Effects of no-till and rice varieties on nitrogen and phosphorus balance in rice fields

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Abstract

Background: Nutrient balance in rice paddy fields can change under different tillage management practices; however, the extent of the change may differ for various rice varieties. A field experiment was conducted over 2 successive years from June 2016 to June 2018 to clarify the effects of different tillage methods and rice varieties on nutrients remaining in the surface soil and those taken up by the rice. There were four tillage/rice variety treatments: no-till/japonica rice (NTJ), no-till/glutinous rice (NTG), conventional tillage/japonica rice (CTJ), and conventional tillage/glutinous rice (CTG) with three replicates of each.

Results: The tillage method and rice variety had interactive effects on the surface balance of nitrogen (N) and phosphorus (P). After the 2-year experiment, total N and P pools in the 20 cm surface soil layer were highest under the NTJ treatment ($4757.0 \text{ kg N ha}^{-1}$, $2428.5 \text{ kg P ha}^{-1}$) and lowest under the CTG treatments ($4726.3 \text{ kg N ha}^{-1}$, $2412.0 \text{ kg P ha}^{-1}$). Under no-till conditions, japonica rice had higher grain yield but lower straw biomass than that of glutinous rice. NTG treatment significantly increased the N and P content in rice grains and straw. The environmental losses of N and P in the rice fields mainly occurred during the rice season. Based on nutrient balance estimation, N losses in the NTJ, NTG, and CTJ treatments were reduced by $15.03 \text{ kg N ha}^{-1}$, $11.55 \text{ kg N ha}^{-1}$, $6.72 \text{ kg N ha}^{-1}$, respectively, as compared with that of the CTG treatment. The corresponding P losses were reduced by $8.02 \text{ kg P ha}^{-1}$, $7.84 \text{ kg P ha}^{-1}$, and $3.96 \text{ kg P ha}^{-1}$. In terms of economic benefits, NTJ also resulted in the highest actual income ($18896.5 \text{ yuan ha}^{-1}$) and the highest ratio of production to investment (6.40).

Conclusion: No-till was more likely to maintain soil N and P nutrients than conventional tillage, and this advantage was most significant when planting japonica rice. In addition, no-till was conducive to N and P uptake by rice, but only japonica rice exhibited increased grain yield. Consequently, the NTJ treatment was recommended.

Background

In recent years, the adoption of the no-till agricultural method has occurred for over approximately 125 million hectares worldwide, which is equivalent to 9% of the global arable land [1]. While minimising soil disturbance, no-till can reduce soil erosion [2], improve soil aggregation ability [3, 4], retain soil moisture [3, 5], and improve soil structure [2, 6]. Consequently, it can also increase crop yields, reduce economic inputs to the agricultural production systems [7], and achieve significant ecological benefits [3, 8]. However, its applicability in different farming contexts is highly debated. Some studies have demonstrated that no-till only increased the nutrient content of the soil in the top 5 cm layer. The lack of soil mixing during long-term no-till practices will lead to nutrient layering [9–11], and may not ensure an increase in crop yield. In addition, no-till will cause ammonia volatilisation in fertilisers, reduce the fixation of phosphorus (P) in the soil, and trigger the loss of fertiliser via runoff [3], thereby lowering the utilisation efficiency of the fertiliser. Therefore, it is necessary to explore whether no-till is beneficial and can improve the nutrient balance, as well as crop yield.

Knowledge of the nitrogen (N) and P balance (fertiliser inputs – crop uptake and harvest removal) is very important to understanding nutrient cycling in an agricultural production system [12–14]. Negative N and P balance (input < output) in the system will reduce soil fertility and crop yield, while a surplus of N and P (input > output) in the system may increase the risk of N and P losses [13–15]. Numerous studies have been conducted on the effects of different rice varieties on the uptake and utilisation efficiency of N and P, and studies have shown that the N and P uptake characteristics is different under various varieties [16–18]. Generally, for varieties with high N and P utilisation, the rice seasonal nutrient consumption is relatively large and less residual nutrients are left in the soil at the end of the rice season [19]. Because the variety of rice affects the uptake of N and P, it can be inferred that rice varieties may affect the N and P balance in paddy fields. However, to date, there is a lack of information on the effects of rice varieties combined with that of tillage methods on nutrient balance.

In this study, we investigated the surface balance of N and P under different tillage methods and rice varieties by measuring N and P concentrations in soil, rice grains, and straw. In addition, the yield and economic benefit from different treatments were also determined. The main objective of this study was to test our hypothesis that no-till can improve the surface nutrient balance but may differ for various rice varieties.

Materials And Methods

Site characterisation

The site that this research focused was situated in Jingshan Town, Yuhang District, Hangzhou City, Zhejiang Province, at $30^{\circ}24'N$, $120^{\circ}6'E$. The site has a subtropical monsoon climate, and the annual rainfall is 1,440 mm.

Experimental design

The field experiment was conducted at over 2 successive years. We divided the 2-year experiment into four parts: the first rice season (R1, June 2016–October 2016), first fallow season (F1, October 2016–June 2017), second rice season (R2, June 2017–October 2017), and second fallow season (F2, October 2017–June 2018). The rice season and fallow season were combined into one planting season, which was defined as the first planting season (T1, June 2016–June 2017) and second planting season (T2, June 2017–June 2018). The two tillage methods (no-till and conventional tillage) were assigned as the main plot factors, and the two rice varieties (japonica rice, Xiushui-134 and glutinous rice, Zhenuo-65) were the subplot factors. The experiments were established in a randomised complete block split-plot design with four treatments: no-till/japonica rice (NTJ), no-till/glutinous rice (NTG), tillage/japonica rice (CTJ), tillage/glutinous rice (CTG), with three replicates each. Each of the 12 plots had an area of 5 m × 3 m.

Each year, 90 kg ha⁻¹ of K₂O, 100 kg ha⁻¹ of P₂O₅, and 250 kg N ha⁻¹ fertiliser were applied during the rice season, and the straw was returned to the field after the rice harvest. The physical and chemical properties of the topsoil layer (0–20 cm) of the rice field before the experiment are shown in Table 1. The irrigation method was wet and dry alternating irrigation [20]. The nylon membranes were used to coat ridges to reduce lateral seepage between adjacent plots.

