uniformity, and seedling uniformity. Maize emergence rate was significantly positively correlated with soil water content in the 0-10 cm layer, while both mechanical sowing uniformity and seedling uniformity were significantly negatively correlated with soil bulk density in the same layer. These findings demonstrate that rotary tillage with straw return improved soil structure, increased soil water content, and enhanced both mechanical sowing quality and seedling vigor for maize under the winter wheat-summer maize cropping pattern in hilly areas of Central Sichuan.

**Keywords:** Mechanically sown summer maize; Straw return; Sowing uniformity; Sowing quality; Seedling vigor; Seedling uniformity; Soil physical properties

## Introduction

Changes in soil tillage practices can alter soil conditions and affect crop sowing quality and seedling growth. Appropriate tillage methods can improve soil structure and enhance crop sowing quality, while inappropriate practices may degrade soil quality. Under the wheat (*Triticum aestivum*)-maize (*Zea mays*) double-cropping system, rational tillage practices can help digest wheat residue, conserve soil moisture, regulate soil temperature, improve soil water conditions, and enhance plough layer sowing conditions to achieve higher crop yields by modifying soil physical properties. Research indicates that tillage methods significantly influence the sowing quality of subsequently planted maize in wheat-maize rotation systems. Straw return can also reduce soil compaction, and different tillage combinations lead to varying sowing quality outcomes.

Studies by Yavuzcan et al. demonstrated that abundant surface residue and no-tillage result in compacted soil, shallow seed coverage after mechanical sowing, and poor sowing quality, whereas rotary tillage creates loose soil favorable for furrow openers and seeders, yielding better emergence rates and sowing uniformity. Gao et al. found that straw return increased plant height and reduced stem thickness during the early growth stage of summer maize, with growth advantages becoming more pronounced as the season progressed, showing increases in plant height, stem diameter, leaf area index, and individual plant biomass. In the rain-fed agricultural areas of Central Sichuan's hilly region, traditional rotary tillage has been practiced year-round, with large amounts of crop straw removed, leading to exposed topsoil and destroyed soil structure. The quality of mechanically sown summer maize is constrained by soil physical properties, representing a key factor limiting maize yield and the adoption of mechanical sowing methods. In previous agricultural production in this region, small land parcels, intercropping practices, poor soil fertility, and low utilization of straw return resulted in frequent open burning. With modern agricultural development, however, an increasing number of large-scale grain producers in the hilly dryland areas of Central Sichuan have rapidly adopted the winter wheat-summer maize system, making it urgent to address issues of poor soil fertility and wheat straw management.

Previous research has focused primarily on the effects of wheat stubble management on maize growth and soil chemical properties, with limited studies on the relationships between soil physical properties, sowing quality, and seedling vigor in mechanically sown maize, particularly regarding purple clay soils in Central Sichuan's hilly areas. This experiment, based on changes in soil physical properties, investigated how these changes affect mechanical sowing and early growth and yield of maize. Through field experiments, we examined the effects of wheat straw return and tillage methods on the physical properties of

purple clay soil and the sowing quality and seedling vigor of mechanically sown maize in Central Sichuan's hilly region, aiming to provide a scientific basis for improving sowing quality of mechanically sown summer maize in this area.

## Materials and Methods

### 1.1 Experimental Site

The experiment was conducted in 2015 and 2016 at Xinjian Village, Hexing Township, Zhongjiang County, Deyang City, Sichuan Province (104°63 E, 30°95 N). The site has a subtropical monsoon climate with annual precipitation of 882.5 mm and mean annual temperature of 16.7°C. Before sowing, the 0-10 cm soil layer had a bulk density of  $1.51 \text{ g} \cdot \text{cm}^{-3}$ , capillary porosity of 32%, and water content of 27%; the 10-20 cm layer had a bulk density of  $1.54 \text{ g} \cdot \text{cm}^{-3}$ , capillary porosity of 30%, and water content of 26.9%.

