Long-Term No-Tillage Direct Seeding Mode of Water-Saving and Drought-Resistance Rice with Double Low Rapeseed

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Abstract: To study the effects of long-term no-tillage direct seeding mode on crop yield and the soil physiochemical properties in a rice/rapeseed rotation system, a comparative experiment with a water-saving and drought-resistance rice (WDR) variety and double low rapeseed variety was conducted under no-tillage direct seeding mode (NTDS) and conventional tillage direct seeding mode (CTDS) for four years, using CTDS as the control. Compared with CTDS, the actual 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 of 6.49% at the fourth year. Correlation analysis showed that the panicle length was significantly related to the actual yield of WDR. Compared with CTDS in terms of the soil properties, the pH of NTDS decreased every year, whereas the contents of soil organic matter and total N of the NTDS increased. The NTDS mode is propitious to improve the paddy soil fertility in the top layer (0–5 cm). In the top 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 soil bulk, contents of soil organic matter, and total N increased, whereas the available N and K decreased. In summary, NTDS increased the rice yield, and could improve the paddy soil fertility of the top layer.

Key words: no-tillage; direct seeding; crop yield; soil properties; water-saving and drought-resistance rice

No-tillage is currently one of the major farming patterns researched and promoted in the world. It is widely used in foreign countries but has a relatively slow development in China (Tang and Zhang, 1996; Bhushan et al, 2007). The rice no-tilling culture is more common in Asia, wherein the main method used is no-tillage direct seeding (NTDS) (Pandey and Velasco, 1999). In China, two methods are mainly used, namely, seedling-broadcast with no-tillage and NTDS. The Yangtze River Basin is the major area for China’s rice and rapeseed production, mainly adopting the rice/rapeseed rotation cropping system. In recent years, farming initiative has declined because of the factors of market, technology, and labor transfer. During winter, farmland abandonment is a serious issue. 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 from NTDS have been reported. However, studies on rice/rapeseed via no-tillage cultivation are rare. NTDS of rice in one season showed that it is conducive to nutrient fortification in the soil surface layer, and does not lead to soil acidification. This method can also gain more yield than conventional tillage direct seeding (CTDS) (Feng et al, 2006; Wu et al, 2007). In the present study, the water-saving and drought-resistance rice (WDR) (Luo, 2010) and double low rapeseed varieties, both of which are suitable for NTDS, were chosen for objects of study. Rice/rapeseed rotation was conducted for a number of successive years using NTDS to determine the yield formation characteristics of rice and physical and chemical changes of soil. This study was designed to provide a basis for the formation of a no-tillage cultivation technology system.

MATERIALS AND METHODS
Tested materials

The rice variety used in this study is a type of WDR, namely, hybrid variety Hanyou 3, which is characterized by water- and fertilizer-saving properties, good lodging resistance, high and stable yield, high quality, wide adaptability, and simple cultivation (Yu et al., 2005). The rapeseed is a middle maturity double low variety, namely, Huyou 17, which is characterized by a rigid stalk, fertilizer tolerance, good lodging resistance, high yield, good performance against viral diseases, strong sclerotinia resistance in the mature 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 three successive years (2007–2010) in Zhuanghang Integrated Experiment Station of Shanghai Academy of Agricultural Science. The experimental field was originally an abandoned agricultural land during new rural construction, and rice/rapeseed tillage cultivation began in 2004. The physical and chemical 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: (1) NTDS mode and (2) CTDS mode (control). Each type of treatment was repeated three times. The area of each plot was 0.2 hm².

The rice was sown annually on May 30, and the seeding rate was 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% fungicide Junchongqing, 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. Once the seedlings were in the three- to four-leaf stages, seedlings were transplanted to fill the missing ones and single seedlings. The rapeseed was sown annually on October 10. Before sowing, a herbicide was administered to the field. The seeds were sown via direct seeding using a no-tillage drill seeder with a seeding rate of 4.5 kg/hm². In the four- to five-leaf stages, seedlings were transplanted to fill the missing ones and single seedlings with a density of about 2 × 105 plants/hm².

The fertilization management standard of WDR was total nitrogen quantity of 240 kg N/hm², which was applied four times using a base fertilizer (35%), seedling fertilizer (15%), tillering fertilizer (35%), and panicle fertilizer (15%). The base fertilizer for the field was applied on May 26. The seedling fertilizer was applied on July 4. The tillering fertilizer was applied on July 16, and the panicle fertilizer was applied after the jointing-booting stage. Phosphorus and potassium fertilizers were applied once as a base fertilizer at 100 (count by P₂O₅) and 90 kg/hm² (count by K₂O), respectively. Water-saving irrigation was used as the water management mode. 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.