Soil sampling and analyses

Parallel soil samples were taken from three points in each plot. All soil samples were air dried, ground, and sieved through a 100-mesh screen. Then the soil samples were used for the determination of basic physical and chemical properties. Before rice harvest, 1 m² of rice plants were taken from each plot. After air-drying, the rice was threshed, and the straw and rice were crushed in a plant mill for testing.

The soil pH (soil/water ratio of 1:5) was measured using a glass electrode pH meter (PHS-3C, Shanghai). The bulk density of the soil was determined using the ring tool method. The determination of soil cation exchange capacity (CEC) was referred to the study of Liang et al. [21]. Soil texture was determined using the method recommended by the Chinese Soil Society (i.e. pipette method). Total N in the soil, grain, and straw were determined by elemental analyser (Vario MAX CNS, Elementar, Germany). Soil total P was digested with an H₂SO₄-HClO₄ solution, whereas rice and straw were digested with an H₂SO₄-H₂O₂ solution. Both were evaluated using the molybdenum-blue colorimetric method. All reagents used were purchased from Sinopharm Chemical Reagent Co., Ltd.

Data processing and analysis

Soil N and P stock were calculated by soil bulk density and N and P concentrations in soil [22].

$B_{R(N/P)} = \text{N/P content in the initial soil} + \text{N/P fertiliser} - \text{Soil N/P stocks at } R_E - \text{Rice grain N/P content} - \text{Rice straw N/P content}.$

$B_{T(N/P)} = \text{N/P content in the initial soil} + \text{N/P fertiliser} - \text{Soil N/P stocks at } T_E - \text{Rice grain N/P content} - \text{Rice straw N/P content}.$

$B_{R(N/P)}$ and $B_{T(N/P)}$ indicated the surface balance of N/P in the rice field during the rice season and planting season, respectively. R_E and T_E indicated the end of the rice season (October 2016 and October 2017) and the end of the planting season (June 2017 and June 2018) in this experiment, respectively.

Microsoft Excel 2016, and Origin 8.0 software were used to plot and process the data. The effects of no-till/conventional tillage, japonica rice/glutinous rice, and their interactions on the N and P concentrations in soil, rice grain, straw, and yield analysed by a two-way ANOVA with SPSS Statistics 20.0.

Results

Residual N and P in soils at the end of rice season

In all the treatments, soil total N increased by the end of the 2-year experiments than that of the initial state. Planting japonica rice increased soil total N in the 0–20 cm layer (Fig. 1a). The improvement rates for total N under different treatment methods were as follows: NTJ (2.63%), CTJ (2.37%), NTG (2.11%), and CTG (2.05%). At the end of 2 years, the total N content was the highest under the NTJ treatment (1.95 g kg⁻¹), and lowest under the CTG treatment (1.93 g kg⁻¹). Based on the increase in the soil total N content during the fallow season and the rice season, the means of total N content increased in fallow seasons F₁ and F₂ by 5.25 mg kg⁻¹ and 7.00 mg kg⁻¹ in the 2-year experimental period. The average increase in soil total N content of R₁ and R₂ was 10.80 mg kg⁻¹ and 20.5 mg kg⁻¹, respectively.

Compared with the total P content in the initial soil sample (983 mg kg⁻¹), the total P content in the soil increased annually and japonica rice contributed to the increase (Fig. 1b). The improvement rates for total P under different treatment methods were NTJ treatment (1.73%), CTJ treatment (1.53%), NTG treatment (1.12%), and CTG treatment (0.92%). After 2-years experiments, the total P content in the paddy soil was the

highest (1000 mg kg⁻¹) in the NTJ treatment and the lowest (992 mg kg⁻¹) in the CTG treatment. The average values of the total P content increase in F1 and F2 were 1.75 mg kg⁻¹ and 1.80 mg kg⁻¹, respectively. The average values of the soil total P content increases in R1 and R2 were 3.50 mg kg⁻¹ and 6.00 mg kg⁻¹, respectively. This indicated that the increase in soil total P during the rice season was higher than that during the fallow season.

Both no-till and the japonica rice variety contributed to the increase of residual N and P in the soils at the end of rice season, but the difference was not significant ($p > 0.05$) (Fig. 2a, 2b). The increase in soil N and P stocks during the rice season was significantly higher than that during the fallow season ($p < 0.05$). Compared with the initial N stocks in the rice field (4613.1 kg N ha⁻¹), the increase rate for the N pool in the rice field soil under the different treatments was: NTJ (3.12%) > CTJ (2.69%) > NTG (2.67%) > CTG (2.45%). At the end of the two rice seasons (R_{1E} and R_{2E}), the increases in soil N stocks in the rice fields were 42.34 kg N ha⁻¹ and 62.56 kg N ha⁻¹, respectively, and at the end of the two fallow seasons (F_{1E}, F_{2E}) was 11.85 kg N ha⁻¹ and 9.35 kg N ha⁻¹, respectively.

Compared with the P stocks in initial rice fields soil (2400.6 kg P ha⁻¹), at the end of 2-year experiment, the increase rate in P stocks in the rice fields soil based on different treatments were: NTJ (3.12%) > CTJ (2.69%) > NTG (2.67%) > CTG (2.45%). At the end of the two rice seasons (R_{1E} and R_{2E}), the increase in soil P stocks in the rice fields was 5.44 kg P ha⁻¹ and 10.42 kg P ha⁻¹, respectively, and at the end of the two fallow seasons (F_{1E}, F_{2E}) was 2.56 kg P ha⁻¹ and 1.81 kg P ha⁻¹, respectively.

