Long-Term No-Tillage Direct Seeding Mode for Water-Saving and Drought-Resistance Rice Production in Rice-Rapeseed Rotation System

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Abstract: To study the effects of long-term no-tillage direct seeding mode on rice yield and the soil physiochemical property in a rice-rapeseed rotation system, a comparative experiment with a water-saving and drought-resistance rice (WDR) variety and a double low rapeseed variety as materials was conducted under no-tillage direct seeding (NTDS) mode and conventional tillage direct seeding (CTDS) mode for four years, using the CTDS mode as the control. Compared with the CTDS mode, the actual rice yield of WDR decreased by 8.10% at the first year, whereas the plant height, spikelet number per panicle, spikelet fertility, 1000-grain weight, grain yield, actual yield, and harvest index increased with no-tillage years, which led to the actual yield increase by 6.49% at the fourth year. Correlation analysis showed that the panicle length was significantly related to the actual yield of WDR. Compared with the CTDS mode in terms of the soil properties, the pH value of the NTDS mode decreased every year, whereas the contents of soil organic matter and total N of the NTDS mode increased. In the 0–5 cm layer of the NTDS mode, the soil bulk decreased, whereas the contents of soil organic matter, total N, and available N increased. In the 5–20 cm layer of the NTDS mode, the available N and K decreased, whereas the soil bulk, contents of soil organic matter, and total N increased. In summary, the NTDS mode increased the rice yield, and could improve the paddy soil fertility of the top layer.

Key words: no-tillage direct seeding; rice yield; soil physiochemical property; water-saving and drought-resistance rice; rotation system

No-tillage is currently one of the major farming patterns in the world, but it has a relatively slow development in China (Tang and Zhang, 1996; Bhushan et al, 2007; Chen et al, 2013). The rice no-tilling culture is more common in Asia, wherein the main method is no-tillage direct seeding (NTDS) (Pandey and Velasco, 1999; Yang et al, 2013). In China, the Yangtze River Basin is the major area for rice and rapeseed production, where the rice-rapeseed rotation system is mainly adopted. In recent years, farming initiative has declined because of the factors of market, technology, and labor transfer. Farmland abandonment and the decline in farmer initiatives have led to rapeseed acreage reduction (Xia, 2006; Wu et al, 2009).

Studies on single cropping rice and paddy field rapeseed under the NTDS mode have been reported (Feng et al, 2006; Wang et al, 2011). However, studies on rice-rapeseed via long-term no-tillage cultivation are rare. The NTDS mode of rice in one season is conducive to nutrient fortification in the soil surface layer, and does not lead to soil acidification with higher rice yield than conventional tillage direct seeding (CTDS). In the present study, water-saving and drought-resistance rice (WDR) (Luo, 2010) and double low rapeseed variety, both of which are suitable for the NTDS mode, were chosen, and rice-rapeseed rotation was conducted for a number of successive years under the NTDS mode to determine the yield formation characteristics of rice and physiochemical properties of soil, which will provide a basis for the formation of a no-tillage cultivation technology system.

Received: 14 February 2014; Accepted: 14 April 2014
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MATERIALS AND METHODS

Tested materials

Hybrid rice variety Hanyou 3 was used in this study, which is characterized by water- and fertilizer-saving, good lodging resistance, high and stable yield, high quality, wide adaptability, and simple cultivation (Yu et al., 2005). Also, a middle maturity double low rapeseed variety Huyou 17 was chosen, which is characterized by strong stalk, fertilizer tolerance, good lodging resistance, high yield, good performance against viral diseases, strong sclerotinia resistance at the maturation stage, thick shell, good antinatural burst of silique when ripe, strong threshing resistance, and mechanical harvesting applicability (Sun et al., 2005).

Field trial design

A field experiment was conducted for a period of four successive years (2007–2010) in Zhuanghang Integrated Experiment Station of Shanghai Academy of Agricultural Science, China. The experimental field was an abandoned agricultural land during new rural construction, and rice-rapeseed tillage cultivation began in 2004. The physiochemical properties of soil in 2007 are shown in Table 1. The experiment was conducted using a rice-rapeseed rotation system with two types of treatment, the NTDS mode and CTDS mode (CK), with three replications. The area of each plot was 0.2 hm².

