Effects and Evaluation of Conservation Tillage on Soil Fertility under Rice-Rapeseed Rotation (Postprint)

Authors: Yin Zhiyao, Huang Li, Xue Bin, Huang Yanan, Li Xiaokun, Lu Jianwei

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

Abstract

This study selected three long-term fixed experiment sites for rice-rape rotation in Wuxue City, Jingzhou City, and Wuhan City of Hubei Province (with experiment durations of 9 years, 5 years, and 3 years, respectively). Through continuous monitoring of soil bulk density, porosity, pH, organic matter, total nitrogen, total potassium, alkali-hydrolyzable nitrogen, available phosphorus, and available potassium, the effects of straw return and no-tillage on soil physical properties and nutrients in various soil layers (0–20 cm and 20–40 cm) during the rice season (October 2015) and rape season (May 2016) were investigated under different cultivation years and methods. The Nemerow index method was applied to comprehensively evaluate the soil fertility level of each soil layer, aiming to explore the effects of long-term straw return on soil fertility. The results showed that: 1) Straw return treatment decreased soil bulk density by 2.00%-16.54% and increased total soil porosity by 1.00%-15.07% in both the rice and rape seasons; whereas under no-tillage treatment, the changes in the rape season were opposite to these trends, and the changes in the rice season were not significant. 2) Straw return treatment increased the contents of organic matter (4.76%-35.07%), total nitrogen (1.80%-32.03%), available phosphorus (20.95%-65.82%), alkali-hydrolyzable nitrogen (5.97%-37.00%), and available potassium (8.71%-133.04%) in the 0–20 cm soil layer across the three experiment sites, with available potassium showing the highest increase magnitude; no-tillage treatment had no significant effect on soil nutrients, but when combined with straw application, its effect on increasing various nutrients was relatively the best compared with other treatments. The effects of various treatments on the 20–40 cm soil layer were similar to those on the 0–20 cm soil layer, but the overall increasing effect was less significant than the latter. 3) Among all experimental treatments, the two treatments of no-tillage plus straw return and nitrogen-phosphorus-potassium fertilizer application plus straw return resulted

in relatively large increases in the comprehensive fertility coefficient of each soil layer (7.56%-25.93%), and their effects on improving soil fertility were relatively better.

Full Text

Effect of Conservation Tillage on Soil Fertility Under Rice-Rape Rotation System

YIN Zhiyao, HUANG Li, XUE Bin, HUANG Yanan, LI Xiaokun, LU Jianwei

Key Laboratory of Arable Land Conservation (Middle and Lower Reaches of Yangtze River), Ministry of Agriculture, Huazhong Agricultural University, Wuhan 430070, China

Abstract: This study evaluated the long-term effects of straw return and no-tillage on soil physical properties and nutrient content under rice-rape rotation systems at three long-term experimental sites in Hubei Province (Wuxue, Jingzhou, and Wuhan) with trial durations of 9, 5, and 3 years, respectively. Continuous monitoring of soil bulk density, porosity, pH, organic matter, total nitrogen, total potassium, available nitrogen, available phosphorus, and available potassium was conducted for both the rice season (October 2015) and rape season (May 2016) across two soil layers (0-20 cm and 20-40 cm). The Nemerow index method was applied to comprehensively assess soil fertility levels in each layer, aiming to elucidate the impacts of long-term straw return on soil fertility. Results showed that: (1) Straw return reduced soil bulk density by 2.00%-16.54% and increased total porosity by 1.00%-15.07% in both rice and rape seasons. In contrast, no-tillage produced opposite effects in the rape season, while showing no significant changes in the rice season. (2) Straw return increased organic matter (4.76%-35.07%), total nitrogen (1.80%-32.03%), available phosphorus (20.95%-65.82%), available nitrogen (5.97%-37.00%), and available potassium (8.71%-133.04%) in the 0-20 cm layer across all three sites, with available potassium showing the greatest increase. No-tillage alone had no significant effect on nutrients, but when combined with straw return, it produced the best overall improvement compared to other treatments. Effects in the 20-40 cm layer followed similar patterns but were less pronounced than in the 0-20 cm layer. (3) Among all treatments, no-tillage plus straw return and NPK fertilizer plus straw return produced the greatest increases in integrated soil fertility coefficients (7.56%-25.93%), demonstrating superior effects on soil fertility improvement.