### 1.2 Experimental Design

The experiment employed a two-factor randomized block design with four treatments: rotary tillage with straw return (RTS), no-tillage with straw return (NTS), rotary tillage without straw return (RT), and no-tillage without straw return (NT).

- **RTS:** Wheat straw was rotary tilled together with soil, incorporating the straw into the soil.
- **NTS:** Wheat straw was left on the soil surface without any tillage before direct sowing.
- **RT:** Wheat straw was manually removed, followed by rotary tillage.
- **NT:** Wheat straw was manually removed, followed by direct sowing without tillage.

The maize variety was 'Zhenghong 505' (from Sichuan Agricultural University Zhenghong Seed Industry Co., Ltd.), and the preceding wheat variety was 'Mianmai 367' (from Mianyang Agricultural Science Research Institute). Wheat was harvested on May 10, with a straw return rate of  $6,000 \text{ kg} \cdot \text{hm}^{-2}$ . Straw return and tillage treatments were implemented on May 13, with a rotary tillage depth of 15 cm. Maize was sown mechanically on May 15, with 2-3 seeds per hill, thinned to one plant per hill, at a planting density of  $6.5 \times 10^4 \text{ plants} \cdot \text{hm}^{-2}$ . The planting pattern used wide-narrow rows: 90 cm for wide rows and 40 cm for narrow rows, with 23 cm between hills. Each plot was  $156 \text{ m}^2$  ( $3.9 \text{ m} \times 40 \text{ m}$ ) with six rows, and the experiment had three replications. Fertilizer application consisted of N  $225 \text{ kg} \cdot \text{hm}^{-2}$  (urea, 46%), P O  $60 \text{ kg} \cdot \text{hm}^{-2}$  (superphosphate, 12%), and K O  $90 \text{ kg} \cdot \text{hm}^{-2}$  (potassium chloride, 60%), with all nutrients applied as basal fertilizer.

### 1.3 Measurements

**1.3.1 Soil Physical Properties** Soil capillary porosity and bulk density were measured using the core cutter method, and water content was determined by the oven-drying method. Using a five-point sampling method, soil samples were collected at the intersection point of the two diagonals and at the midpoints between the intersection and the four corners of each plot during the jointing, huge bell bottom, tasseling, and maturity stages of maize. Measurements were taken for bulk density, water content, and capillary porosity in the 0-10 cm and 10-20 cm layers within narrow maize rows, with three replications per treatment.

**1.3.2 Sowing Quality** After maize emergence, a five-point sampling method was used to select five points per treatment. At each point, we investigated 4 m of row length to determine emergence rate, exposed seed rate, number of hills, and plants per hill. Gaps exceeding 30 cm between hills were counted as one ridge break, those exceeding 60 cm as two breaks, and so on. The standard deviation of plants per hill was calculated to determine sowing uniformity.

**1.3.3 Seedling Vigor** At the three-leaf stage, five representative seedlings were sampled from each plot to measure plant height, stem diameter, and leaf area. Fresh weights of roots, stems, and leaves were measured separately, then oven-dried at 105°C for 30 minutes and at 80°C to constant weight. Leaf area was determined using the length-width coefficient method.

**1.3.4 Seedling Uniformity** At the four-leaf stage, physiological plant height was measured for all plants in a randomly selected 4 m row length per treatment. Uniformity was calculated using the inverse of the coefficient of variation ( $1/cv$ ): where  $cv$  is the coefficient of variation,  $S$  is the standard deviation,  $\bar{x}$  is the sample mean,  $x_i$  represents individual sample values, and  $n$  is the sample size.

### 1.4 Data Processing

Data were processed and analyzed using Microsoft Excel 2007 and the DPS 7.05 data processing system.