Nutrient uptake by rice tissues

The no-till treatment with glutinous rice did not have a significant effect on the total N content of the rice straw ($p > 0.05$), but it significantly increased the total P content in the rice straw and total N and total P content in rice grains ($p < 0.05$). In addition, the content of total N and total P in rice grains was much higher than that in rice straw ($p < 0.05$) (table 2). During the 2-year experimental period, the change in total N content in rice straw and grain remained consistent under the different treatment conditions. The order of total N content in rice straw treated during different periods was NTG (R_{1E}, 8.20 g kg⁻¹; R_{2E}, 8.31 g kg⁻¹) > CTG (R_{1E}, 8.16 g kg⁻¹; R_{2E}, 8.27 g kg⁻¹) > NTJ (R_{1E}, 8.11 g kg⁻¹; R_{2E}, 8.21 g kg⁻¹) > CTJ (R_{1E}, 8.20 g kg⁻¹; R_{2E}, 8.31 g kg⁻¹) (Table 2). The total N content of straw treated with NTG remained the highest (8.20 g kg⁻¹–8.31 g kg⁻¹). Compared with the CTJ treatment, the total N content of straw increased by 1.61%–2.09%. No significant difference in the total N content of rice straw differed among the different tillage method and rice variety treatments ($p > 0.05$). However, the total N content of the grains under NTG treatment increased by 6.79%–9.77% than the CTJ treatment, which was significantly different ($p < 0.05$).

At R_E, the order of total P content in rice straw under different treatment conditions was NTG > NTJ > CTG > CTJ, whereas the order of total P content in rice grains was NTG > CTG > CTJ > NTJ. The total P content of rice straw (1.22 g kg⁻¹–1.25 g kg⁻¹) and grains (2.35 g kg⁻¹–2.38 g kg⁻¹) under the NTG treatment remained the highest. The content of total P in rice straw (1.03 g kg⁻¹–1.06 g kg⁻¹) under the CTJ treatment and that of rice grains (2.11 g kg⁻¹–2.15 g kg⁻¹) under the NTJ treatment were the lowest. Compared with CTJ, NTG significantly increased the total P content in rice straw by 17.92%–18.45%, and the total P content of rice grain treated with NTG was 10.70%–11.37% higher than that treated with NTJ, both of them showed a significant difference ($p < 0.05$).

The no-till and japonica rice treatment was beneficial to improving the N content of rice grains. In the 2-year experiment, N accumulation in rice grains showed an upward trend (Fig. 3a), and P accumulation in rice grains showed a similar trend (Fig. 3b). The N and P accumulation in the no-till rice fields were 2.23 kg N ha⁻¹ and 0.14 kg P ha⁻¹ higher than those in the conventional tillage treatment, respectively. Japonica rice increased the N accumulation of the rice grains by 2.65 kg N ha⁻¹ and P accumulation by 0.37 kg P ha⁻¹, as compared with that of glutinous rice. Both of no-till and glutinous rice variety contributed to the increase in P accumulation in rice straw. At the end of the second rice season (October 2017), the N and P accumulation in rice straw showed an upward trend (Fig. 4a, 4b). The N and P accumulation in rice straw under the NTG treatment was the highest (70.30 kg N ha⁻¹, 10.58 kg P ha⁻¹), and was 9.38% and 26.40% higher than that of CTJ treatment, respectively, all of which were significantly different ($p < 0.05$). In the 2-year experiment, the no-till treatment increased the N and P accumulation in rice straw by 1.02 kg N ha⁻¹ and 0.37 kg P ha⁻¹, respectively, as compared with the conventional tillage treatment. The accumulation of N and P in rice straw in the glutinous rice treatment was 2.08 kg N ha⁻¹ and 0.53 kg P ha⁻¹ higher than those of japonica rice.

There was a slight improvement in rice grain yield in the no-till treatment ($p > 0.05$); however, rice variety had a significant effect on the improvement of rice grain yield ($p < 0.05$). The grain yield of japonica rice was higher than that of glutinous rice. At the end of the two rice seasons, the grain yield of rice treated with the NTJ treatment was highest (R_{1E}: 7090 kg ha⁻¹; R_{2E}: 7332 kg ha⁻¹) (Table 3), and yield was increased by 11.23% (R_{1E}) and 11.62% (R_{2E}), as compared with that of the corresponding NTG treatment, respectively. The yield of grain in the CTJ treatment was the second and was 11.17% (R_{1E}) and 11.24% (R_{2E}) higher than that of the CTG treatment for the same period. However, the NTJ treatment only increased grain yield by 1.04%–1.34% compared with that of the CTJ treatment, whereas the NTG treatment increased yield by only 1.00% compared with that of the CTG treatment. The no-till treatment improved the yield of rice straw (0.03%–1.69%), but the

difference was not significant ($p > 0.05$). However, rice variety and the yield of rice straw were significantly correlated ($p < 0.05$). The yield of rice straw in the NTG treatment was always the highest (8292 kg ha⁻¹–8360 kg ha⁻¹) (Table 3) and was 2.51% (R_{1E}) and 1.54% (R_{2E}) greater than the corresponding NTJ treatment. The yield of rice straw in the CTG treatment was the second highest, and a significant difference occurred between the CTG and CTJ treatments ($p < 0.05$). There was a greater yield of rice straw (2.83% [R_{1E}] and 2.99% [R_{2E}]) under the CTG than CTJ treatment. The yield under the NTG treatment only increased by 0.03%–0.89% compared with that of the CTG treatment, whereas the yield in the NTJ treatment increased by only 1.20%–1.69% compared with that of the CTJ treatment.

Soil nutrient balance analysis

By calculating the N/P balance in the rice fields during two consecutive seasons, it was found that no-till and japonica rice were conducive to improving the in-situ reduction of N and P in the rice fields (Tables 4 and 5). The environmental loss of N and P during the planting season was lower than that during the rice season. Compared with the rice and planting seasons in the first year, the N and P environmental losses decreased during the rice and planting seasons in the second year.

The environmental losses of N and P in the rice fields mainly occurred during the rice season. At different time periods, the environmental losses of N and P in rice fields treated with CTG were the largest. After 2-year experiments, N losses in the NTJ, NTG, and CTJ treatments were reduced by 15.03 kg N ha⁻¹, 11.55 kg N ha⁻¹, and 6.72 kg N ha⁻¹, respectively, as compared with that of the CTG treatment. The corresponding P losses were reduced by 8.02 kg P ha⁻¹, 7.84 kg P ha⁻¹, and 3.96 kg P ha⁻¹.