Keywords: Rice-rape rotation system; Conservation tillage; Straw return; No-tillage; Soil nutrient; Integrated fertility index

Introduction

Soil quality represents a comprehensive reflection of soil characteristics, with soil fertility being a crucial component. Maintaining and enhancing soil fertility is a critical issue for ensuring sustainable agricultural development. Conservation tillage, including reduced or no-tillage and surface mulching, represents a primary technology for sustainable agriculture. Compared with conventional tillage, conservation tillage significantly reduces agricultural production inputs while contributing to soil fertility improvement and erosion reduction, and has been widely adopted both domestically and internationally. Therefore, investigating the effects of conservation tillage on soil fertility is essential for improving farmland productivity and optimizing field management.

Previous research has demonstrated that straw return combined with fertilization significantly influences soil nutrient status, soil structure improvement, and crop yield enhancement. However, findings regarding whether no-tillage can maintain or improve soil fertility have been inconsistent. Luo et al. reported that no-tillage could increase topsoil organic matter, total nitrogen, and total phosphorus content to some extent, providing certain soil fertility benefits. Conversely, Xu et al. found that compared with conventional tillage, no-tillage increased organic carbon, total nitrogen, available nitrogen, and available potassium in the 0–5 cm layer but decreased these parameters in the 5–20 cm layer, while also reducing bulk density and increasing porosity in the 0–20 cm layer. Wu et al. concluded that with prolonged no-tillage duration, soil physical properties deteriorated and crop yields decreased.

Scientific and objective evaluation of soil fertility levels is crucial for research on soil fertility improvement. Cao et al. first proposed the concept of numerical soil fertility evaluation, which calculates the contribution value of each soil fertility indicator to determine comprehensive soil fertility status. Yang et al. demonstrated that straw return increased the integrated soil fertility coefficient compared with no straw return. Other studies indicated that no-tillage improved surface soil fertility but had minimal effects on subsoil layers. Liu et al. found that no-tillage alone decreased the integrated fertility coefficient, but when combined with straw return, it produced the best improvement effect. In agricultural production, pH, organic matter, and nitrogen, phosphorus, and potassium nutrients are commonly used to comprehensively measure soil fertility.

Numerous studies on conservation tillage effects on soil fertility have been conducted in China in recent years. However, most previous results encompassed combined effects of no-tillage and straw return, making it difficult to distinguish individual effects. Additionally, most research focused on long-term experiments at single locations, lacking comparisons across different tillage durations and environmental conditions, with few comprehensive evaluations of tillage effects on soil fertility. Therefore, this study selected three long-term experimental sites under rice-rape rotation in Wuxue, Jingzhou, and Wuhan, Hubei Province.

By continuously monitoring seven indicators (pH, organic matter, total nitrogen, total potassium, available nitrogen, available phosphorus, and available potassium), we evaluated comprehensive soil fertility status and investigated the effects of straw return and no-tillage on soil fertility in 0–20 cm and 20–40 cm layers, providing scientific evidence for conservation tillage research and soil fertility management.

1.1 Experimental Design

Experimental soils were collected from long-term rice-rape rotation experimental fields in Wuxue, Jingzhou, and Wuhan, Hubei Province. The Wuxue site, initiated in 2007, is located in Dajin Town (29°59 21 N, 115°36 53 E) at 24 m elevation with a subtropical monsoon humid climate (mean annual temperature 16.9°C, average rainfall 1489 mm and evaporation 1361 mm during 1985–2014). The Jingzhou site, started in 2011, is located in Chuan Dian Town (30°35 28 N, 112°04 33 E) at 80 m elevation with a subtropical monsoon climate (mean annual temperature 17.9°C, annual rainfall 1055 mm and evaporation 853 mm). The Wuhan site, initiated in 2013, is located at the Huazhong Agricultural University experimental base (30°28 10 N, 114°21 21 E). All three sites have paddy soils developed from Quaternary sediments. Initial soil properties are presented in Table 1 .

Four treatments with three replications were established at each site, comprising six plots (20 m^2 each) arranged in a randomized block design. The Wuxue site included: conventional tillage, conventional tillage + straw return, no-tillage, and no-tillage + straw return. The Jingzhou and Wuhan sites both included conventional tillage and conventional tillage + straw return. Conventional tillage involved plowing before each crop season, while no-tillage involved no plowing. Detailed fertilization rates for each site are provided in Table 2 . After rice and rape harvest, all straw was returned to the field in straw return treatments and completely removed in non-return treatments. Soil samples from 0–20 cm and 20–40 cm layers were collected using S-shaped sampling in October 2015 (rice harvest) and May 2016 (rape harvest), then mixed, air-dried, sieved after removing stones and roots, and stored for analysis.

