# 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 identify appropriate straw returning methods and tillage practices for mechanized corn production under the wheat-corn double cropping system in purple soil regions of central Sichuan hilly areas, ameliorate soil problems such as poor fertility and excessive stickiness, improve seedbed conditions and sowing quality in the plow layer, and achieve high crop yields, four treatments were established: rotary tillage with straw returning (RTS), no-till with straw returning (NTS), rotary tillage without straw returning (RT), and no-till 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 mechanized summer corn 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 layer at the jointing stage and soil water content in the 0–10 cm layer throughout the entire growth period under no-till treatment, while significantly decreasing emergence rate, sowing uniformity, and seedling uniformity. Compared with no-till, 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-till, and significantly increased emergence rate, sowing uniformity, seedlings per hole, and seedling uniformity, with emergence rate increasing by 17.9%. Corn 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 is evident that rotary tillage under wheat straw returning improved soil structure, increased soil water content, and was more conducive to enhancing the quality of mechanized corn sowing and

seedling vigor in the wheat-summer corn cropping system in the hilly areas of central Sichuan.

## Full Text


## Abstract

With continuous development of agricultural science and technology and improvement of ecological and environmental awareness in China, rational use of crop straw has become an efficient and sustainable agricultural practice. With the rapid development of winter wheat-summer maize rotation systems, concerns have grown about soil barrenness, wheat straw waste, and other cultivation issues. However, research targeting purple clay soils has been limited. Therefore, an experiment was conducted to determine suitable straw return and tillage methods for mechanically sown maize under the wheat-maize double-cropping system in purple soils of hilly areas in Central Sichuan, while investigating problems of soil fertility, excessive viscosity, sowing conditions, and plough layer quality for high yields. The experiment consisted of 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 aims were to study the effects of tillage patterns with wheat straw return on physical properties of purple clay soils and on quality of mechanically sown summer maize in hilly areas of Central Sichuan.

The results showed that compared with RT, RTS significantly increased capillary porosity in the 0–10 cm soil layer at the elongation stage and increased water content in the 0–10 cm soil layer under no-tillage treatment throughout the entire growth period, while significantly reducing emergence rate and the uniformity of mechanical sowing and seedling quality of maize. Compared with NTS, RT reduced soil bulk density and water content in the 0–10 cm layer but increased capillary porosity, emergence rate, seedling height, stem diameter, leaf area, and dry mass of maize. 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 and significantly improved emergence rate (by 17.9%), plants per hill, and uniformity of mechanical sowing and seedling uniformity of maize.

Maize emergence rate was significantly positively correlated with soil water content in the 0–10 cm layer. Both mechanical sowing uniformity and seedling uniformity were significantly negatively correlated with soil bulk density in the 0–10 cm layer. It was thus clear that rotary tillage with straw return improved soil structure, increased soil water content, and benefited the quality of mechanical sowing and seedling quality of maize under the winter wheat-summer maize cropping pattern in hilly areas of Central Sichuan, China.


**Keywords:** Mechanically sowed summer maize; Straw return; Mechanical sowing uniformity; Sowing quality; Seedling quality; Seedling uniformity; Soil physical properties

## Introduction

Changes in soil tillage practices can alter soil conditions and affect crop sowing quality and seedling growth. Adopting reasonable tillage methods can improve soil structure and enhance crop sowing quality, while improper tillage can degrade soil quality. Under the wheat (*Triticum aestivum*)-maize (*Zea mays*) double-cropping system, appropriate tillage methods can digest wheat residue straw, conserve soil moisture, regulate soil temperature, improve soil water conditions, and enhance sowing conditions in the plough layer to achieve higher crop yields. Research has shown that tillage methods significantly affect mechanical sowing quality of subsequent maize crops in wheat-maize rotation systems. Straw return can also reduce soil compaction, and different tillage practices combined with straw return lead to varying sowing quality outcomes.