The seeds of rice variety Hanyou 3 were sown annually on 30 May, with the seeding rate of 45 kg/hm². After seed drying for 1–2 d, the seeds were soaked for 48 h in a solution consisting of 30 g of 17% fenitrothion-ethylicin, 10 g of 10% imidacloprid, and 9 kg of water to accelerate germination and shell breaking. After chemical control and weeding of the field, the seeds were directly sown into the moist soil. The seeds of rapeseed variety Huyou 7 were sown annually on 10 October. Before sowing, a herbicide was sprayed. The seeds were direct seeded using a no-tillage drill seeder with a seeding rate of 4.5 kg/hm².

The fertilization management standard of WDR was total nitrogen (N) of 240 kg/hm², which was applied as base fertilizer (35%), seedling fertilizer (15%), tillering fertilizer (35%), and panicle fertilizer (15%), respectively on 26 May, 4 July, 16 July, and at the jointing-booting stage. Phosphorus (P) and potassium (K) fertilizers were applied once as base fertilizer at 100 (count by P₂O₅) and 90 kg/hm² (count by K₂O), respectively. Water-saving irrigation was used. After seedling transplantation, the surface soil was kept moist, and basin irrigation was used only during fertilization. The pest, disease, and weeds were controlled based on the occurrence rule of WDR in Shanghai, China.

The fertilization management standard of rapeseed was total N of 240 kg/hm² (count by pure N), which was applied as base fertilizer (50%), seedling fertilizer (20%), and bud stage fertilizer (30%). P and K fertilizers were applied once as base fertilizer at 120 (count by P₂O₅) and 120 kg/hm² (count by K₂O), respectively. The pest, disease, weeds, and water were controlled as needed.

Analysis of rice yield and soil physiochemical properties

Upon maturity of the rice variety, five positions were chosen along the diagonal, and five single plants from each position were investigated to test the yield traits measured with the average. A rice combine harvester (Kubota PRQ-488) was used for harvesting in accordance with plot distinction. Rice grains were dried with impurities being removed and weighed. The standard yield was calculated according to the moisture content, which was determined by a rapid moisture meter and usually defined the average as 13.5%.

After rice was harvested and before rapeseed was sown in 2009 and 2010, the soil samples from the surface layer (0–5 cm) and subsurface layer (5–20 cm) of the arable layer were taken to the Institute of Ecology, Shanghai Academy of Agricultural Sciences, China to test their physiochemical properties. Soil pH was determined using a potentiometry (immersion method) with a water-soil ratio of 5:1. The organic matter content was measured using K dichromate oxidation, which is an external heating method. The total N content was measured by the semi-micro Kjeldahl method, and available N was detected by alkaline hydrolysis diffusion. Available P was measured

Table 1. Physiochemical properties of the tested soil.

<table>
<thead>
<tr>
<th>Soil layer</th>
<th>pH</th>
<th>Organic matter (%)</th>
<th>Total N (%)</th>
<th>Available N (mg/kg)</th>
<th>Available P (mg/kg)</th>
<th>Available K (mg/kg)</th>
<th>Soil bulk (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5 cm</td>
<td>6.82</td>
<td>1.78</td>
<td>0.13</td>
<td>36.22</td>
<td>24.91</td>
<td>130.00</td>
<td>1.42</td>
</tr>
<tr>
<td>5–20 cm</td>
<td>6.87</td>
<td>1.63</td>
<td>0.11</td>
<td>32.88</td>
<td>23.00</td>
<td>101.38</td>
<td>1.47</td>
</tr>
</tbody>
</table>
RESULTS

Agronomic characters and yield components of Hanyou 3

The average of the agronomic characters and yield components of Hanyou 3 under the NTDS and CTDS mode are shown in Table 2. In the comparison of the average of plant heights, all plant heights under the NTDS mode were lower than those of the control for the first three years (2007–2009). The average plant height under the NTDS mode in 2010 was higher than that under the CTDS mode insignificantly. No significant difference was observed in the panicles number per unit area and average panicle length for four years between the two treatments. The numbers of spikelets per panicle under the NTDS mode were lower than those of the control in 2007 and 2008. However, an opposite trend was observed in 2009 and 2010. In 2007, the difference in the number of spikelets per panicle was significant between the NTDS and CTDS modes. The seed setting rates under the NTDS mode were lower than those of the control in 2007 and 2009, and the difference between the treatment and control in 2008 was highly significant. The seed setting rates under the NTDS mode were higher than those of the control in 2008 and 2010, and the difference between the treatment and control in 2008 was highly significant. The 1000-grain weight under the NTDS mode was higher than that of the control for four consecutive years, and the difference was significant in 2010. In the first year (2007), the single plant yield and actual yield under the NTDS mode were lower than those of the control, with a highly significant difference in the actual yield. In the next three years, the yields under the NTDS mode were higher than that of the control. In the fourth year, the actual yield of the NTDS mode was 562.32 kg/hm² higher than that of the control. The harvest index under the NTDS mode was lower than that of the control in 2008 but higher in 2009 and 2010.

