Long-term Effect of Year-Round Tillage Patterns on Yield and Grain Quality of Wheat

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Abstract: A 7-year field experiment under a rice-wheat rotation system was conducted at Guanghan County in the Chengdu Plain of China from 2004 to investigate the long-term effect of different combinations of year-round tillage patterns and crop straw management on grain yield and quality of wheat. Treatments were rotary-till wheat + rotary-till rice without any straw (conventional treatment, CK), zero-till wheat with rice straw mulching + rotary-till rice with no wheat straw (WZRR), zero-till wheat with rice straw mulching + rotary-till rice with no wheat straw + autumn vegetable (WZRRV), zero-till wheat with rice straw mulching + zero-till rice with wheat straw mulching (WZRZ), and zero-till wheat with rice straw mulching + zero-till rice with wheat straw mulching under ridge-till (WRZB). There was little variation amongst years in grain yield and yield components with the treatment, while CK had lower yields in most years than other treatments with a slight decreasing trend; spike numbers per area had no significant change with the elapse of time. An obvious descending trend in grain number per spike and grains per area for CK and increase in 1000-grain weight for all treatments were observed; zero tillage and straw mulching improved wheat tiller ability, soil available nitrogen, phosphorus, and potassium contents at major growth stages, and leaf area index, SPAD, a portable chlorophyll meter reading, and dry matter at middle and late stages. Most grain quality traits of wheat were nearly the same in all treatments in all year-round tillage patterns.

Key words: Grain quality, Grain yield, Long-term effect, Tillage patterns, Wheat.

Grain yield and quality traits of wheat are not only influenced by genetic background, but also by cultivation management, environmental conditions and other external conditions. Zero tillage and straw mulching, as the key techniques of conservation agriculture, have been widely studied. Compared to conventional tillage, zero or minimal tillage has the advantages of simplifying field preparation, improving soil structure and increasing crop yield (Yuan et al., 1991; Xu et al., 2000; Liu et al., 2007; Xie et al., 2007; Huang et al., 2009). Straw mulching can also improve soil organic matter, reduce water and wind erosion and enhance crop production (Wu et al., 2006; Chen et al., 2008; Huang et al., 2009; Wang et al., 2011). However, the effect of zero or minimal tillage without the combination of straw mulching, including uneven nutrient availability, nutrient deficiency in late growth stages and yield depression, becomes negative (Hammel, 1995; Gao and Li, 2005; Govaerts et al., 2005; Xie et al., 2007).

Therefore, it is important to understand the effects of combining zero or minimal tillage, straw mulching and rotation tillage since they have major impacts on production in conservation agriculture (Govaerts et al., 2005; Wang et al., 2006). Govaerts et al. (2005) and Riley et al. (2008) studied the long-term effects of different tillage methods or one crop production system on dry land and found complex interactions of crop growth and yield with tillage, straw mulching, and rotation tillage. The main cropping system in the Chengdu plain is a rice-wheat double cropping system, and farmers can plant
a short duration vegetable between the rice and wheat crops to supplement their income. Wheat planting is mainly with zero tillage while rice planting is basically with rotary tillage. Rice straw is reasonably utilized by returning to the fields; however the returning of wheat straw is generally not undertaken and remains a major problem (Li et al., 2009). Tillage patterns and straw mulching have great impacts on wheat sowing, transplanting seedlings and annual yield increases. Many studies focus on single factors such as straw management, tillage options or different cropping system, but lack multifactor combinations on long-term research. To address this, we conducted a long-term field experiment under a rice-wheat system to investigate the long-term effect of different combinations of year-round tillage patterns and crop straw management on the growth and correlated characteristics of rice and wheat, to provide information for optimization of regional tillage systems. This article describes the results pertaining to wheat.

