Effects of Different Tillage and Straw Return Practices on Spring Wheat Emergence and Yield in the Hexi Irrigation District *Postprint

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Date: 2017-11-08T00:00:00+00:00

Abstract

Seedling emergence rate and uniformity largely determine crop growth status and yield performance. Addressing the research gap regarding the effects of different tillage practices combined with straw return on wheat emergence and population dynamics in oasis irrigated areas, investigating the impacts of different straw return and tillage methods on wheat emergence and yield, as well as their correlations, holds significant guiding importance for optimizing tillage practices. From 2014 to 2015, a field experiment was conducted in the Hexi oasis irrigated area of Gansu to examine the effects of different straw return and tillage measures [no-till with 25-30 cm high stubble standing straw return (NTSS), no-till with 25-30 cm high stubble mulching straw return (NTS), tillage with 25-30 cm high stubble straw return (TS), and conventional tillage without stubble (CT)] on wheat emergence status, yield, and yield components, aiming to provide a basis for optimizing wheat cultivation techniques in the experimental area. The results showed that compared with CT, NTSS and NTS reduced wheat emergence rate and uniformity, while TS increased wheat emergence rate and uniformity. NTSS and NTS exhibited 7.4%-10.5% and 14.6%-19.1% higher tiller numbers, 13.5%-20.1% and 33.0%-34.7% higher tiller-to-ear rates, 7.5%-9.3% and 10.3%-11.2% higher effective ear numbers, 15.7%-16.1% and 18.5%-22.6% higher grains per ear, and 7.2%-8.9% and 13.9%-14.2% higher thousand-grain weight compared with CT, respectively, whereas TS showed no significant differences from CT in these indicators. Compared with CT, NTSS and NTS increased yield by 16.6%-17.4% and 18.6%-21.4%, respectively, with NTS demonstrating a greater yield increase, being 10.3%-11.0% higher than TS. The increase in ear number and grains per ear was the main reason for high yield under reduced tillage with straw return, while emergence rate and uniformity had no significant effect on yield. Meanwhile, both NTSS and NTS achieved higher harvest indices, with improvement rates of 9.4%-10.7% and 10.5%-11.1%,

respectively, indicating that another reason for increased grain yield under reduced tillage with straw return was enhanced translocation of photosynthates to grains. This study demonstrates that reduced tillage with straw return is an ideal tillage practice for high wheat yield in the experimental area.

Full Text

Preamble

Chinese Journal of Eco-Agriculture, Feb. 2017, Vol. 25, No. 2: 180–187
ChinaXiv Cooperative Journal
DOI: 10.13930/j.cnki.cjea.160788

Yin W, Chen G P, Chai Q, Guo Y, Feng F X, Zhao C, Yu A Z, Liu C. Effect of tillage and straw retention mode on seedling emergence and yield of spring wheat in the Hexi Irrigation Area[J]. *Chinese Journal of Eco-Agriculture*, 2017, 25(2): 180–187

Effect of Tillage and Straw Retention Mode on Seedling Emergence and Yield of Spring Wheat in the Hexi Irrigation Area*

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Abstract: Seedling emergence rate and uniformity largely determine crop growth and yield performance. However, research on the effects of different tillage practices combined with straw retention on wheat seedling emergence and population dynamics in oasis irrigation areas remains limited. Investigating the impacts of various straw retention and tillage methods on wheat emergence and yield, as well as their relationships, is crucial for optimizing tillage practices. From 2014 to 2015, a field experiment was conducted in the Hexi Oasis Irrigation Area of Gansu Province to examine the effects of different straw retention and tillage treatments on wheat seedling emergence, yield, and yield components. The treatments included reduced tillage with 25–30 cm high stubble standing (NTSS), reduced tillage with 25–30 cm long straw covering (NTS), tillage with 25–30 cm long straw incorporation (TS), and conventional tillage without straw retention (CT, control). Results showed that compared with CT, NTSS and NTS reduced wheat seedling emergence rate and uniformity, while TS increased both parameters. NTSS and NTS increased tiller number by 7.4%-10.5% and 14.6%-19.1%, effective spike rate by 13.5%-20.1% and 33.0%-34.7%, spike number by 7.5%-9.3% and 10.3%-11.2%, kernels per spike by 15.7%-16.1% and 18.5%-22.6%, and thousand-kernel weight by 7.2%-8.9% and 13.9%-14.2%, respectively, compared with CT. No significant differences were observed between TS and CT for these parameters. Grain yield under NTSS and NTS was 16.6%-17.4% and 18.6%-21.4% higher than CT, respectively, with NTS showing the greatest increase–10.3%-11.0% higher than TS. The increased spike number and kernels per spike were the main reasons for higher yields under reduced tillage with straw retention, while emergence rate and uniformity had no significant effect on yield. Both NTSS and NTS achieved higher harvest indices, with increases of 9.4%-10.7% and 10.5%-11.1%, respectively, indicating that reduced tillage with straw retention also enhanced the conversion of photosynthates to grain. This study demonstrates that reduced tillage with straw retention is an ideal tillage practice for high wheat yields in the experimental region.