## Results

### 2.1.1 Soil Bulk Density

As shown in , rotary tillage significantly reduced soil bulk density at the seedling stage in both 2015 and 2016, with more pronounced effects in 2016. In 2015, rotary tillage with straw return decreased soil bulk density in both the 0-10 cm and 10-20 cm layers. Under the same straw return conditions, rotary tillage resulted in significantly lower bulk density than no-tillage across all growth stages in both layers, with reductions of 3.2%-16.4% throughout the growth period. In 2016 under straw return conditions, rotary tillage reduced bulk density by

2.0%-12.1% in the 0-10 cm layer and 3.1%-6.6% in the 10-20 cm layer compared with no-tillage. Straw return significantly affected soil bulk density, with the ranking of treatments being NT > NTS > RT > RTS. Overall, bulk density in both the 0-10 cm and 10-20 cm layers at the jointing stage followed the pattern NT > NTS > RT > RTS, with RTS showing the lowest values.

### 2.1.2 Soil Capillary Porosity

As presented in , soil capillary porosity showed consistent trends across treatments in 2015 and 2016. Tillage method significantly affected capillary porosity, with rotary tillage treatments consistently higher than no-tillage treatments. Capillary porosity ranged from 35.0% to 44.2% under rotary tillage and 31.2% to 43.2% under no-tillage, representing a significant increase of 0.7%-13.2% with rotary tillage. In 2015, straw return had no significant effect on capillary porosity. However, in 2016, straw return increased capillary porosity by 2.1%-24.3% under rotary tillage and by 1.2%-16.8% under no-tillage, with significant differences between these treatments.

### 2.1.3 Soil Water Content

Crop utilization of soil water is jointly affected by soil quality and crop growth status. As shown in , under the same straw management, no-tillage treatments consistently had higher water content in the 0-10 cm layer than rotary tillage treatments. In 2015, no-tillage increased soil water content by 26.4%, 3.4%, 3.7%, and 8.5% at the jointing, huge bell bottom, tasseling, and maturity stages, respectively, compared with rotary tillage. In 2016, the corresponding increases were 16.1%, 7.5%, 0.4%, and 0.2%. This occurred because no-tillage reduces soil disturbance, thereby inhibiting ineffective evaporation from the soil surface and increasing surface water content. Under no-tillage conditions, straw return treatments had higher water content than non-return treatments in the 0-10 cm layer. No significant differences were observed in the 10-20 cm layer across growth stages. Overall, the no-tillage with straw return treatment exhibited the highest water content in the 0-10 cm layer.

## 2.2 Effects of Straw Return and Rotary Tillage on Mechanical Sowing Quality of Summer Maize

As shown in , tillage method significantly affected mechanical sowing quality of summer maize. Compared with no-tillage, rotary tillage significantly improved sowing quality and emergence rate, increasing emergence by 26.7% in 2015 and 9.9% in 2016. In terms of sowing quality, rotary tillage reduced exposed seed rate, ridge breaks, and sowing uniformity index (where lower values indicate more uniform sowing), with significantly lower exposed seed rates than no-tillage. Straw return decreased maize emergence rate, with values of 62.0% and 78.0% under no-tillage straw return, significantly lower than without straw return. Straw return also increased exposed seed rate, ridge breaks, and sowing uniformity index, with the index increasing by 3.3% in 2015 and 5.7% in

2016 compared with non-return treatments. Overall, rotary tillage improved mechanical sowing quality and emergence rate, while straw return reduced sowing quality and emergence.

### 2.3 Effects of Straw Return and Rotary Tillage on Summer Maize Seedling Vigor

As presented in , tillage method significantly affected seedling vigor of mechanically sown summer maize. Compared with no-tillage, rotary tillage significantly improved seedling vigor, increasing seedling length, leaf area, root length, and uniformity by 38.9%, 76.8%, 19.3%, and 70.8% in 2015, respectively, and stem-leaf dry weight and root dry weight by 116.3% and 47.1%. In 2016, the corresponding increases were 24.6%, 39.1%, 1.9%, and 132.8% for length, leaf area, root length, and uniformity, with stem-leaf and root dry weights increasing by 60.9% and 0.5%. Under the same tillage method, straw non-return treatments showed higher seedling length, leaf area, and stem-leaf dry matter than straw return treatments. The root-shoot ratio at the seedling stage followed the pattern NTS > RTS > NT > RT, with significant differences among treatments. These results indicate that rotary tillage improved overall seedling vigor and uniformity, ensuring complete and uniform stands, while straw return reduced seedling vigor and uniformity.