Materials and Methods

1. Growth conditions
The experiments were carried out from 2004 to 2011 at the Guanghan County, Sichuan Province, China (104º12’ E, 30º99’ N; 500 m above sea level). Soil samples were collected by using a 5 point diagonal method in every plot from three layers (0 – 15 cm, 15 – 30 cm, 30 – 45 cm) to measure soil fertility. Soil characters prior to the trial were as follows: layer 0 – 15 cm: pH 7.33, organic matter was 3.05%, total N, P and K were 0.187%, 0.088% and 1.570%, respectively. Available N, P and K were 220.0 mg kg⁻¹, 26.0 mg kg⁻¹ and 130.6 mg kg⁻¹, respectively; layer 15 – 30 cm: pH 7.60, organic matter was 3.05%, total N, P and K were 0.187%, 0.088% and 1.570%, respectively. Available N, P and K were 126.4 mg kg⁻¹, 12.5 mg kg⁻¹ and 96.7 mg kg⁻¹, respectively.

2. Experimental design and management
Five year-round tillage patterns were arranged in a randomized complete block design with three replicates, including: 1) rotary-till wheat + rotary-till rice without any straw (conventional treatment, CK); 2) zero-till wheat with rice straw mulching + rotary-till rice with no wheat straw (WZRR); 3) zero-till wheat with rice straw mulching + rotary-till rice with no wheat straw + Autumn vegetable (WZRRV); 4) zero-till wheat with rice straw mulching + zero-till rice with wheat straw mulching (WZRRZ); 5) and zero-till wheat with rice straw mulching + zero-till rice with wheat straw mulching under ridge-till (WRZB), (Table1). Each tillage plot was 10.5 m × 8.5 m.

The sowing date, sowing quantity, fertilizing amount and field management were the same in all treatments. The wheat cultivar, Chuanmai42, was sown around 29 October each year with fertilization including 135 kg ha⁻¹ of N, 75 kg ha⁻¹ of P₂O₅, and 75 kg ha⁻¹ of K₂O. Sixty percent of N and all of the P, K were applied as basal fertilizer and the remaining 40% N was applied as top-dressing at the jointing stage. Zero-till wheat was sown with a seeder (simple 2BJ-2) with line socket spacing of 20 cm × 10 cm, at a sowing density of 150 kg ha⁻¹, then chopped straw was used to mulch: CK wheat was sown with a seeder after rotary till with line socket spacing of 20 cm × 10 cm, then shallow soil was used for mulching; 1 m ridge spacing with 15 cm ridge height was used for ridge-till and 4 rows of wheat were sown on the ridge by hand with line socket spacing of 25 cm × 10 cm. Chopped rice straw was used for mulching. A hybrid rice cultivar Il you838 (in year 2005 – 2008) and Chuanxiang 9838 (in year 2009 – 2011) were sown on 10 April each year, approximately one week after the wheat harvest (on dry land). 165 kg ha⁻¹ of pure N, 75 kg ha⁻¹ of P₂O₅ and 75 kg ha⁻¹ of K₂O were added to the rice field after seeding. For WZRRV, the straw was removed after the rice harvest and returned after the autumn vegetable harvest for wheat mulching. The autumn vegetable was lettuce and followed common farmer practices: line spacing was 30 cm and socket spacing was 25 cm, 75 kg ha⁻¹ of pure N, 60 kg ha⁻¹ of P₂O₅, 55 kg ha⁻¹ of K₂O and 15000 kg of manure were added to the field. Other management options were used according to

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Table 1. Design of experimental treatments.

| Treatment | Wheat   | Rice    | Autumn vegetable |
|-----------|---------|---------|------------------|
|           | Tillage | Residue management | Tillage | Residue management |          |
| CK        | Rotary tillage | Residue moved from field | Rotary tillage | Residue moved from field | –       |
| WZRR      | Zero tillage | Residue moved from field | Rotary tillage | All residue mulching retention | –       |
| WZRRV     | Zero tillage | Residue moved from field | Rotary tillage | All residue mulching retention | Lettuce |
| WZRZ      | Zero tillage | All residue mulching retention | Zero tillage | All residue mulching retention | –       |
| WRZB      | Zero tillage and ridge-tillage | All residue mulching retention | Zero tillage and ridge-tillage | All residue mulching retention | –       |
ordinary high yield field operations.