Keywords: Spring wheat; Straw retention; Tillage pattern; Seedling emergence; Yield

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Crop high yield results from the compensatory coordination of yield components [1]. During the process of tapping yield potential, crop emergence rate and uniformity influence yield by affecting population dynamic growth [2]. Studying the emergence rate, uniformity, and their influencing mechanisms in high-yielding wheat (*Triticum aestivum L.*) holds important theoretical and technical guidance value for optimizing wheat management practices. Among the many factors affecting wheat emergence and yield, direct factors such as soil hydrothermal characteristics [3], planting density [4], and sowing date [5-6], as well as indirect factors including planting pattern [7], sowing method [8], mulching method [9], tillage measures [10-11], and stubble characteristics [12] have received considerable attention. It has been proven that creating suitable soil hydrothermal environments combined with appropriate tillage measures, sowing equipment, density, and timing can serve as regulatory measures to optimize wheat emergence rate and uniformity [13-14]. Research shows that conservation tillage technology, primarily featuring reduced or no-tillage and straw retention, is applied in agricultural production mainly through soil and water conservation, yield improvement, and reduction of wind and water erosion and greenhouse gas emissions [15-16]. However, its large-scale adoption is hindered by low emergence rates and poor uniformity, necessitating the development of suitable tillage measures to mitigate these negative impacts on yield. Nevertheless, systematic studies on whether conservation tillage systems integrating reduced/no-tillage and straw retention can weaken the adverse effects of emergence rate and uniformity on yield by optimizing straw retention methods are scarce, leaving a knowledge gap regarding high-yield wheat models and theories that combine reduced/no-tillage with straw retention for water conservation. Therefore, this study, focusing on optimizing the utilization of wheat stubble, explores the feasibility of reducing yield risks under different tillage measures and straw retention methods, aiming to provide theoretical support for enhancing yield potential, reducing production risks, and optimizing high-yield and efficient wheat cropping systems in the experimental region.

1.1 Experimental Site Description

The field experiment was conducted from 2013 to 2015 at the Oasis Agricultural Research and Teaching Base of Gansu Agricultural University in Huangyang Town, Liangzhou District, Wuwei City, Gansu Province (37°30 N, 103°5 E). The experimental area is located at the eastern end of the Hexi Corridor and belongs to a cold temperate arid climate zone with an aridity index of 5.85. The soil bulk density is 1.57 $g \cdot cm^{-3}$, with a soil layer thickness of approximately 120 cm. The multi-year average rainfall is about 156 mm, while annual potential evaporation reaches approximately 2,400 mm, making irrigation water resources limited. The region has a mean annual temperature of 7.2 °C, with accumulated temperatures of 3,513 °C for $ $0 °C and 2,985 °C for $ $10 °C. Low spring temperatures can affect crop emergence. Wheat is the main grain crop in this region, with conventional deep plowing as the primary tillage practice and straw removed from fields.