### 2.4 Analysis of Factors Affecting Sowing Quality and Seedling Vigor

As shown in , significant correlations existed between sowing quality, seedling vigor, and soil physical properties in the 0-10 cm layer. Emergence rate was significantly positively correlated with soil water content, while exposed seed rate was highly significantly negatively correlated with water content. Sowing uniformity was highly significantly negatively correlated with bulk density and significantly positively correlated with capillary porosity. Seedling uniformity was highly significantly negatively correlated with soil bulk density. These relationships demonstrate that soil physical properties significantly affect mechanical sowing uniformity and seedling uniformity, while soil water content influences emergence rate and exposed seed rate.

### 2.5 Effects of Straw Return and Rotary Tillage on Maize Yield

As shown in , straw return and rotary tillage significantly affected ear traits and grain yield. Straw return significantly increased ear length, ear diameter, grains per ear, 100-kernel weight, and yield. Compared with non-return treatments, straw return reduced bare tip length by 0.2 cm in 2015 while increasing ear length by 1.2 cm, ear diameter by 1.1 mm, grains per ear by 9.8%, 100-kernel weight by 11.9%, and final yield by 7.7%. In 2016, the corresponding improvements were 0.5 cm reduction in bare tip length, 1.2 cm increase in ear length, 4.1 mm increase in ear diameter, 6.1% increase in grains per ear, 8.7% increase in 100-kernel weight, and 4.2% increase in yield.

Compared with no-tillage, rotary tillage in 2015 reduced bare tip length by 0.1 cm, increased ear length by 0.7 cm, grains per ear by 2.3%, 100-kernel weight by 6.5%, and final yield by 2.8%. In 2016, rotary tillage reduced bare tip length by 0.3 cm, increased ear length by 0.6 cm, ear diameter by 2.6 mm, grains per ear by 3.6%, 100-kernel weight by 2.2%, and yield by 5.6%. Overall, the combination of rotary tillage with straw return significantly improved maize yield.

## Discussion

Tillage methods significantly affect soil physical properties and consequently influence crop growth. Our results demonstrate that different tillage methods have varying effects on soil bulk density, capillary porosity, and water content, with impacts diminishing with increasing soil depth. Straw return loosens soil, with minimal effect on capillary porosity initially but significantly reducing soil infiltration capacity later as straw decomposes. After crushing and ammoniation, straw return significantly increases stable infiltration rate and cumulative infiltration compared with non-return treatments, thereby reducing bulk density and increasing capillary porosity. Rotary tillage with straw return creates large soil pores, increasing early-stage evaporation and reducing water content, while later the straw conserves moisture and increases water content. No-tillage with straw return shows higher water content than non-return treatments, primarily because straw mulch inhibits soil water evaporation, consistent with findings by Zhang et al. and Wu et al. Rotary tillage reduces bulk density and increases capillary porosity, whereas no-tillage increases bulk density due to lack of soil disturbance, resulting in significantly higher bulk density than rotary tillage. Overall, the interaction of straw return and rotary tillage effectively improves soil physical properties, reduces water evaporation, and increases water content during later growth stages, thereby meeting the water requirements of summer maize. These effects were most evident in the 0–10 cm surface layer, with minimal differences in the 10–20 cm layer.