3. Grain yield and agronomic traits

Three of the $1 \text{ m}^2$ area sampling points were fixed in each plot to investigate the number of seedlings, winter solstice seedlings, highest seedlings and effective spikes every year. SPAD value and dry matter of main growth stage were determined by investigating three points per plot and 2 – 3 sockets per point. Grain yield, stem height, spike length and spike numbers were determined after the plants had reached full maturity.

4. Soil traits and leaf SPAD

Soil water content, soil available nutrient and leaf SPAD were determined between 2008 and 2009 (the 5th year of the experiment). At jointing stage, soil samples were collected from three soil layers ($0 – 15 \text{ cm}$, $15 – 30 \text{ cm}$, $30 – 45 \text{ cm}$) by randomly sampling at five points in each replicate of each treatment. The soil samples were then mixed for soil water content determination. Soil measurements started 11 days after rainfall ($0.4 \text{ mm}$) which had little impact on the analysis of soil water content. Soil water content was measured by the oven drying method ($w/w$); available $N$, $P$, $K$ content of the soil layer $0 – 15 \text{ cm}$ were measured at tillering, jointing, anthesis and mature stages, available $N$ was analyzed by the alkaline permanganate method, available $P$ by sodium bicarbonate extraction (Olsen method) and available $K$ by neutral normal ammonium acetate extraction (Jackson, 1973). At anthesis, three points and three plants per point were chosen from each replicate of each treatment, and 10 plants were randomly picked out to determine SPAD values of flag leaf, second leaf and third leaf. Mean SPAD values at the bottom, middle and top parts of leaves were used in this study.

5. Quality traits

One kg wheat was collected and stored for three months after harvest for quality analysis at the Institute of Crop Science, Chinese Academy of Agricultural Science in 2008 and 2009. Grain bulk density was assessed according to the method of GB/T5498-1985 using a density instrument (Model HGT-1000, Hengqi Co., Ltd, Shanghai); grain protein content was measured according to the method of AACC39-10 using Near-Infrared Analysis Instrument (Model Perten DA7200, Sweden); wheat grains were milled to determine wet gluten content, zeleny sedimentation volume, falling number and farinograph softening parameters. Wet gluten content was measured according to the method of GB/T14608-93 using a gluten Instrument (Model Perten 2200, Sweden); Zeleny sedimentation volume, falling number and farinograph softening parameters were determined according to the methods of AACC56-63, AACC56-81B and AACC54-21, respectively.
6. Meteorological parameters during wheat growth

Wheat was sown in October and harvested in the middle of May each year. The monthly average temperatures and precipitation during the wheat growing period are listed in Table 2. Abnormal fluctuations occurred in early May 2006 with a continuous period of high temperatures. This resulted in a marked reduction in the 1000-grain weight.

Heavy rain from anthesis to maturity in 2008 caused an outbreak of scab. A mild climate in 2010 resulted in longer wheat growth and grain filling period and heavier 1000-grain weight of wheat. Long-term low temperature at anthesis stage in 2010 inhibited the grain yield and grain number per spike.

7. Statistical analysis

Experimental data and figures were subjected to analyses of Microsoft Excel 2007, and the statistical analyses were performed using an SPSS 9.0 software package.

Results

1. Interannual change of grain yield and related properties
(1) Grain yield
There was a significant difference in grain yield among
treatments in 2006, 2007 and 2010, but not in other years (Table 3). In 2006, 2008, 2009, 2010 and 2011, grain yield in CK was less than in other treatments. The grain yield in CK decreased as time progressed, $y = -0.125x + 7.426$ ($R^2 = 0.363$, $P = 0.052$), but less change was observed in other treatments. The yield in WZRR and WZRRV was higher while that in WZRZ and WRZB was stable over the first five years (Table 3).