1.2 Experimental Design

A preliminary experiment was established in 2013 to create different tillage and straw retention methods for wheat planting in the following year. The treatments included: (1) reduced tillage with 25–30 cm high stubble standing (NTSS), (2) reduced tillage with 25–30 cm long straw covering (NTS), (3) tillage with 25–30 cm long straw incorporation (TS), and (4) conventional low-stubble tillage without straw retention (CT). In the subsequent year, fertilizer was applied and rotary tillage (reduced tillage) was performed before wheat sowing, forming four treatments: NTSS, NTS, TS, and CT. Each treatment had three replications with a plot area of 48 m^2, arranged in a randomized block design. Systematic measurements of relevant indicators for wheat under different tillage and straw treatments were conducted in 2014 and 2015.

The wheat cultivar used was 'Ningchun 2' . Sowing dates were March 21, 2014, and March 29, 2015, with harvest dates of July 24, 2014, and July 28, 2015, respectively. The sowing density was 6.75 million $grains \cdot hm^{-2}$. A uniform fertilization level was applied: pure nitrogen at 225 $kg \cdot hm^{-2}$ and P_2O_5 at 150 $kg \cdot hm^{-2}$, all as basal fertilizer. The irrigation regime followed local standard practices: 1,200 $m^3 \cdot hm^{-2}$ for winter storage irrigation, and 750 $m^3 \cdot hm^{-2}$, 900 $m^3 \cdot hm^{-2}$, and 750 $m^3 \cdot hm^{-2}$ during the seedling, booting, and grain-filling stages, respectively.

1.3 Measurement Indicators and Calculation Methods

Twenty days after wheat emergence, five points were selected using the diagonal method. Within each 1.2 m × 1 m area, wheat emergence rate, uniformity, and seedling age were investigated.

1.3.1 Emergence Rate and Emergence Uniformity Coefficient Emergence rate = Number of seedlings / Sowing quantity (1)

The emergence uniformity coefficient was used to assess emergence evenness, calculated as:
Coefficient of variation = (Standard deviation / Mean) × 100% (2)

1.3.2 Seedling Age Twenty days after sowing, the number of wheat plants at the one-leaf, two-leaf, and three-leaf stages was counted to determine emergence uniformity under different tillage practices.

1.3.3 Tiller Number, Spike Number from Tillers, and Spike Rate After the wheat tillering stage, the basic seedling number and total stem number per hectare were investigated. At harvest, spike number was counted as the harvest spike number per plot, and tiller spike number and tiller spike rate were calculated.

Tiller number per hectare = Total stem number per hectare - Basic seedling number per hectare (3)
Spike number from tillers = Harvest spike number - Basic seedling number (4)
Tiller spike rate = Spike number from tillers / Tiller number (5)

1.3.4 Yield, Yield Traits, and Harvest Index At maturity, grain yield (GY) and biomass yield (BY) were measured by plot, and harvest index (HI) was calculated as HI = GY/BY. Twenty wheat plants were randomly selected to count kernels per spike. Grain moisture content was measured using a PM-8188 grain moisture meter with five replications, and the average value was used. Thousand-kernel weight (TKW) was calculated at 14% moisture content.

1.4 Statistical Data Analysis

Data were processed using Microsoft Excel 2007. SPSS 17.0 software was used for statistical analysis with Duncan' s method, correlation analysis using Linear correlation, and path analysis using Correlation and Regression methods.

2.1 Effects of Different Tillage and Straw Retention Methods on Wheat Emergence Rate, Uniformity, and Evenness

Compared with conventional low-stubble tillage (CT), reduced tillage with straw covering (NTS) decreased wheat emergence rate by 5.4%-6.0%, while tillage with straw incorporation (TS) increased emergence rate by 4.1%-5.4%, with both differences reaching significance (Table 1). Among straw retention treatments, TS achieved the highest emergence rate, significantly higher than NTS by 10.0%-12.1% ($P < 0.05$). Analysis of the emergence uniformity coefficient revealed that reduced tillage with straw retention resulted in poorer emergence uniformity than conventional tillage without straw retention, though TS showed better uniformity than CT.