Economic benefits under different tillage methods and rice varieties

From the perspective of economic benefits, the production cost of the no-till treatment was lower than that of conventional tillage method (Table 6). The no-till method saved 1500 yuan ha⁻¹ for machine tillage and the same cost for fertiliser and rice seeds was assumed (the difference between the prices of the two rice seeds was negligible). The average price of japonica rice seeds (Xiushui-134) was approximately 2640 yuan t⁻¹, and the average price of glutinous rice seeds (Zhenuo-65) was approximately 2900 yuan t⁻¹ [23]. The NTJ treatment had the highest output-investment ratio (6.40), and the real income per hectare was 18896.5 yuan. The NTJ treatment increased revenue by 2,033.9 yuan (12.06%) compared with that of the CTG treatment, 1,764.0 yuan (10.30%) compared with that of the CTJ treatment, and 317.3 yuan (1.71%) compared with that of the NTG treatment.

Discussion

There have been some controversies regarding the increase in yield with the no-tillage practice, which may be related to planting conditions [24–27]. In our study, although the positive effect on the yield of rice from the no-till method was small, the practice was deemed successful at maintaining a comparable or higher rice yield, as well as nutrients in the rice soil under certain conditions. We found that both the grain yield and the growth rate of grain under the NTJ practice were highest, which indicated that different tillage methods and rice varieties had an effect on rice yield. Our results are supported by the finding of previous studies [7, 28, 29]. Through the interactive analysis of the three influencing factors of tillage method, rice variety, and planting time on grain yield and straw biomass, we found that the tillage methods had a non-significant effect on grain yield and straw biomass ($p > 0.05$), but rice variety had a significant effect on rice yield ($p < 0.05$), which is consistent with the results of Qin et al. [30]. Rice yield is closely related to factors, such as grain number per panicle, 1000-grain weight, seed setting rate, and plant height [28, 31]. The yield of rice grain for japonica rice was the highest, and the biomass of straw grown with glutinous rice was the highest, indicating a close relationship between rice variety and rice yield. In addition, the nutrient uptake capacity of japonica rice was also higher, which may be concluded that the rice yield is related to the uptake of N and P by rice. This study showed that total N and total P in rice grains were higher than that in rice stalks, which indicated a greater availability of N, P, and other elements to the grains of the various rice tissues. Under the NTG treatment, the content of total N and total P in rice straw and rice grains were the highest. The above results indicated that the accumulation of dry matter, N, and P in rice was affected by rice variety and tillage conditions [32, 33].

In terms of nutrient uptake, the no-till method improved the physical and chemical properties of paddy soil and effectively maintained soil nutrients, which was consistent with the nutrient demand of rice [29, 34]. Crop straw is rich in carbon, N, P, potassium, and other nutrients. Therefore, straw mulching is an important nutritional supplement, thereby increasing the uptake of nutrients by crops. In addition, returning straw can improve soil fertility, improve soil physical and chemical properties, and enhance microbial characteristics of the soil. As important technical measures in agricultural production, the combination of a no-till system and straw mulching not only improved soil water, fertiliser, and gas conditions [5, 35, 36], but also increased surface coverage and reduced surface runoff [35, 37–39]. The comprehensive effects of management measures such as nutrients, water, and fertiliser were conducive to an increase in rice yield.

The no-till practice reduced the frequency of soil disturbance and caused less damage to the soil structure, which reduced the losses of soil N and P during erosion. Conversely, conventional tillage methods break up soil aggregates and reduce the stability of aggregates [40, 41].

Therefore, the soil N and P content of rice fields under no-till management were higher. Caron et al. [42] reported that the porosity index in soil under no-till management was three times that of conventional tillage. The increase of large pores in the vertical direction in no-till soil could enhance water permeability in the soil profile. Under the conditions of no-till management with straw mulching, the rice root system development was better, which improved the utilisation of rice field water and soil nutrients, making it easier for grains to obtain nutrients, thereby increasing yield [43–45]. However, the effect of no-till management on N and P accumulation in grain and straw was small, which could have possibly occurred because no-till and straw mulching reduced the soil nutrient output in most non-irrigated areas. The contents of soil total N and total P during the rice season increased more than that in the fallow season, and the stocks of N and P were also higher. The annual environmental losses during the planting season for 2 consecutive years were less than those during the rice season, mainly because of the effects of fertilisation during the rice season and the return of straw to the field during the fallow season. Although rice straw residues contained some N and P, other researchers have pointed out that it takes time for straw mulching to release nutrients into the soil [45]. Therefore, there were lower environmental losses during the planting season because the soil during the rice season could acquire more nutrients through fertilisation and straw mulching [46].

The results of the 2-year experiment showed that the NTJ treatment had the best effect on N and P emission reduction in rice fields, whereas the CTG treatment had the lowest ability to reduce N and P emission from the rice fields. This was mainly because the losses of N and P from rice fields were closely related to tillage methods, rice yield, fertiliser application, rainfall, and other factors. With the growth of rice, the amount of N and P in the soil increased, indicating that both N and P in the soil were effectively fixed [10], which possibly occurred because the no-till method changed the physical and chemical properties of the soil, increased soil porosity, and affected the formation and path of runoff, thereby reducing surface runoff and nutrient loss [6, 47–49].

From the perspective of economic benefits, the NTJ method had the highest production-to-investment ratio, and different tillage methods (no-till/conventional tillage) had a relatively large impact on the production costs. The production cost of the no-till treatment was lower than that of conventional tillage, and the yield of the no-till treatment of rice was slightly higher than that of the conventional tillage, indicating that no-till contributed to the increased economic benefits [31, 50].

One important issue is that although we did not consider the effect of rice residue retention on the N and P balance, it can still be shown that the no-till method could reduce soil nutrient loss while maintaining slightly higher yield relative to conventional tillage, thus, increasing environmental benefits. The comprehensive analysis showed that the no-till / japonica rice (Xiushui-134) contributed to the reduction of N and P losses in paddy fields and the improvement of grain yield, which is worthy of promotion.