Previous studies have demonstrated that abundant surface residue and no-tillage result in compacted soil, shallow seed covering after mechanical sowing, and poor sowing quality. However, when combined with rotary tillage, the soil becomes loose, facilitating passage of furrow openers and seeders, resulting in better emergence rates and sowing uniformity. Other research has found that straw return increases plant height and leaf length while decreasing stem thickness during the early growth stages of summer maize. As the growth period progresses, summer maize growth accelerates, with increases in plant height, stem diameter, leaf area index, and individual plant biomass, showing clear growth advantages.

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 after harvest, leading to exposed topsoil and destroyed soil structure. Mechanical sowing quality of summer maize is affected by soil physical properties, representing a key factor limiting maize yield and the promotion of mechanical sowing methods. In previous agricultural production in Central Sichuan' s hilly areas, small land plots, intercropping practices, poor soil fertility, and low utilization of straw return resulted in frequent open burning of straw. With modern agricultural development, an increasing number of large-scale grain producers in the dryland hilly areas of Central Sichuan and the rapid development of winter wheat-summer maize planting patterns have created urgent needs to address soil infertility and wheat straw management issues.

Previous research has focused primarily on effects of wheat stubble management on maize growth and soil chemical properties, while studies on correlations among soil physical properties, sowing quality, and seedling quality of mechanically sown maize are limited, particularly regarding purple clay soils in Central Sichuan' s hilly areas. This experiment focused on changes in soil physical properties and their effects on mechanical sowing and early growth and yield of maize. Through field experiments, we studied the effects of wheat straw return and tillage methods on soil physical properties and mechanical sowing quality and seedling quality of maize in purple clay soils of Central Sichuan' s hilly areas, aiming to provide a scientific basis for improving sowing quality of mechanically sown summer maize in this region.

### 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 g · cm $^{3}$, capillary porosity of 32%, and water content of 27%; the 10–20 cm layer had a bulk density of 1.54 g · cm $^{3}$, capillary porosity of 30%, and water content of 26%.

### 1.2 Experimental Design

A two-factor randomized block design was used 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). For RTS, wheat straw was rotary tilled together with soil, incorporating the straw into the soil. For NTS, wheat straw was left on the soil surface without any tillage before direct sowing. For RT, wheat straw was manually removed before rotary tillage. For NT, wheat straw was manually removed before direct sowing.

The maize variety used was 'Zhenghong 505' (Sichuan Agricultural University Zhenghong Seed Industry Co., Ltd.), and the preceding wheat variety was 'Mianmai 367' (Mianyang Agricultural Science Research Institute). Wheat was harvested on May 10, with a straw return amount of 6,000 kg · hm $^{2}$. Straw return and tillage treatments were performed 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 $6.5 \times 10$ plants · hm $^{2}$. Wide-narrow row planting was used, with wide row spacing of 90 cm, narrow row spacing of 40 cm, and hill spacing of 23 cm. Each plot area was 156 $m^2$ (3.9 m × 40 m), with six rows per plot and three replications. Fertilizer application consisted of N 225 kg · hm $^{2}$ (urea, 46%), P O 60 kg · hm $^{2}$ (superphosphate, 12%), and K O 90 kg · hm $^{2}$ (potassium chloride, 60%), with all N, P, and K applied as basal fertilizer in one application.

### 1.3 Measurement Methods

**1.3.1 Soil Physical Properties** Soil capillary porosity and bulk density were measured using the core cutter method, and water content was measured using the oven-drying method. Five-point sampling was used at the maize jointing stage, huge bell bottom stage, tasseling stage, and maturity stage. Samples were taken from the intersection point of the two diagonals and the midpoints between the intersection and the four corners of each plot to measure soil bulk density, water content, and capillary porosity in the 0–10 cm and 10–20 cm layers of narrow maize rows, with three replications per treatment.

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

**1.3.3 Seedling Quality** 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 samples were placed in an oven at 105°C for 30 minutes, dried at 80°C to constant weight, and weighed. Leaf area was measured using the length-width coefficient method.

**1.3.4 Seedling Uniformity** At the fourth-leaf stage, plant height was surveyed with all plants measured in a randomly selected 4 m row length per treatment. Uniformity was calculated using the inverse of the coefficient of variation (1/cv).

**1.4 Data Processing** Data processing and analysis were performed using Microsoft Excel 2007 and the DPS 7.05 data processing system.