Further investigation of seedling age at 20 days after sowing indicated that seedlings across treatments were mainly at the three-leaf stage (Table 1). At the three-leaf stage, TS and CT had the highest seedling numbers, with TS having 13.3%-15.3% and 23.6%-30.6% more seedlings than NTSS and NTS, respectively, and CT having 8.5%-11.6% and 18.3%-26.5% more seedlings than NTSS and NTS, respectively ($P < 0.05$). No significant difference was observed between TS and CT. At the two-leaf stage, reduced tillage with straw retention (NTSS and NTS) had higher seedling numbers, with increases of 3.9%-8.2% and 11.9%-22.4% compared with CT, respectively. NTS had the highest seedling number at the two-leaf stage, significantly higher than TS by 7.3%-14.0% ($P < 0.05$). At the one-leaf stage, NTSS and NTS also had higher seedling numbers. Overall, reduced tillage with straw retention (NTSS and NTS) showed lower emergence evenness, with NTS being the lowest, while TS demonstrated the highest evenness.

2.2 Effects of Different Tillage and Straw Retention Methods on Wheat Population Growth

Tillage with straw incorporation (TS) increased basic seedling number, whereas reduced tillage with straw covering (NTS) decreased it (Table 2). Compared with CT, TS increased seedling number by 4.1%-5.4%, while NTS decreased it by 5.4%-6.0% ($P < 0.05$). NTSS and NTS had 3.2%-4.1% and 9.1%-10.8% lower seedling numbers than TS, respectively ($P < 0.05$), with NTS showing the largest reduction. However, NTSS and NTS increased wheat tiller number by 7.4%-10.5% and 14.6%-19.1% compared with CT, and by 4.3%-9.8% and 11.3%-18.3% compared with TS, respectively, with significant effects ($P < 0.05$).

Similar to tiller number, NTSS and NTS also increased spike number from tillers and tiller spike rate (Table 2). Compared with CT, spike number from tillers under NTSS and NTS was 25.4%-29.0% and 54.3%-58.4% higher, respectively, and 13.4%-18.5% and 41.8%-43.3% higher than TS, respectively ($P < 0.05$). The tiller spike rate under NTSS and NTS was 13.5%-20.1% and 33.0%-34.7% higher than CT, and 3.3%-13.6% and 21.1%-27.3% higher than TS, respectively, with significant effects ($P < 0.05$). Overall, NTS had the greatest effect on increasing spike number from tillers and tiller spike rate, forming the basis for high wheat yields.

2.3 Effects of Different Tillage and Straw Retention Methods on Wheat Yield and Yield Components

2.3.1 Wheat Yield and Harvest Index Straw retention significantly increased wheat grain yield compared with conventional low-stubble tillage (Table 3). Over the two experimental years, reduced tillage with straw retention (NTSS and NTS) increased yield by 16.6%-17.4% and 18.6%-21.4%, respectively ($P < 0.05$), while TS significantly increased yield by 10.2%-10.9%, demonstrating a clear yield-enhancing effect of reduced tillage with straw retention. NTSS and NTS were 5.8%-6.0% and 7.7%-9.5% higher than TS, respectively, with NTS showing the greatest increase, reaching yields of 7,618 $kg \cdot hm^{-2}$ and 7,203 $kg \cdot hm^{-2}$. This indicates that 25-30 cm high stubble harvesting with straw covering combined with reduced tillage (NTS) is beneficial for increasing wheat grain yield. Straw retention also increased biomass yield, with NTSS, NTS, and TS showing increases of 6.0%-6.6%, 7.3%-9.3%, and 5.9%-6.1% compared with CT, respectively ($P < 0.05$). Tillage methods combined with straw retention had no significant effect on biomass yield.

Reduced tillage with straw retention (NTSS and NTS) improved the conversion efficiency of photosynthates (Table 3). Compared with CT, harvest index under NTSS and NTS was 9.4%-10.7% and 10.5%-11.1% higher, respectively, and 5.3%-5.9% and 6.1%-6.3% higher than TS, respectively, with significant effects ($P < 0.05$). NTS showed the greatest improvement in photosynthate conversion efficiency to grain under reduced tillage, indicating that 25-30 cm straw covering combined with reduced tillage (NTS) is an appropriate straw management practice for enhancing conversion efficiency.