Conclusion

Our study found that the no-till method was able to maintain more soil N and P nutrients than conventional tillage, and this advantage was more significant when planting japonica rice. In addition, the no-till method was conducive to the N and P uptake by rice, and glutinous rice in the rice fields under the no-till treatment effectively increased N and P content in straw and grain, but no-till had no significant effect on the increase in rice yield. However, rice varieties were significantly correlated with rice yield, and japonica rice improved rice grain yield. The NTJ treatment reduced the environmental losses of N and P in rice fields. Herein, we synthesised results and recommend the NTJ treatment to improve the nutrient balance.

Declarations

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Authors' contributions

XL designed the experiment, XL and YC performed the sampling and analysis, JY accomplished manuscript. All authors were involved in revising the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data sources are provided in “Material and methods”, as well as in “Results”.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Abbreviations

NTJ: no-till/japonica rice planting; NTG: no-till/glutinous rice planting; CTJ: conventional tillage/japonica rice planting; CTG: conventional tillage/glutinous rice planting;

R₁: the first rice season: (June 2016-October 2016); R₂: the second rice season (June 2017-October 2017); R_{1E}: the end of the first rice season; R_{2E}: the end of the second rice season.

F₁: the first fallow season (October 2016-June 2017); F₂: the second fallow season (October 2017-June 2018); F_{1E}: the end of the first fallow season; F_{2E}: the end of the second fallow season.

T₁: the first planting season (June 2016-June 2017); T₂: the second fallow season (June 2017-June 2018); T_{1E}: the end of the first planting season; T_{2E}: the end of the second planting season.

CEC: cation exchange capacity.

References

1. FAO (2011) Save and Grow. A Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production
2. Skaalsveen K, Ingram J, Clarke LE (2019) The effect of no-till farming on the soil functions of water purification and retention in north-western Europe: A literature review. *Soil Tillage Res* 189:98–109. <https://doi.org/10.1016/j.still.2019.01.004>
3. Sanaullah M, Usman M, Wakeel A, et al (2020) Terrestrial ecosystem functioning affected by agricultural management systems: A review. *Soil Tillage Res* 196:. <https://doi.org/10.1016/j.still.2019.104464>
4. Barreto RC, Madari BE, Maddock JEL, et al (2009) The impact of soil management on aggregation, carbon stabilization and carbon loss as CO₂ in the surface layer of a Rhodic Ferralsol in Southern Brazil. *Agric Ecosyst Environ* 132:243–251. <https://doi.org/10.1016/j.agee.2009.04.008>
5. Zhao C, Chai Q, Cao W, et al (2019) No-tillage reduces competition and enhances compensatory growth of maize (*Zea mays* L.) intercropped with pea (*Pisum sativum* L.). *F Crop Res* 243:107611. <https://doi.org/10.1016/j.fcr.2019.107611>
6. Vogeler I, Rogasik J, Funder U, et al (2009) Effect of tillage systems and P-fertilization on soil physical and chemical properties, crop yield and nutrient uptake. *Soil Tillage Res* 103:137–143. <https://doi.org/10.1016/j.still.2008.10.004>
7. Page KL, Dang YP, Dalal RC, et al (2019) Changes in soil water storage with no-tillage and crop residue retention on a Vertisol: Impact on productivity and profitability over a 50 year period. *Soil Tillage Res* 194:104319. <https://doi.org/10.1016/j.still.2019.104319>
8. Franchini JC, Debiassi H, Balbinot Junior AA, et al (2012) Evolution of crop yields in different tillage and cropping systems over two decades in southern Brazil. *F Crop Res* 137:178–185. <https://doi.org/10.1016/j.fcr.2012.09.003>
9. Niu Y, Cai Y, Chen Z, et al (2019) No-tillage did not increase organic carbon storage but stimulated N₂O emissions in an intensively cultivated sandy loam soil: A negative climate effect. *Soil Tillage Res* 195:104419. <https://doi.org/10.1016/j.still.2019.104419>
10. Page K, Dang Y, Dalal R (2013) Impacts of conservation tillage on soil quality, including soil-borne crop diseases, with a focus on semi-arid grain cropping systems. *Australas Plant Pathol* 42:363–377. <https://doi.org/10.1007/s13313-013-0198-y>
11. Martínez I, Chervet A, Weisskopf P, et al (2016) Two decades of no-till in the Oberacker long-term field experiment: Part I. Crop yield, soil organic carbon and nutrient distribution in the soil profile. *Soil Tillage Res* 163:141–151. <https://doi.org/10.1016/j.still.2016.05.021>
12. Stackpoole SM, Stets EG, Sprague LA (2019) Variable impacts of contemporary versus legacy agricultural phosphorus on US river water quality. *Proc Natl Acad Sci U S A* 116:20562–20567. <https://doi.org/10.1073/pnas.1903226116>