The fertilization management standard of rapeseed was total nitrogen quantity of 240 kg/hm² (count by pure N), which was applied using 50% base fertilizer, 20% seedling fertilizer, and 30% bud stage fertilizer. Phosphorus and potassium fertilizers were applied once as a 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.

Crop yield and analysis of the physical and chemical properties of soil

Upon maturity of the rice crop, five positions diagonal from each plot were chosen for sampling. Five single plants from each position were used for indoor test species, and the average was obtained to analyze the yield characteristics. A calculation method was used to determine the actual plot output. A rice combine harvester (Kubota PRQ-488) was used for harvesting in accordance with plot distinction. The rice was dried, searched for impurities to be removed, and weighed. A rapid moisture meter was used to determine moisture. Use the rapid moisture meter for determination of moisture, and transfer them into standard yield as the plot actual output by 13.5% of moisture content.

Table 1. Agrochemical characteristics 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>
After the 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 to test their physical and chemical properties. Soil pH was determined using potentiometry (immersion method) with a water-soil ratio of 5:1. The organic matter content was measured using potassium dichromate oxidation, which is an external heating method. The total nitrogen content was measured by the semi-micro Kjeldahl method, and available nitrogen was detected by alkaline hydrolysis diffusion. Available phosphorus was measured by sodium bicarbonate extraction-Mo-Sb colorimetry, whereas available potassium was measured by ammonium acetate extraction–flame photometry.

The collected data were processed using EXCEL. S-Plus software was used for ANOVA, correlation analysis, and path analysis.

RESULTS

Agronomic characters and yield performance of Hanyou 3 cultivated by these two modes

The mean values of the yield-related traits and harvest index of Hanyou 3 under NTDS and CTDS are shown in Table 2. In the comparison of the average plant heights, all plant heights of NTDS were lower than those of the control group for the first three years (2007–2009). The average plant height under NTDS in 2010 was higher than that under CTDS but not significantly. No significant difference was observed in the panicles of per unit area and average panicle length for four years between the two groups. The number of spikelets per panicle under NTDS was lower than that of the control group in 2007 and 2008. However, an opposite trend was observed in 2009 and 2010. During 2007, the difference was significant between NTDS and CTDS. The maturation rate under NTDS was lower than that of the control group in 2007 and 2008, and the difference between the treatment and control groups in 2007 was highly significant. The maturation rate under NTDS was higher than that of the control group in 2008 and 2010, and the difference between the treatment and control groups in 2008 was highly significant. The 1000 grain weight under NTDS was higher than that of the control group for four consecutive years, and the
difference reached a significant level in 2010. In the first year (2007), the single plant yield and actual yield of NTDS were lower than those of the control group, with a highly significant difference in the actual yield. In the next three years, the yield of NTDS was higher than that of the control group. In the fourth year, the actual yield of NTDS was 562.32 kg/hm$^2$ higher than that of the control group. The harvest index of NTDS was lower than that of the control group in 2008 but higher than that of the control group in 2009 and 2010.

Correlation analysis on yield trait and actual yield showed that the spike length and yield of Hanyou 3 were significantly related to each other under NTDS, and the correlation coefficient was 0.94.

**Influence of rice-oilseed rape crop rotation continuous no-tillage on soil physical and chemical properties**

**Influence on soil bulk density**

The capital letters above the figures represent significant differences at the 0.01 level, and the small letters above the figures represent significant differences at the 0.05 level.

Fig. 1-A shows that the bulk density of the surface soils (0–5 cm) decreased, whereas the bulk density of the subsurface soils (5–20 cm) increased with longer 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 both years. 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 the fourth year (2010). This result indicates that long-term no-tillage under paddy-upland rotation resulted in porous surface soil and subsurface soil compaction.

**Influence on soil pH**

![Fig. 1. Changes soil characters in different no-tillage years. A, Soil bulk; B, pH; C, Organic matter content; D, Total N content.](image)
Analyses on the pH of the soil surface (0–5 cm) and subsurface (5–20 cm) showed that the soil pH under the two tillage methods decreased with increasing cultivation time, and the pH of the no-tillage soil was even lower than that of the control group (Fig. 1-B). Compared with the control group, the pH of the surface and subsurface soils decreased by 0.14 and 0.31 units, respectively, in the fourth year of no-tillage. The subsurface soil exhibited the largest difference.