## Results

### 2.1 Effects on Soil Physical Properties

**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 significant effects in 2016. In 2015, rotary tillage with straw return reduced soil bulk density in both 0–10 cm and 10–20 cm layers. Under the same straw return conditions, soil bulk density in both layers at all growth stages was significantly lower under rotary tillage than no-tillage. Compared with no-tillage, rotary tillage reduced bulk density by 3.2%–16.4% throughout the growth period. In 2016 under straw return conditions, rotary tillage reduced soil 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 NT > NTS > RT > RTS across both tillage methods. Overall, soil bulk density in both 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 shown in , soil capillary porosity trends were generally consistent between 2015 and 2016. Tillage method significantly affected soil capillary porosity, with rotary tillage higher than no-tillage at all stages. Capillary porosity under rotary tillage ranged from 35.0% to 44.2%, compared with 31.2% to 43.2% under no-tillage, representing a significant increase of 0.7%–13.2%. In 2015, wheat straw return had no obvious effect on soil capillary porosity. In 2016, under rotary tillage conditions, straw return increased soil capillary porosity by 2.1%–24.3%; under no-tillage conditions, straw return increased capillary porosity by 1.2%–16.8%, with significant differences between treatments.

**2.1.3 Soil Moisture 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 had higher soil moisture content in the 0–10 cm layer than rotary tillage treatments. In 2015, no-tillage increased soil moisture 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, suppressing ineffective evaporation from the soil surface and increasing surface water content. Under no-tillage conditions, straw return treatments had higher 0–10 cm soil moisture content than non-return treatments. Soil moisture in the 10–20 cm layer showed no significant differences across growth stages. Overall, the no-tillage with straw return treatment had the highest 0–10 cm soil moisture content.

### 2.2 Effects 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. For sowing quality, rotary tillage had lower exposed seed rate, ridge break number, and sowing uniformity (where lower values indicate more uniform sowing), with exposed seed rate significantly lower than no-tillage. Straw return reduced maize emergence rate, with emergence rates of 62.0% and 78.0% under straw return, significantly lower than without straw return. Simultaneously, straw return increased exposed seed rate, ridge break number, and sowing uniformity, with sowing uniformity increasing by 3.3% and 5.7% in 2015 and 2016, respectively, 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 on Seedling Quality of Summer Maize

As shown in , tillage method significantly affected seedling quality of mechanically sown summer maize. Compared with no-tillage, rotary tillage significantly improved seedling quality, increasing seedling length, leaf area, root length, and uniformity by 38.9%, 76.8%, 19.3%, and 70.8%, respectively, in 2015, with stem-leaf dry weight and root dry weight increasing 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 dry weight and root dry weight increasing by 60.9% and 0.5%. Under the same tillage method, straw non-return treatments had 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 summer maize seedling quality, ensuring complete and uniform seedlings, while straw return reduced seedling quality and uniformity.

### 2.4 Analysis of Factors Influencing Sowing Quality and Seedling Quality

As shown in , significant correlations existed between summer maize sowing quality, seedling quality, and 0–10 cm soil physical properties. Emergence rate was significantly positively correlated with soil water content; exposed seed rate was highly significantly negatively correlated with soil 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 results 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 on Maize Yield

As shown in , straw return and rotary tillage significantly affected maize ear traits and yield. Straw return significantly increased ear length, ear diameter, grains per ear, 100-kernel weight, and yield. Compared with non-return treatments in 2015, straw return reduced bare tip length by 0.2 cm, increased ear length by 1.2 cm, increased ear diameter by 1.1 mm, increased grains per ear by 9.8%, increased 100-kernel weight by 11.9%, and increased final yield by 7.7%. In 2016, straw return reduced bare tip length by 0.5 cm, increased ear length by 1.2 cm, increased ear diameter by 4.1 mm, increased grains per ear by 6.1%, increased 100-kernel weight by 8.7%, and increased final yield by 4.2%. Compared with no-tillage, rotary tillage in 2015 reduced bare tip length by 0.1 cm, increased ear length by 0.7 cm, increased grains per ear by 2.3%, increased 100-kernel weight by 6.5%, and increased final yield by 2.8%. In 2016, rotary tillage reduced bare tip length by 0.3 cm, increased ear length by 0.6 cm, increased ear diameter by 2.6 mm, increased grains per ear by 3.6%, increased 100-kernel weight by 2.2%, and increased final yield by 5.6%. Overall, the rotary tillage with straw return treatment significantly increased maize yield.