13. Chen MP, Chen JN (2007) Inventory of regional surface nutrient balance and policy recommendations in China. *Huanjing Kexue/Environmental Sci* 28:1305-1310 (in chinese)
14. Li J, Du Z, Yan C, Gao W (2018) Evolution of cropland nitrogen and phosphorus apparent balance in plateau region: A case study of Kunming City. *Acta Sci Circumstantiae* 38:4823-4830 (in chinese)
15. Hanrahan BR, King KW, Williams MR, et al (2019) Nutrient balances influence hydrologic losses of nitrogen and phosphorus across agricultural fields in northwestern Ohio. *Nutr Cycl Agroecosystems* 113:231–245. <https://doi.org/10.1007/s10705-019-09981-4>
16. Suriyagoda L, Sirisena D, Kekulandara D, et al (2020) Biomass and nutrient accumulation rates of rice cultivars differing in their growth duration when grown in fertile and low-fertile soils. *J Plant Nutr* 43:251–269. <https://doi.org/10.1080/01904167.2019.1676903>
17. Fan J, Zhang Y, Turner D, et al (2010) Root Physiological and Morphological Characteristics of Two Rice Cultivars with Different Nitrogen-Use Efficiency. *Pedosphere* 20:446–455. [https://doi.org/10.1016/S1002-0160\(10\)60034-3](https://doi.org/10.1016/S1002-0160(10)60034-3)
18. Wei H, Hu L, Zhu Y, et al (2018) Different characteristics of nutrient absorption and utilization between inbred japonica super rice and inter-sub-specific hybrid super rice. *F Crop Res* 218:88–96. <https://doi.org/10.1016/j.fcr.2018.01.012>
19. Zhang Q, Wang G (2006) Yield of inbred rice and hybrid rice and soil nutrient balance under long-term fertilization. *Plant Nutr Fertil Sci* 12:340-345 (in chinese)
20. Liang X, Chen Y, Nie Z, et al (2013) Mitigation of nutrient losses via surface runoff from rice cropping systems with alternate wetting and drying irrigation and site-specific nutrient management practices. *Environ Sci Pollut Res* 20:6980–6991. <https://doi.org/10.1007/s11356-012-1391-1>
21. Sparks DL, Page AL, Helmke PA, et al (1996) Cation Exchange Capacity and Exchange Coefficients
22. Chapuis Lardy L, Brossard M, Lopes Assad ML, Laurent JY (2002) Carbon and phosphorus stocks of clayey Ferralsols in Cerrado native and agroecosystems, Brazil. *Agric Ecosyst Environ* 92:147–158. [https://doi.org/10.1016/S0167-8809\(01\)00303-6](https://doi.org/10.1016/S0167-8809(01)00303-6)
23. China Grain and Oil Information Network. <http://www.chinagrain.cn/>
24. Van den Putte A, Govers G, Diels J, et al (2010) Assessing the effect of soil tillage on crop growth: A meta-regression analysis on European crop yields under conservation agriculture. *Eur J Agron* 33:231–241. <https://doi.org/10.1016/j.eja.2010.05.008>
25. De Vita P, Di Paolo E, Fecondo G, et al (2007) No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in southern Italy. *Soil Tillage Res* 92:69–78. <https://doi.org/10.1016/j.still.2006.01.012>
26. Pittelkow CM, Liang X, Linquist BA, et al (2015) Productivity limits and potentials of the principles of conservation agriculture. *Nature* 517:365–368. <https://doi.org/10.1038/nature13809>
27. Liang X, Zhang H, He M, et al (2016) No-tillage effects on grain yield, N use efficiency, and nutrient runoff losses in paddy fields. *Environ Sci Pollut Res* 23:21451–21459. <https://doi.org/10.1007/s11356-016-7338-1>
28. Moe K, Moh SM, Htwe AZ, et al (2019) Effects of Integrated Organic and Inorganic Fertilizers on Yield and Growth Parameters of Rice Varieties. *Rice Sci* 26:309–318. <https://doi.org/10.1016/j.rsci.2019.08.005>
29. Jiang X, Xie D (2009) Combining Ridge with No-Tillage in Lowland Rice-Based Cropping System: Long-Term Effect on Soil and Rice Yield. *Pedosphere* 19:515–522. [https://doi.org/10.1016/S1002-0160\(09\)60144-2](https://doi.org/10.1016/S1002-0160(09)60144-2)
30. Qin J, Hu F, Li D, et al (2010) The Effect of Mulching, Tillage and Rotation on Yield in Non-flooded Compared with Flooded Rice Production. *J Agron Crop Sci* 196:397–406. <https://doi.org/10.1111/j.1439-037X.2010.00430.x>
31. Guo Y, Yin W, Hu F, et al (2019) Reduced irrigation and nitrogen coupled with no-tillage and plastic mulching increase wheat yield in maize-wheat rotation in an arid region. *F Crop Res* 243:107615. <https://doi.org/10.1016/j.fcr.2019.107615>
32. Dordas C (2009) Dry matter, nitrogen and phosphorus accumulation, partitioning and remobilization as affected by N and P fertilization and source-sink relations. *Eur J Agron* 30:129–139. <https://doi.org/10.1016/j.eja.2008.09.001>
33. Papakosta DK, Gagianas AA (1991) Nitrogen and Dry Matter Accumulation, Remobilization, and Losses for Mediterranean Wheat during Grain Filling. *Agron J* 83:864. <https://doi.org/10.2134/agronj1991.00021962008300050018x>
34. Zarea MJ (2011) Conservation Tillage and Sustainable Agriculture in Semi-arid Dryland Farming. In: Lichtfouse E (ed) *Biodiversity, Biofuels, Agroforestry and Conservation Agriculture*. Springer Netherlands, Dordrecht, pp 195–238
35. Ma L, Kong F, Wang Z, et al (2019) Growth and yield of cotton as affected by different straw returning modes with an equivalent carbon input. *F Crop Res* 243:107616. <https://doi.org/10.1016/j.fcr.2019.107616>
36. Xavier CV, Moitinho MR, De Bortoli Teixeira D, et al (2019) Crop rotation and succession in a no-tillage system: Implications for CO₂ emission and soil attributes. *J Environ Manage* 245:8–15. <https://doi.org/10.1016/j.jenvman.2019.05.053>
37. Chen Z, Wang H, Liu X, et al (2017) Changes in soil microbial community and organic carbon fractions under short-term straw return in a rice–wheat cropping system. *Soil Tillage Res* 165:121–127. <https://doi.org/10.1016/j.still.2016.07.018>