2.3.2 Wheat Yield Components Reduced tillage with straw retention significantly increased spike number (SN), kernels per spike (KNS), and thousand-kernel weight (TKW) (Table 3). Compared with CT, SN under NTSS and NTS increased by 7.5%-9.3% and 10.3%-11.2%, respectively, with NTS showing a greater effect, being 4.1%-4.7% higher than TS ($P < 0.05$). KNS under NTSS and NTS was 15.7%-16.1% and 18.5%-22.6% higher than CT, respectively, with NTS showing the largest increase, being 12.0%-12.8% higher than TS ($P < 0.05$). TKW under NTSS and NTS increased by 7.2%-8.9% and 13.9%-14.2% compared with CT, respectively, with NTS having the greatest effect, being 10.3%-11.0% higher than TS ($P < 0.05$). Overall, among the three straw retention treatments, reduced tillage combined with 25-30 cm high stubble straw covering (NTS) produced the highest yield components, forming the basis for high wheat yields.

2.4 Correlation of Wheat Grain Yield with Yield Components, Emergence Rate, and Emergence Uniformity

Correlation analysis showed that wheat yield components (spike number, kernels per spike, thousand-kernel weight) were extremely significantly positively correlated with grain yield (Table 4), while emergence rate and uniformity showed no significant correlation with grain yield. This indicates that reduced tillage with straw retention increased grain yield by enhancing yield components rather than through emergence characteristics. Notably, spike number and kernels per spike were extremely significantly positively correlated with thousand-kernel weight, suggesting that under reduced tillage with straw retention, yield increase could be achieved through simultaneous improvement of multiple yield components, representing a key direction for future research.

2.5 Analysis of the Mechanism Among Yield Components

Path analysis of grain yield and its components revealed that both spike number and kernels per spike had positive direct path coefficients to grain yield (Table 5

), with spike number contributing most to grain yield. This demonstrates that high grain yield can only be achieved on the basis of adequate spike number per unit area (including effective tillers). Analysis of indirect path coefficients showed that spike number contributed most to yield by increasing kernels per spike, while kernels per spike contributed most by increasing spike number. This indicates that appropriate tillage and wheat straw retention practices mainly increase grain yield by improving spike number.

Conservation tillage with straw retention after harvesting the previous crop often results in low seedling preservation rates and poor emergence quality, leading to yield reduction [17] and hindering technology promotion. Previous research on straw retention conservation tillage has focused on soil physical and chemical properties [18], soil hydrothermal characteristics [19], soil fertility improvement [20], water conservation and erosion prevention [15], pest and weed control [14], and yield performance [21-22], while systematic studies on the effects of different straw retention methods on crop emergence are rare. Therefore, this study focused on the effects of different wheat straw retention and tillage methods on wheat emergence and yield. Research indicates that the main factors affecting wheat emergence include uneven soil moisture distribution or water deficiency, straw (or stubble) obstruction, improper sowing depth, and seed rot [17]. This study found that compared with conventional tillage without straw retention, reduced tillage with straw retention decreased wheat emergence rate, while straw incorporation through tillage increased it. Conventional tillage without straw retention caused greater soil moisture loss, leading to insufficient or uneven soil moisture that affected wheat emergence. Reduced tillage with straw retention decreased emergence rate mainly due to uneven straw distribution, partial straw accumulation, low sowing quality, and obstruction of seedling growth, even causing seedling death. Straw incorporation through tillage improved emergence rate because tillage facilitated sowing, improved sowing quality, and the water-conserving effect of straw retention promoted germination and emergence. This suggests that in this study, the negative impact of straw obstruction on emergence decreased with tillage, indicating that plowing can reduce straw density in soil and minimize straw hindrance to wheat emergence.