Correlation analysis of yield components with actual yield showed that the panicle length and yield of...
Hanyou 3 was significantly related to each other under the NTDS mode, with the correlation coefficient of 0.94.

**Influences of long-term no-tillage rice-rapeseed rotation on soil physiochemical properties**

**Influence on soil bulk density**

Fig. 1-A showed that the bulk density of the surface soil (0–5 cm) decreased, whereas the bulk density of the subsurface soil (5–20 cm) increased with long-term no-tillage years of paddy-upland rotation. Compared with the control, the bulk density of the surface soil decreased, and reached a significant level in 2009 and 2010. By contrast, the bulk density of the subsurface soil was lower than that of the control in both years, and reached a significant level in 2010. This result indicated that long-term no-tillage under paddy-upland rotation resulted in porous surface soil and subsurface soil compaction.

**Influence on soil pH value**

Analysis on the pH values of the soil surface (0–5 cm) and subsurface (5–20 cm) showed that the soil pH value under the two tillage methods decreased with increasing cultivation time, and the pH value of the no-tillage soil was even lower than that of the control (Fig. 1-B). Compared with the control, the soil pH values of the surface and subsurface respectively decreased by 0.14 and 0.31 units, in the fourth year of no-tillage. The subsurface soil exhibited the largest difference.

![Fig. 1. Changes of soil bulk density, pH value, organic matter content and total N content in different no-tillage years.](image-url)

* and **: Significant difference at 0.05 and 0.01 levels between no-tillage and conventional tillage (CK), respectively. Bars represent standard error.
Influences on soil organic matter and total N content

Soil organic matter and total N content are important indicators of soil fertility level. With the increase of the no-tillage years, the soil organic matter content increased. Compared with that in 2007, the soil organic matter content in 2009 and 2010 increased by 6.18% and 11.24%, respectively, whereas that of the control did not change significantly. The organic matter in the no-tillage soil surface rapidly increased, which was higher than that of the control, reaching a significant level in the fourth year. By contrast, the organic matter content in the subsurface soil slowly increased, and was not significantly different from that of the control (Fig. 1-C).

With the increase of no-tillage years, the total N contents in the surface and subsurface soils were higher than that of the control. ANOVA showed that the N content in the subsurface soil was significantly higher than that of the control in 2009, but the difference in 2010 was insignificant. Compared with that in 2010, the total N content increased in the no-tillage soil, but did not significantly change in the control (Fig. 1-D).

Influences on available N, available P, and available K in the soil

The measurement results of available N, available P, and available K in the soil surface showed that the available N content of the no-tillage soil was significantly higher than that of the control (Fig. 2). The differences between the contents of available P and K in the no-tillage surface soil and control were not significant. The contents of available P and available K in both treatments increased with increasing farming time.

With increasing farming time, the contents of available N in the subsurface under the NTDS and CTDS modes showed a downward trend compared with those in 2007. However, the contents of available N decreased

![Figure 2](image_url)  
**Fig. 2.** Changes of available N, available P, available K in 0–5 cm soil layer and 5–20 cm soil layer in different no-tillage years. * and **, Significant difference at 0.05 and 0.01 levels between no-tillage and conventional tillage (CK), respectively. Bars represent standard error.
faster, whereas the changes in available P and K showed no obvious trends. In 2009 and 2010, the available N, P, and K contents in the soil subsurface under the NTDS mode were lower than those under the CTDS mode. The available N content in 2009 and the available P content in 2010 were significantly different. The difference in available K content under the NTDS mode in 2010 was highly significant.