38. Li F yong, Liang X, Liu Z, Tian G (2019) No-till with straw return retains soil total P while reducing loss potential of soil colloidal P in rice-fallow systems. *Agric Ecosyst Environ* 286:. <https://doi.org/10.1016/j.agee.2019.106653>
39. Yadav GS, Das A, Lal R, et al (2019) Impact of no-till and mulching on soil carbon sequestration under rice (*Oryza sativa* L.)-rapeseed (*Brassica campestris* L. var. rapeseed) cropping system in hilly agro-ecosystem of the Eastern Himalayas, India. *Agric Ecosyst Environ* 275:81–92. <https://doi.org/10.1016/j.agee.2019.02.001>
40. Jilling A, Kane D, Williams A, et al (2020) Rapid and distinct responses of particulate and mineral-associated organic nitrogen to conservation tillage and cover crops. *Geoderma* 359:114001. <https://doi.org/10.1016/j.geoderma.2019.114001>
41. Wang H, Wang S, Wang R, et al (2019) Direct and indirect linkages between soil aggregates and soil bacterial communities under tillage methods. *Geoderma* 354:113879. <https://doi.org/10.1016/j.geoderma.2019.113879>
42. Caron J, Kay BD, Perfect E (1992) Short-term decrease in soil structural stability following brome grass establishment on a clay loam soil. *Plant Soil* 145:121–130. <https://doi.org/10.1007/BF00009548>
43. Qin R, Stamp P, Richner W (2004) Impact of tillage on root systems of winter wheat. *Agron J* 96:1523–1530. <https://doi.org/10.2134/agronj2004.1523>
44. Chakraborty D, Nagarajan S, Aggarwal P, et al (2008) Effect of mulching on soil and plant water status, and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agric Water Manag* 95:1323–1334. <https://doi.org/10.1016/j.agwat.2008.06.001>
45. Yan F, Sun Y, Hui X, et al (2019) The effect of straw mulch on nitrogen, phosphorus and potassium uptake and use in hybrid rice. *Paddy Water Environ* 17:23–33. <https://doi.org/10.1007/s10333-018-0680-9>
46. Ju J, Cai Y, Zuo W, et al (2019) Effects of Nitrogen Management on Soil Nitrogen Content and Rice Grain Yield in Double Cropping Rice Production Area with Continuous Full Amount of Straw Returning. *Commun Soil Sci Plant Anal* 50:2655–2668. <https://doi.org/10.1080/00103624.2019.1671447>
47. Jordán A, Zavala LM, Gil J (2010) Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. *Catena* 81:77–85. <https://doi.org/10.1016/j.catena.2010.01.007>
48. Wang J, Lü G, Guo X, et al (2015) Conservation tillage and optimized fertilization reduce winter runoff losses of nitrogen and phosphorus from farmland in the Chaohu Lake region, China. *Nutr Cycl Agroecosystems* 101:93–106. <https://doi.org/10.1007/s10705-014-9664-3>
49. Sun Y, Zeng Y, Shi Q, et al (2015) No-tillage controls on runoff: A meta-analysis. *Soil Tillage Res* 153:1–6. <https://doi.org/10.1016/j.still.2015.04.007>
50. Singh A, Phogat VK, Dahiya R, Batra SD (2014) Impact of long-term zero till wheat on soil physical properties and wheat productivity under rice-wheat cropping system. *Soil Tillage Res* 140:98–105. <https://doi.org/10.1016/j.still.2014.03.002>

Tables

Table 1 Chemical and physical properties of the initial paddy soil in the experimental sites

Land use	pH	Total P	Total C	Total N	CEC	pb	Soil Texture		
							sand	silt	clay
			g kg ⁻¹		cmol kg ⁻¹	g cm ⁻³	%		
Paddy field	6.17	0.98	17.21	1.89	13.5	1.215	9.0	59.3	31.7

CEC, cation exchange capacity; pb, soil bulk density.

Table 2 Effect of tillage methods and different rice varieties on nutrient content of rice tissues

Rice tissues	Time	Treatment	Total C	Total N	Total P
			<hr/> g kg ⁻¹ <hr/>		
Straw	2016.10	NTJ	376.84±3.18b	8.11±0.51a	1.10±0.28b
		NTG	384.85±1.44a	8.20±0.88a	1.22±0.35a
		CTJ	378.95±4.64b	8.07±0.02a	1.03±0.25b
		CTG	388.83±0.18a	8.16±0.40a	1.08±0.08b
	2017.10	NTJ	386.51±0.84c	8.21±0.48a	1.12±0.26ab
		NTG	397.90±3.65a	8.31±0.67a	1.25±0.14a
		CTJ	391.07±0.62b	8.14±0.51a	1.06±0.09b
		CTG	402.11±2.43a	8.27±0.64a	1.10±0.36ab
Grain	2016.10	NTJ	419.65±1.12ab	12.25±0.84b	2.11±0.28b
		NTG	422.18±0.91a	13.06±0.22a	2.35±0.12a
		CTJ	418.25±0.47b	12.23±0.21b	2.19±0.10b
		CTG	420.03±0.72ab	12.54±0.02ab	2.25±0.01ab
	2017.10	NTJ	420.80±1.93a	12.34±0.24b	2.15±0.02b
		NTG	423.71±1.48a	13.48±0.02a	2.38±0.01a
		CTJ	418.85±1.47a	12.28±0.12b	2.21±0.01b
		CTG	421.76±1.39a	12.65±0.01b	2.28±0.03ab

NTJ, NTG, CTJ, CTG indicate no-till/japonica rice, no-till/glutinous rice, conventional tillage/japonica rice, conventional tillage/glutinous rice, respectively. Different lowercase letters in each column indicate significant differences set at $p = 0.05$ level.

Table 3 Effect of tillage methods and different rice varieties on grain and straw yields

Time	Treatment	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)
2016.10	NTJ	7090±201b	8089±99a
	NTG	6374±782a	8292±74b
	CTJ	7017±205b	7993±150a
	CTG	6312±113a	8219±125b
2017.10	NTJ	7332±207b	8233±100b
	NTG	6569±377a	8360±46c
	CTJ	7235±202b	8096±37a
	CTG	6504±58a	8338±54c

NTJ, NTG, CTJ, CTG indicate no-till/japonica rice, no-till/glutinous rice, conventional tillage/japonica rice, conventional tillage/glutinous rice, respectively. Different lowercase letters in each column indicate significant differences set at $p = 0.05$ level.