In practice, corresponding measures should be taken for each factor affecting crop yield, particularly addressing seedling preservation at the production source to establish a foundation for high-yield crop cultivation. For reduced tillage with straw retention technology that decreases wheat emergence rate, issues of uneven soil moisture distribution or water deficiency can be addressed through straw management and water management, with timely irrigation based on field soil moisture conditions after sowing to preserve and promote seedlings. For problems of straw affecting sowing quality and emergence, first, straw should be distributed as uniformly as possible; second, tillage methods after straw retention should be optimized to reduce straw density in soil, thereby solving both straw obstruction and soil moisture issues caused by straw. For inconsistent sowing depth, improved sowing machinery or methods can be adopted, such as mechanical instead of manual sowing. Studies have also shown that sowing rate significantly affects wheat emergence rate and yield [8]; therefore, for reduced tillage with straw retention that decreases crop emergence rate, mechanical operations or improved straw spreading machinery can be used to achieve more uniform distribution of crushed straw in the field, and increasing sowing rate or selecting varieties with strong tillering ability and high tiller spike rate can compensate for the negative effects of reduced emergence.

Numerous studies have shown that low emergence rate and poor uniformity lead to crop yield reduction, with emergence rate and uniformity coefficient being major factors affecting wheat yield. Wheat emergence rate is significantly positively correlated with effective spike number, negatively correlated with thousand-kernel weight, and significantly positively correlated with kernels per spike [2]. After no-tillage straw retention, low emergence rate and poor uniformity affect wheat yield by influencing thousand-kernel weight, effective spike number, and kernels per spike [2]. However, this study shows that in the Hexi Oasis Irrigation Area, reduced tillage combined with straw retention, although decreasing wheat emergence rate and increasing emergence uniformity coefficient, actually increased wheat yield. Correlation analysis indicated that wheat emergence rate and uniformity coefficient had no significant correlation with grain yield. Unlike studies showing that straw retention reduces both emergence rate and yield, this study' s pre-sowing rotary tillage increased straw uniformity and improved sowing quality compared with no-tillage straw retention. Under reduced tillage with straw retention in this study, high wheat yield was mainly attributed to the good water conservation effect and suitable soil temperature of conservation tillage [19], which increased tiller number and spike number from tillers, thereby improving effective spike number. Additionally, reduced tillage with straw retention increased kernels per spike and grain weight, particularly improving photosynthate transfer to grain, possibly because straw retention with reduced tillage significantly increased soil water content and optimized nutrient and water demand patterns across growth stages, laying a foundation for meeting the vigorous nutrient and water demands during the grain-filling stage and thus improving photosynthate conversion efficiency. However, conventional tillage had significantly lower spike number than straw retention treatments due to lower tiller number and tiller spike rate. Conventional tillage had higher temperatures and faster growth during early growth stages, consuming more water and nutrients, resulting in lower soil moisture and nutrients during anthesis, which reduced later growth and development, weakened photosynthetic rate, and consequently decreased spike rate, kernels per spike, and grain weight. Most importantly, reduced tillage with straw retention increased wheat grain yield possibly because low emergence rate and low temperatures during early growth stages favored root growth but not shoot development [23], leading to slow early growth and low nutrient consumption. During later growth stages, as temperatures increased, the suitable soil temperature and moisture under reduced tillage with straw retention, combined with remaining nutrients from early stages, achieved a "staggered nutrient allocation" that met the vigorous nutrient demands during the late growth stage (grain-filling stage). This indicates that yield increase under reduced tillage with straw retention mainly occurred during the late growth stage. Correlation analysis between grain yield and its components showed that increased yield under reduced tillage with straw retention was mainly due to improved spike number and kernels per spike. The 25–30 cm wheat straw retention with reduced tillage can serve as a regional high-yield wheat cultivation technology.

Reduced tillage with straw retention decreased wheat emergence rate and uniformity, while tillage with straw incorporation increased them. Straw retention improved wheat grain yield and harvest index, increasing yield by 10.2%–21.4% and harvest index by 4.4%–11.1% compared with conventional tillage. The combination of straw retention with reduced tillage showed higher yield-increasing effects and greater photosynthate transfer to grain. The high yield was mainly attributed to increased spike number (resulting from higher tiller number and tiller spike rate) and kernels per spike, while emergence rate and uniformity had no significant effect on yield. Wheat straw retention is a feasible model for sustainable wheat production in this experimental region, with reduced tillage straw retention serving as a viable tillage practice for regulating yield components and mitigating the impact of emergence on yield to achieve high yields in oasis irrigation areas.

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