**DISCUSSION**

**Impacts of NTDS and CTDS mode on rice yields**

The results of this four-year continuous cropping experiment showed that the plant height, spikelet number per panicle, seed-setting rate, and 1000-grain weight of Hanyou 3 all increased under the NTDS mode cultivation from 2008, whereas the effective panicles per unit area and panicle length did not significantly alter. At the first year of the NTDS mode, the plant height, spikelet number per panicle, seed-setting rate, and 1000-grain weight of Hanyou 3 were significantly lower than those under the CTDS mode, with a yield loss of 8.10%. In terms of plant height, spikelet number per panicle, seed-setting rate, and 1000-grain weight, the NTDS mode demonstrated advantages, and the final yield increased and exceeded under the CTDS mode. Rice yield and its source-sink characteristics in no-tillage treatment were higher than those in conventional tillage treatment, which is consistent with the results of previous studies (Wu et al, 2009; Huang et al, 2011). Correlation analysis showed that the panicle length and yield of Hanyou 3 was significantly correlated under the NTDS mode. The yield of the CTDS mode showed a declining trend with increasing rotation time, whereas that of the NTDS mode showed an increasing trend yearly. However, the difference was not significant, and these results require further study.

**Impacts of no-tillage on physiochemical of soil**

Soil bulk density is a composite indicator that reflects soil tightness, pore condition, and other features. Whether the implementation of no-tillage will cause soil compaction and plow layer shallowing is a common concern. The application of the NTDS mode for four successive years in this study resulted in loose surface soil and increased soil fertility. However, the soil bulk density of the subsurface increased and nutrients decreased, which were consistent with the results of previous studies (Zhang et al, 2006; Jiang et al, 2007). Lan et al (2009) showed that the soil bulk density initially increases and then decreases after water and dry farming, and the maximum value appears in the seventh to eighth years under the NTDS mode, which significantly differed with that under the CTDS mode. Long-term no-tillage resulted in soil compaction. In accordance with the conditions of the experiment in this study, the selected cultivated rice and rapeseed varieties demonstrated certain advantages. However, further studies are necessary to address the following problems: whether no-tillage will reduce the speed of soil compaction, the number of years for no-tillage to reach its threshold value and the conditions in which continuing no-tillage are unsuitable.

Soil pH value is one of the important factors affecting soil fertility. It has a great impact on crop growth and development, microbial activities, and nutrient availability. Researchers have studied the root activity of rice from no-tillage soil and rhizosphere soil (Huang et al, 2005; Jiang et al, 2009), and their results showed that the root activity of rice from no-tillage is stronger than that from conventional tillage, which led to the pH value changes in the rhizosphere and non-rhizosphere soil of no-tillage farmland. In this study, all soil pH values under the NTDS mode were lower than these under the CTDS mode. No-tillage resulted in soil acidification. The soil pH of the 0–5 cm surface continuously decreased, but that of 5–20 cm subsurface showed a tendency to stabilize. This result may be due to the surface being enriched with nutrients. Moreover, subsurface compaction resulted in the following phenomena: roots of crops were located in the surface, subsurface roots decreased, and the activity of surface-level roots increased.

In terms of soil nutrients, the contents of surface organic matter, total N, and available N in the no-tillage soil surface increase yearly; the nutrients gather in the surface soil, which was similar to the results of previous studies (Zhang et al, 2006; Jiang et al, 2007; Lan et al, 2009). However, in this study, the variations in available P and K were not obvious presumably because of the no-tillage years. The contents of available N, P, and K in the subsurface soil decreased, which may be related to the cultivation patterns of WDR. Thus, the changes in total P and total K contents require further investigation.

**Weed control and fallen paddy sprouting problem of soil in NTDS mode**

Under the experimental conditions of this study, more
weeds were observed on the long-term no-tillage soil than that on the tillage soil, which increased during summer. The density of weeds and dominant weed also differed from those in normal paddy fields. The dosage and frequency of herbicide were increased to prevent weeds in the trials. The authors are currently engaged in the further study of weed occurrence and control problems in rice and rapeseed farmland under the NTDS mode. The sprouting of previous crops is common in a no-tillage farmland, and this situation will worsen for consecutive no-tillage farmland. This problem can result in uneven heading phenomenon, and will have a direct impact on production if serious. How to deal with the fallen seed sprouting problem will be prepared and published in another article.

In recent years, along with research on conservation tillage technology in China, relatively mature technology modes have been established to adapt to China’s national conditions. Numerous conservation tillage special tools have been developed, and the operation mechanism to promote conservation tillage has been proposed. Demonstrative applications have achieved some success. This study provides a strong basis for the promotion of the NTDS mode.

ACKNOWLEDGEMENTS

This research was supported by the Key Project of Developing Agriculture through Science and Technology of Shanghai Municipal Agricultural Commission, China (Grant No. 2010-1-1), Shanghai Science and Technology Development Funds, China (Grant No. 11QA1405900) and the National High-Tech Research and Development Program of China (Grant No. 2012AA101102).

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