Surface morphology, climatic conditions, and sowing methods under different tillage systems all affect crop sowing quality and seedling uniformity. Our study examined the effects of straw return on mechanical sowing quality and early growth of summer maize from a cultivation perspective. While straw return conserves soil moisture, it inhibits maize emergence, resulting in lower emergence rates and poorer plant height uniformity. Analysis of seedling vigor indicators, root-shoot ratio, and soil physical properties revealed that rotary tillage creates loose soil favorable for furrow openers and seeders, resulting in better sowing quality and increased plant height, longer leaves, and greater dry matter accumulation during early growth compared with no-tillage. No-tillage soil remains compact with abundant previous crop roots and surface residue, leading to shallow seed coverage and relatively poor sowing quality. The combination of straw return with rotary tillage maximizes mechanical sowing quality, compensates for losses in sowing quality and seedling vigor caused by straw return alone, overcomes initial disadvantages of straw return, improves maize mechanical sowing

quality, and provides ecological benefits such as soil protection and reduced water evaporation. Grain yield at maturity followed the pattern: straw return with rotary tillage > no straw return with rotary tillage > straw return with no-tillage > no straw return with no-tillage, with rotary tillage treatments yielding higher than no-tillage treatments by improving emergence rate and effective ear number.

Through agronomic adjustments, the negative effects of excessive straw can be mitigated, reducing adverse impacts on subsequent crops and improving yield and quality. Wheat straw return reduces bulk density, and two consecutive years of straw return increased capillary porosity in the 0-10 cm layer by 5.6%. Under no-tillage conditions, straw return increased soil water content by 8.0%-27.1% compared with non-return. Under straw return conditions, rotary tillage improved soil physical properties, reducing bulk density by 2.0%-12.1% compared with no-tillage, increasing emergence rate by 18.0%, improving mechanical sowing quality and uniformity, and enhancing seedling height, leaf area, and individual plant dry weight, thereby significantly improving seedling vigor. Without straw return, rotary tillage reduced bulk density by 0.6%-14.0% and increased capillary porosity by 1.6%-18.0% compared with no-tillage, increasing emergence rate by 2.4%. Compared with no-tillage without straw return, rotary tillage with straw return reduced bare tip length, increased ear length, ear diameter, and 100-kernel weight, and increased yield by 15.0%. The rotary tillage with straw return treatment improved soil physical properties and overall soil quality, compensated for deficiencies in sowing quality and seedling vigor observed with no-tillage straw return, benefited later maize growth, and increased yield. Therefore, rotary tillage with wheat straw return is more conducive to improving mechanical sowing quality and seedling vigor of maize under the wheat-summer maize system in Central Sichuan' s hilly region.

## References

- [1] Fu B J, Chen L D, Ma K M. The effect of land use change on the regional environment in the Yangjuangou catchment in the Loess Plateau of China[J]. *Acta Geographica Sinica*, 1999, 54(3): 241-246
- [2] Ji S N, Unger P W. Soil water accumulation under different precipitation, potential evaporation, and straw mulch conditions[J]. *Soil Science Society of America Journal*, 2001, 65(2): 442-448
- [3] 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
- [4] Zhao Y L, Xue Z W, Guo H B, et al. Effects of tillage and straw returning on water consumption characteristics and water use efficiency in the winter wheat and summer maize rotation system[J]. *Scientia Agricultura Sinica*, 2014, 47(17): 3359-3371