Table 4 Residues and apparent balance of nitrogen in paddy soil

Time		Bulk Density	Soil nitrogen storage	Nitrogen fertilizer	Nitrogen storage			B _{RN}	Soil nitrogen storage	B _{TN}
					Soil	Grain	Straw			
		g cm ⁻³			kg N ha ⁻¹					
2016.06~	NTJ	1.215	4613.1±6	250	4667.7±10a	86.84±2.1a	63.99±3.6b	44.54±5.1b	4679.9±8a	32.35±3c
2017.06	NTG				4653.1±11ab	83.24±1.1b	67.99±2.1a	58.78±4.2a	4665.2±10ab	46.58±4b
	CTJ				4654.1±10ab	85.84±2.0ab	62.08±1.9b	61.04±5.7a	4664.9±5ab	50.24±5ab
	CTG				4646.8±8b	79.15±2.1b	66.25±1.1ab	70.87±4.9a	4659.0±7b	58.68±6a
2017.06~	NTJ	1.221	4679.9±8a	250	4750.1±9a	90.48±3.6a	65.95±3.1ab	23.36±3.5c	4757.0±8a	16.48±1c
2018.06	NTG	1.222	4665.2±10ab		4726.1±4bc	88.55±4.2ab	70.30±4.1a	30.38±4.4b	4736.5±5bc	19.96±2b
	CTJ	1.219	4664.9±5ab		4727.7±10bc	88.85±1.8b	64.27±3.1b	34.11±3.8a	4737.0±4b	24.79±2a
	CTG	1.220	4659.0±7b		4715.5±10c	82.28±4.1c	68.96±3.3a	42.29±7.9a	4726.3±6c	31.51±4a

NTJ, NTG, CTJ, CTG indicate no-till/japonica rice, no-till/glutinous rice, conventional tillage/japonica rice, conventional tillage/glutinous rice, respectively. End of rice season: October 2016 and October 2017, End of winter fallow season: June 2017 and June 2018. B_{RN}: Environmental loss of nitrogen in rice season; B_{TN}: Annual environmental loss of nitrogen. Different lowercase letters in each column indicate significant differences set at $p = 0.05$ level.

Table 5 Residues and apparent balance of phosphorus in paddy soil

Time		Bulk density	Soil phosphorus storage	Phosphate fertilizer	Phosphorus storage			B _{RP}	Soil phosphorus storage	B _{TP}
					Soil	Grain	Straw			
		g cm ⁻³			kg P ha ⁻¹					
2016.06	NTJ	1.215	2400.6±4	44	2410.7±22a	14.96±0.4a	8.70±0.7ab	10.22±1.8c	2413.2±4.2a	7.78±2.1b
~	NTG				2405.8±14ab	14.99±0.5ab	10.12±0.6a	13.65±0.4b	2408.3±5.1a	11.21±2.6ab
2017.06	CTJ				2406.3±19ab	15.37±0.6a	7.92±0.9b	15.00±2.3b	2409.2±4.3a	12.11±3.5a
	CTG				2401.4±8b	14.20±0.2b	8.75±0.6ab	20.22±1.9a	2403.9±7.5a	17.78±3.2a
2017.06	NTJ	1.221	2413.2±4.2a	44	2427.7±6a	15.76±0.2a	9.00±0.4ab	4.71±0.3c	2428.5±1.5a	3.83±0.5b
~	NTG	1.222	2408.3±5.1a		2420.7±11ab	15.63±0.3ab	10.58±1.0a	5.38±1.3bc	2422.1±2.4b	4.01±0.7b
2018.06	CTJ	1.219	2409.2±4.3a		2417.6±12ab	15.99±0.2a	8.37±1.3b	11.20±1.5b	2421.0±2.2b	7.89±1.3a
	CTG	1.220	2403.9±7.5a		2410.4±9b	14.83±0.3b	9.17±0.8ab	13.52±0.8a	2412.0±3.7c	11.85±1.6a

NTJ, NTG, CTJ, CTG indicate no-till/japonica rice, no-till/glutinous rice, conventional tillage/japonica rice, conventional tillage/glutinous rice, respectively. Different lowercase letters in each column indicate significant differences set at $p = 0.05$ level. End of rice season: October 2016 and October 2017. End of winter fallow season: June 2017 and June 2018. B_{RP}: Environmental loss of phosphorus in rice season; B_{TP}: Annual environmental loss of phosphorus.

Table 6 Comparison of economic benefits of different tillage treatments

Treatment	Yield (kg ha ⁻¹)	Gross income (yuan ha ⁻¹)	Production costs		Net income (yuan ha ⁻¹)	Relative value (%)	Benefit: Cost
			Tillage costs	Other costs			
			(yuan ha ⁻¹)	(yuan ha ⁻¹)			
NTJ	8483	22396.5	0	3500	18896.5	112.06	6.40
NTG	7613	22079.2	0	3500	18579.2	110.18	6.31
CTJ	8383	22132.5	1500	3500	17132.5	101.60	4.43
CTG	7538	21862.6	1500	3500	16862.6	100	4.37

NTJ, NTG, CTJ, CTG indicate no-till/japonica rice planting, no-till/glutinous rice planting, conventional tillage/japonica rice planting, conventional tillage/ glutinous rice planting, respectively. Yield: Two-year average drying yield; The price of japonica rice is calculated in 2.64 yuan per kilogram, the price of glutinous rice is calculated in 2.90 yuan per kilogram; other costs include the cost of fertilizer, seeds, etc.; Net income=gross income-production costs.

Figures

Figure 1

Soil nutrient content under different tillage methods and rice varieties treatments. NTJ, no-till/japonica rice; NTG, no-till/glutinous rice; CTJ, conventional tillage/japonica rice; CTG, conventional tillage/glutinous rice.

Figure 2

Soil nutrient stocks under different tillage methods and rice varieties treatments. NTJ, no-till/japonica rice; NTG, no-till/glutinous rice; CTJ, conventional tillage/japonica rice; CTG, conventional tillage/glutinous rice. Different lowercase letters in each column indicate significant differences set at $p = 0.05$ level.

Figure 3

Rice grain nutrient accumulation under different tillage methods and rice varieties treatments. NTJ, no-till/japonica rice; NTG, no-till/glutinous rice; CTJ, conventional tillage/japonica rice; CTG, conventional tillage/glutinous rice. Different lowercase letters in each column indicate significant differences set at $p = 0.05$ level.

Figure 4

Rice straw nutrient accumulation under different tillage methods and rice varieties treatments. NTJ, no-till/japonica rice; NTG, no-till/glutinous rice; CTJ, conventional tillage/japonica rice; CTG, conventional tillage/glutinous rice. Different lowercase letters in each column indicate significant differences set at $p = 0.05$ level.