2. Yield components
The spike number was significantly lower in 2010 than in other years (less than 400 spikes m$^{-2}$) (Fig. 1). The spike number in CK and WRZB in 2005 was smaller and the spike number in WZRZ in 2006 was larger than in other treatments. Smaller spike number in CK from 2005 to 2011 except 2009 may be due to the lower grain yield than in other treatments.

Grain number per spike in all treatments was minimum in 2009 and 2011, while no significant difference with the treatment was found. The grain number per spike in CK held steady from 2005 to 2008, but declined in 2009 and 2010. In treatment WZRR, grain number per spike was small, especially from 2005 to 2009 (Fig. 1). Furthermore, the grain number per area in each treatment was nearly the same from 2005 to 2011 with the exception of 2006 when it increased to 1500 grains m$^{-2}$.

The differences in 1000-grain weight among treatments in 2006 were significant (Fig. 1), with the highest value in WRZB and the lowest value in CK. In 2010, 1000-grain weight in CK was significantly higher than in other treatments, while in other years there were no obvious differences among treatments (Fig. 1).

3. Morphological and biological traits
In CK, plant height was 2 – 5 cm lower, tiller number per plant was 0.2 – 0.9 smaller, number of spikelets per head was 1.0 – 1.8 smaller, number of setting spikelets was 0.2 – 1.0 smaller and biomass yield was lower than in other treatments. The spike length in both CK and WZRR were nearly the same and were shorter than in other treatments, and there was no significant difference in harvest index among treatments (Table 4). In addition, an obvious difference among treatments was observed in percentage of lodging, which was the highest in WZRZ (58.8%), followed by WZRRV (49.4%). Ridge-till gave a higher level of lodging resistance.

(2) Soil water and soil nutrients in the fifth year
(1) Soil water content at jointing
The soil water content was the highest in WZRR and WZRRV in the three soil layers (Fig. 2). In all treatments except CK the water conservation ability was high. In the soil layer 0-15 cm, the soil water content was the highest in WZRR and WZRRV.

Available nutrient content of soil during the growth period
Available N content did not significantly vary with the treatment, nor did it change significantly during the growth period (Fig. 3). Available potassium did not vary much with the treatment; however, it declined consistently from flowering to maturity in all treatments except WZRR (Fig. 3). Available phosphate (P) significantly varied with

### Table 4. Effects of different year-round tillage patterns on morphological and biological traits of wheat.

| Treatment | PH (cm) | TNP (no.) | NSL (no.) | NSSL (no.) | BY (t ha$^{-1}$) | SL (cm) | HI (no.) | PL (%) |
|-----------|---------|-----------|-----------|------------|-----------------|--------|---------|-------|
| CK        | 89.6    | 1.7       | 19.0      | 15.5       | 14.9            | 10.4   | 0.431   | 19.4  |
| WZRR      | 92.0    | 2.4       | 20.0      | 15.7       | 15.2            | 10.4   | 0.441   | 14.8  |
| WZRRV     | 93.0    | 2.6       | 20.4      | 16.1       | 16.0            | 10.6   | 0.425   | 49.4  |
| WZRZ      | 94.6    | 2.5       | 20.8      | 16.5       | 15.7            | 10.8   | 0.430   | 58.8  |
| WRZB      | 93.3    | 1.9       | 20.6      | 16.3       | 15.6            | 10.8   | 0.432   | 9.6   |
| LSD0.05   | 2.0     | 0.3       | 0.6       | 0.8        | TS              | TS     | TS      | 27.2  |

PH: plant height; TNP: tiller number per plant; NSL: number of spikelet per spike; NSSL: number of setting spikelet per spike; BY: biomass yield; SL: spike length; HI: harvest index; PL: percentage of lodging.