- [5] Zhang J J, Wang Y, Fan T L, et al. Effects of different tillage and fertilization modes on the soil physical and chemical properties and crop yield under winter wheat/spring corn rotation on dryland of East Gansu, Northwest China[J]. Chinese Journal of Applied Ecology, 2013, 24(4): 1001-1008
- [6] Zheng C Y, Cui S M, Wang D, et al. Effects of soil tillage practice on dry matter production and water use efficiency in wheat[J]. Acta Agronomica Sinica, 2011, 37(8): 1432-1440
- [7] Zhang Y, Liang A Z, Zhang X P, et al. Priming effects of soil moisture on soil respiration under different tillage practices[J]. Environmental Science, 2016, 37(3): 1106-1113
- [8] Sun L J, Zhang R Z, Huang G B. Effects of the conservation tillage on the physicochemical characteristics of soil surface in the semi-arid areas of the Loess Plateau[J]. Agricultural Research in the Arid Areas, 2007, 25(6): 207-211
- [9] Ding K L, Hann M J. Effects of soil management on soil properties and crop yield[J]. Transactions of the CSAE, 2000, 16(3): 28-32
- [10] Yang C S, Zhao X, Li C H, et al. Effects of different treatments of winter wheat residues on planting quality and early-stage growth of summer maize (*Zea mays* L.)[J]. Journal of Henan Agricultural Sciences, 2009, (1): 25-27
- [11] Li C H, Zhao X, Liu T X, et al. Effects of different treatments of winter wheat residues on eco-physiological responses of mechanized sowing summer maize (*Zea mays* L.)[J]. Transactions of the CSAE, 2008, 24(1): 162-166
- [12] Gao Y B, Tao H B, Zhu J C, et al. Effects of wheat stubble height on growth and water use efficiency of mechanized sowing summer maize[J]. Scientia Agricultura Sinica, 2015, 48(19): 3803-3810
- [13] Li J G. Effects of tillage measure on the population of mechanical sowing wheat and soil moisture-conserving, & evaluate its application effect with comprehensive evaluation, in Sichuan Hilly Areas[D]. Ya' an: Sichuan Agricultural University, 2014
- [14] Yavuzcan H G. Wheel traffic impact on soil conditions as influenced by tillage system in Central Anatolia[J]. Soil and Tillage Research, 2000, 54(3/4): 129-138
- [15] McGarry D, Bridge B J, Radford B J. Contrasting soil physical properties after zero and traditional tillage of an alluvial soil in the semi-arid subtropics[J]. Soil and Tillage Research, 2000, 53(2): 105-115
- [16] Ozpinar S, Cay A. Effect of different tillage systems on the quality and crop productivity of a clay-loam soil in semi-arid north-western Turkey[J]. Soil and Tillage Research, 2006, 88(1/2): 95-106
- [17] Mielke L N, Wilhelm W W, Richards K A, et al. Soil physical characteristics of reduced tillage in a wheat-fallow system[J]. Transactions of the ASAE, 1984, 27(6): 1654-1659

- [18] Bao S D. Soil and Agricultural Chemistry Analysis[M]. Beijing: Chinese Agricultural Press, 1980
- [19] 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): 240-254
- [20] Lao X R, Wu Z Y, Gao Y C. Effect of long-term returning straw to soil on soil fertility[J]. Transactions of the CSAE, 2002, 18(2): 49-52
- [21] Zhang L, Zhang Z D, Guo Z Y, et al. Effects of subsoiling tillage and straw returning to field on soil physical properties[J]. Bulletin of Soil and Water Conservation, 2015, 35(1): 102-106
- [22] Wang Z L. Effects of different straw incorporation manners on soil physical and chemical properties and crop growth[D]. Yangling: Northwest Agriculture and Forestry University, 2012
- [23] Wu J, Zhu Z L, Zheng J G, et al. Influences of straw mulching treatment on soil physical and chemical properties and crop yields[J]. Southwest China Journal of Agricultural Sciences, 2006, 19(2): 192-195
- [24] Gong L. Effects of straw returning on physical & chemical characteristics of brown soil and growth of corn[D]. Beijing: Chinese Academy of Agricultural Sciences, 2014: 36
- [25] Fan Y D. Effects of different mulching and straw returning methods on soil moisture of wheat in rainfed conditions[D]. Lanzhou: Gansu Agricultural University, 2013
- [26] Gong L, Sun W T, Bao H J, et al. Effects of different tillage managements on soil moisture and growth of maize[J]. Journal of Maize Sciences, 2011, 19(3): 118-120

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

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