Influence on soil organic matter and total nitrogen content
Soil organic matter and total nitrogen content are important indicators of soil fertility level. With the increase in the no-tillage years, the soil organic matter content increased. Compared with 2007, the soil organic matter contents in 2009 and 2010 increased by 6.18% and 11.24%, respectively, whereas that of the control group did not change significantly. The organic matter in the no-tillage soil surface rapidly increased, which was higher than that of the control group, 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 group (Fig. 1-C).

With the increase in no-tillage years, the total nitrogen contents in both the surface and subsurface soils were higher than that of the control group. ANOVA showed that the nitrogen content in the subsurface soil was significantly higher than that of the control group in the third year, but the difference in the fourth year was insignificant (Fig. 1-D). Compared with 2007 (Fig. 1-A), the total nitrogen content in the no-tillage soil increased, but the total nitrogen content in the control group did not significantly change.

Influence on quick-acting nitrogen, available phosphorus, and quick-acting potassium in the soil
The measurement results of quick-acting nitrogen, available phosphorus, and quick-acting potassium in the soil surface show (Fig. 2) that the available nitrogen content of the no-tillage soil was higher than that of the control. The difference in 2009 was highly significant, whereas the difference in 2010 was at the significant level. The differences between the contents of available phosphorus and quick-acting potassium in the no-tillage surface soil and control groups were not significant. The contents of available phosphorus and quick-acting potassium in both groups increased with increasing farming time.

With increasing farming time, the contents of available nitrogen in the subsurface of NTDS and CTDS showed a downward trend compared with those in 2007. However, the contents of available nitrogen decreased faster, whereas the changes in available phosphorus and potassium showed no obvious trends. In 2009 and 2010, the available nitrogen, phosphorus, and potassium contents in the soil subsurface of NTDS were lower than those of CTDS. The available nitrogen contents in 2009 were significantly different. The available phosphorus contents in 2010 were significantly different. The difference in available potassium contents in NTDS in 2010 was highly significant.

DISCUSSION
Impact of NTDS and CTDS on the rice yield
The results of this four-year continuous cropping experiment show that the plant height, floret number of per panicle, seed setting rate, and 1000 kernel weight of Hanyou 3 all changed after NTDS cultivation in water farming, whereas the effective panicles per unit area and panicle length did not significantly alter. In the early stage of NTDS, the yield-related traits of Hanyou 3 were lower than those of CTDS, with a yield loss of 8.10%. As the no-tillage time increased, the effective panicles per unit area and panicle length did not significantly alter. In terms of plant height, floret number of per panicle, seed setting rate, and 1000 kernel weight, NTDS demonstrated advantages, and the final yield increased and exceeded that of CTDS. Different tillage methods resulted in changes in rice yield and its source-sink characteristics, which was 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 were significantly correlated under NTDS. The crop yield of CTDS showed a declining trend with increasing rotation time, whereas that of NTDS showed an increasing trend yearly. However, the difference was not significant, and these results require further study.

Impact of no-tillage on the physical and chemical properties 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 NTDS 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., 2000; 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 year of NTDS, which significantly differs from CTDS. Long-term no-tillage results 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 is unsuitable.

The pH of the soil 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 of rice from conventional tillage, which leads to the pH changes in the rhizosphere and non-rhizosphere soil of no-tillage farmland. In this study, all the pH values of the NTDS soil were lower than those of the CTDS soil. No-tillage resulted in soil acidification. The pH of the 0–5 cm surface soil continuously decreased, but the pH changes of the soil 5–20 cm below the surface 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 activity of surface-level roots increased.

In terms of soil nutrients, the contents of surface organic matter, total nitrogen, and available nitrogen in the no-tillage soil surface increase yearly; the
nutrients gather in the surface soil, which is similar to the results of previous studies (Zhang et al, 2000; Jiang et al, 2007; Lan et al, 2009). However, in this study, the variation in available phosphorus and potassium was not obvious presumably because of the no-tillage years. The contents of available nitrogen, phosphorus, and potassium in the subsurface soil decreased, which may be related to the cultivation patterns of WDR. Thus, the changes in total phosphorus and total potassium contents require further investigation.

Weed control and fallen paddy sprouting problem in NTDS soil

Under the experimental conditions mentioned in this article, more weeds were observed on the continuous 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 the use of herbicide were increased to prevent weeds in the trials. The author is currently engaged in the further study of weed occurrence and control problems in rice and rapeseed farmland under NTDS. 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. Handling methods to deal with the fallen paddy 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 models 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. One harvest a year per region has met the promotion conditions, and two crops a year per region also achieved good results. This study provides a strong basis for the promotion of NTDS.

REFERENCES

Du Xing-bin, et al. No-Tillage Direct Seeding Mode in Rice/Rapeseed Rotation System