NS: no significant difference.
the treatment and growth stage (Fig. 3). It was consistently higher in WZRRV than in the other treatments through most of the growth stages. In WZRRV, WRZB and CK, the P concentration reached a peak at the jointing stage and declined thereafter. In WZRR and WZRZ, the P concentration was generally high throughout the season.

3. Physiological traits at anthesis

The SPAD values showed no significant difference between flag leaf and the second leaf in any treatment, but were different in the third leaf. The SPAD values were lower in CK than in any other treatments, and the highest in WZRR and WZRRV (data not shown). Green leaf area per stem and the leaf area index showed no significant differences with the treatment (Table 5). The dry weight of stem showed a slight variation in CK, but was significantly lighter than in WRZB. There was no significant difference among the other treatments. Similarly, the dry weight per unit leaf area varied slightly, but was significantly heavier in CK and WZRZ than in WRZB (Table 5).

Table 5. The green leaf area, LAI and dry matter of individual and population of wheat at flowering stage in the fifth year (2008) of the permanent experiment.

| Treatment | Green leaf area per stem (cm²) | Distribution of green leaf area of top three leaves | LAI (no.) | Dry matter per stem (g) | Dry matter per unit area (g m⁻²) |
|-----------|-------------------------------|-----------------------------------------------|----------|------------------------|---------------------------------|
| CK        | 94.3 a                        | Flag leaf (%) 36.3, Second leaf (%) 37.5, Third leaf (%) 26.1 | 5.35 a   | 2.23 b                 | 1.26 a                          |
| WZRR      | 101.1 a                       | Flag leaf (%) 36.3, Second leaf (%) 41.6, Third leaf (%) 22.1 | 5.52 a   | 2.27 ab                | 1.24 ab                         |
| WZRRV     | 99.6 a                        | Flag leaf (%) 43.1, Second leaf (%) 46.9, Third leaf (%) 19.8 | 5.43 a   | 2.28 ab                | 1.21 ab                         |
| WZRZ      | 105.6 a                       | Flag leaf (%) 37.3, Second leaf (%) 39.4, Third leaf (%) 22.9 | 5.79 a   | 2.32 ab                | 1.27 a                          |
| WRZB      | 104.4 a                       | Flag leaf (%) 36.4, Second leaf (%) 40.6, Third leaf (%) 23.1 | 5.47 a   | 2.36 a                 | 1.15 b                          |

Within a column, values followed by the same letter are not significantly different at \( P < 0.05 \).
4. Effect of year-round tillage patterns on grain quality

The grain quality in 2008 and 2009 is shown in Table 6. The most consistent effect on quality parameters was observed in WZRR in which the zeleny sedimentary volume was smaller, and dough development time was shorter in both years. Similar trends were observed in WZRRV. In these treatments, grain protein content was lower than in other treatments in both years, although the difference was significant only in 2008. In CK, the gluten index was significantly lower than in the other treatments in both years.

Discussion

Jia et al. (2004) and Govaerts et al. (2005) reported that the effects of tillage and straw management on crop yield and related traits were limited to a short term, the effects becoming more obvious after approximately 5 years. Other researches, however, indicated that wheat yield did not change under long-term zero or reduced-tillage practices (Zhuang et al., 1999; Wang et al., 2009). However, the interpretation of the results in these studies is complicated because different variables such as cropping systems, cultivars and management measures were used. In this study, grain yield in all treatments decreased during the first 5 years, yield in CK, decreased within 7 years, though slightly, while the change in other treatments was less obvious (Table 7). The spike number did not show any obvious change; grain number per spike showed a descending trend, the formula for 5 years was: $y = –2.03x + 46.30$ ($R^2 = 0.307$, $P = 0.104$), the formula for 7 years was: $y = –1.838x + 45.99$ ($R^2 = 0.464$, $P = 0.050$); Grain number per area in CK also showed a descending trend during the 7 years. The number of grains per spike was smaller in WZRR and this was reflected in the higher spike number.