## Discussion

Tillage methods significantly affect soil physical properties, thereby influencing crop growth. This study showed that different tillage methods had varying effects on soil bulk density, capillary porosity, and water content, with effects gradually weakening as soil depth increased. Straw return loosened soil, with minimal effect on capillary porosity in the early stage; however, straw decomposition in later stages significantly reduced soil infiltration capacity. After crushing and ammoniation treatment, straw return significantly increased stable infiltration rate and cumulative infiltration compared with non-return treatments, thereby reducing soil bulk density and increasing capillary porosity. Rotary tillage with straw return created large soil pores, leading to increased early-stage soil water evaporation and reduced water content; in later stages, straw played a water-conserving role, increasing soil water content. No-tillage with straw return had higher soil water content than non-return treatments, primarily because straw mulching suppressed soil water evaporation, consistent with findings by Zhang et al. and Wu et al. Rotary tillage reduced soil bulk density and increased capillary porosity, while no-tillage increased soil bulk density, mainly because rotary tillage disturbed and loosened soil, whereas undisturbed no-tillage soil had significantly higher bulk density. Overall, the interaction of straw return and rotary tillage effectively improved soil physical properties, reduced water evaporation, and increased water content in later growth stages, thereby meeting water requirements for summer maize growth. These effects were mainly observed in the 0–10 cm surface soil layer, with no obvious effects in the 10–20 cm layer.

Surface morphology, climatic conditions, and sowing methods under different tillage practices all affect crop sowing quality and seedling uniformity. This study examined effects of straw return on mechanical sowing quality and early growth of summer maize from a cultivation perspective. Straw return conserved water but inhibited maize emergence, resulting in lower emergence rates and poorer plant height uniformity. Analysis of seedling quality indicators, root-shoot ratio, and soil physical properties revealed that rotary tillage loosened soil, facilitating passage of furrow openers and seeders, resulting in better sowing quality and increased plant height, longer leaves, and increased dry matter during early growth stages, showing clear advantages over no-tillage in sowing quality and seedling quality. No-tillage soil was compacted with abundant previous crop roots and surface residue, resulting in shallow seed covering after mechanical sowing and relatively poor sowing quality. The combination of straw return with rotary tillage maximally ensured mechanical sowing quality, compensated for losses in sowing quality and seedling quality caused by straw return, overcame initial disadvantages of straw return, improved maize mechanical sowing quality, and provided better ecological benefits such as soil protection and suppressed water evaporation. Maize 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. Rotary tillage improved emergence rate and effective panicle number, thereby increasing yield. Through agronomic regulation, negative effects of excessive straw can be mitigated, reducing adverse effects of straw return on subsequent crops and improving crop yield and quality.

## Conclusion

Wheat straw return reduced soil bulk density, increasing 0–10 cm soil capillary porosity by 5.6% over two consecutive years. Under no-tillage conditions, straw return increased soil water content by 8.0%–27.1% compared with non-return. Under wheat straw return conditions, rotary tillage improved soil physical properties compared with no-tillage, reducing soil bulk density by 2.0%–12.1%, increasing maize emergence rate by 18.0%, improving mechanical sowing quality and uniformity, and increasing plant height, leaf area, and individual plant dry weight, thereby significantly improving seedling quality. Under non-return conditions, rotary tillage reduced soil bulk density by 0.6%–14.0% and increased soil capillary porosity by 1.6%–18.0% compared with no-tillage, increasing maize emergence rate by 2.4%. Compared with no-tillage without straw return, rotary tillage with straw return reduced maize 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 quality under straw return with no-tillage, benefited later growth of summer maize, and increased yield. Therefore, rotary tillage with straw return is more conducive to improving mechanical sowing quality and seedling quality of maize under the wheat-summer maize planting pattern in Central Sichuan' s hilly areas.

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