| Year | Treatment | VSG (g L$^{-1}$) | GPC (%) | SED (ml) | FN (s) | WGC (%) | GLI (no.) | WA (%) | DST (min) | SOF (F.U.) | QN (no.) |
|------|-----------|------------------|---------|----------|--------|---------|-----------|--------|------------|------------|----------|
| 2008 | CK        | 758 b            | 10.7 a  | 38.9 a   | 281 a  | 21.2 a  | 93.4 b    | 51.2 a | 1.5 a      | 128 a      | 29 a     |
|      | WZRR      | 766 b            | 9.8 b   | 30.1 b   | 277 b  | 19.8 b  | 99.3 a    | 49.8 a | 1.0 b      | 126 a      | 17 a     |
|      | WZRRV     | 765 b            | 10.3 ab | 39.0 a   | 264 b  | 21.0 a  | 96.4 a    | 49.8 a | 1.4 ab     | 98 a       | 21 a     |
|      | WZRZ      | 768 ab           | 10.7 a  | 42.0 a   | 289 a  | 20.9 a  | 96.4 a    | 50.5 a | 1.6 a      | 90 a       | 21 a     |
|      | WRZB      | 786 a            | 10.8 a  | 39.1 a   | 295 a  | 21.5 a  | 96.8 a    | 51.5 a | 1.5 a      | 105 a      | 22 a     |

Within a column, values followed by the same letter are not significantly different at $P < 0.05$.

| Yield-related traits | Treatments $^1$ | 7-years duration |
|----------------------|-----------------|------------------|
|                      | Equation        | $R^2$            | $P$              |
| Grain yield (t ha$^{-1}$) | CK              | $y = –0.125x + 7.426$ | 0.362 | 0.052 |
|                      | Aotr.           | $y = –0.056x + 7.412$ | 0.072 | 0.561 |
| Spike number (m$^2$)  | CK              | $y = 1.2x + 408.6$ | 0.002 | 0.916 |
|                      | Aotr.           | $y = 1.5x + 424.6$ | 0.000 | 0.859 |
| Grain number (spike$^{-1}$) | CK            | $y = –1.70x + 44.98$ | 0.464 | 0.050 |
|                      | Aotr.           | $y = –0.84x + 40.97$ | 0.118 | 0.447 |
| Grain number (m$^2$)  | CK              | $y = –732.9x + 18579$ | 0.524 | 0.041 |
|                      | Aotr.           | $y = –390.3x + 17626$ | 0.205 | 0.298 |
| 1000-grains weight (g) | CK              | $y = 2.14x + 41.73$ | 0.383 | 0.139 |
|                      | Aotr.           | $y = 1.44x + 44.51$ | 0.323 | 0.183 |

$^1$ Aotr. Representing average over treatments excluding CK.
1000-grain weight did not change during the first 5 years, but increased in the last 2 years of the study, which was related to the reduction in grain number.

Zero-tillage with high organic matter content and good soil drainage is believed to achieve continuous high yields, while that with low fertility and poor drainage decrease the yield (Dick, 1991). Our study was carried out in a high nutrient soil, and the cultivar, fertilizer and management systems in all the experimental years were kept consistent. Therefore, the yield difference among different treatments reflected the adaptive capacity of annual climate fluctuations, and was ultimately reflected in the growth and yield components under the different tillage systems. For example, in 2006, high temperatures at the late grain filling stage caused the reduction of 1000-grains weight, especially in CK, while the straw mulching treatments, created a better soil water holding capacity (Wang et al., 2009), mitigating the reduction. The number of grains per spike and yield were lower in 2011 probably due to low fertility induced by a sustained low temperature around anthesis. Statistical analysis showed that rainfall at the tillering-jointing stage had a positive correlation with the yield (Zhao et al., 2009). In 2010, low rainfall after sowing resulted in fewer tillers and this was reflected in a reduced spike number. The zero till treatments tended to perform better in this year tillering from the nodes above the soil surface. Straw mulching also helped water conservation under zero till, and this kept the spike growth stable and decreased the drought damage (Zhao et al., 2009).

The effect of tillage on crop growth is mainly through the influence on soil structure. Most studies demonstrate that zero tillage and straw mulching significantly improve soil nutrition in the cultivated layer, especially the top soil either in dry farming or with rice rotations (Wu et al., 2006; Chen et al., 2008; Huang et al., 2009). In our seven-year experiment, there were significant influences of zero tillage and mulching on soil nutrition at different growth stages, particularly in relation to P and K. At the earliest soil measurements (34 days after sowing), the available N content was the highest in WZRRV (including a summer vegetable rotation), and the additional fertilization practice is required to grow this late summer wheat crop. This also accounted for the higher initial and successive P content in the vegetable treatment. Moreover, year-round zero-till wheat with rice straw mulching showed markedly higher available N content than one season zero-till wheat with rice straw mulching, which was not in agreement with the report by Yan et al. (2005). This was mainly due to the fade away of plough pan, the poor stubble growth and insufficient supply of N under long time year-round zero-till treatments. Available N content in CK was lower at the late growth stage than at the early and middle stages, which resulted in a smaller green leaf area per stem and low SPAD value, and further changes in other physiological functions, which are in agreement with some other studies (Huang et al., 2009). The amount of available K may be small in the conventional treatment (CK) and this could be due to leaching caused by the limited amount of applied straw. The depletion of K between anthesis and maturity reflects a specific nutritional demand of the plant during grain fill. P concentration was greatly increased by the autumn vegetable contributing to the high levels of P in WZRRV. The zero-till wheat with rice straw mulching + zero-till rice with wheat straw mulching, and that with ridge-tillage provided a greater available P capacity, which is important in improving soil available P deficiency in the southwest region of China (Guan et al., 2007).

Previous researches indicated that zero tillage can decrease wheat quality, while straw mulching can improve wheat processing quality (Liu et al., 2007; Zhang et al., 2011). Jiang et al. (2007) showed that with straw mulching and rotary tillage, grain protein quality, flour processing quality and noodles cooking quality were improved. Grain protein content was about 10 – 13% on the Chengdu plains, providing low gluten flour, which is suitable for making noodles and biscuits. In our study, no significant difference was observed in most quality traits among the tillage treatments, while zeleny sedimentation volume, and dough development time were decreased in WZRR and WZRRV as compared with CK. Under the rice rotary-tillage, rice growth was better than in year-round zero tillage, and soil water content tested before the next wheat sowing was higher than from year-round zero tillage patterns. The poor quality in zero tillage and rotary-tillage was mainly related to the adaptation of the tillage pattern to climate conditions, rather than soil content. WZRR treatment, as the key tillage pattern on the Chengdu plains, improved grain quality under certain conditions. Furthermore, ridge tillage also improved the volumetric specific gravity, falling number and other traits as compared with CK and this is consistent with other studies (Hao, 2007; Hou et al., 2007). Different results in these studies were mainly due to the different cultivars, climate conditions and soil traits. More research is required to further clarify the long-term effects of tillage patterns and straw mulching on grain quality.

**Conclusion**

The grain yields in different tillage patterns changed according to the prevailing environmental patterns; however, it was the lowest in CK, throughout the seven years. There was a clear downward trend for grain yield in this treatment, decreasing by 0.125 t ha⁻¹. Spike number per area did not change significantly over time; the grain number per spike and grains per area tended to decrease while 1000-grain weight increased in CK. Zero tillage and straw mulching improved wheat tillering ability and soil nutrient content during the growth stages, and improved
some quality parameters, while year round tillage practice had less effect on grain quality.

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