1.2 Measurement Items and Methods

Soil pH was measured potentiometrically (water:soil ratio 1:2.5, Orion 868 pH meter). Organic matter (OM) was determined by potassium dichromate volumetric method with external heating. Total nitrogen (TN) was measured by Kjeldahl method (K-9840 automatic nitrogen analyzer). Available phosphorus (AP) was determined by 0.5 $mol \cdot L^{-1}$ $NaHCO_3$ extraction colorimetry (UV-1600 spectrophotometer). Available nitrogen (AN) was measured by alkaline hydrolysis diffusion method. Total potassium (TK) was extracted with perchloric acid and sulfuric acid, while available potassium (AK) was extracted with 1 $mol \cdot L^{-1}$ ammonium acetate and measured by flame photometry (HG-3 flame photometer). Soil bulk density (BD) was determined by the ring knife method, and total porosity, capillary porosity, and aeration porosity were calculated.

1.3 Nemerow Index Method

Various methods exist for comprehensive soil fertility evaluation. The Nemerow index method eliminates dimensional differences among soil fertility indicators, producing sub-fertility coefficients between 0–3 that enable strong comparability among parameters and similar comparability among attributes within the same level, making it widely used internationally.

(1) Calculation of sub-fertility coefficient (IFIi):

$$IFI_i = \begin{cases} 1 + \frac{x - x_a}{x_c - x_a} & \text{for } x_a < x \leq x_c \\ 2 + \frac{x - x_c}{x_p - x_c} & \text{for } x_c < x < x_p \end{cases}$$

where IFIi is the sub-fertility coefficient, x is the measured attribute value, xa and xp are the lower and upper limits of the grading standard, and xc is the intermediate value. Grading standard values (xa, xc, xp) primarily reference the Second National Soil Survey standards (Table 3), with each grade reflecting respective soil fertility conditions.

(2) Integrated soil fertility coefficient:

$$IFI = \sqrt{\frac{(IFI_i \text{ average})^2 + (IFI_i \text{ minimum})^2}{2}}$$

where IFI is the integrated soil fertility coefficient, IFIi average and IFIi minimum are the mean and minimum sub-fertility coefficients of soil attributes, and n is the number of evaluation indicators.

1.4 Data Processing

Data processing and statistical analysis were performed using Microsoft Excel and SPSS software.

2.1 Effects of Conservation Tillage on Soil Physical Properties

As shown in Table 4 , compared with control treatments (CT, NP, and CK), straw return treatments (CTS, NPS, and S) significantly reduced bulk density by 4.24%–8.55% and increased total porosity and capillary porosity by 1.72%–12.46% in both rice and rape seasons across all three sites. Compared with NT and NPK treatments, NTS and NPKS treatments showed similar trends, with bulk density significantly decreasing by 2.00%–16.54% and total porosity increasing by 1.00%-15.07%, while capillary porosity showed inconsistent patterns. Aeration porosity exhibited no significant changes under straw return treatments at any site.

No-tillage alone showed no significant effects on bulk density, total porosity, capillary porosity, or aeration porosity in the rice season. In the rape season, NT increased bulk density by 1.00% and decreased total porosity by 0.66%, with no significant changes in capillary or aeration porosity. Compared with CTS treatment, NTS treatment increased bulk density by 7.61% and decreased total and capillary porosity by 3.87% and 6.19%, respectively, in the rape season, with no significant change in aeration porosity. These results contrast with Wu et al., possibly because reduced soil disturbance allows soil particle settlement, causing some degree of soil compaction.

The results demonstrate that straw return reduces bulk density while increasing total and capillary porosity, thereby improving soil physical properties, whereas no-tillage alone shows limited improvement in soil physical properties.

2.2 Effects of Conservation Tillage on Total Nutrient Content

At all three sites, organic matter, total nitrogen, and total potassium (except at Jingzhou) contents were significantly higher in the 0–20 cm layer than in the 20-40 cm layer (Table 5). At the Jingzhou site, total potassium distribution varied among treatments, likely because roots, fresh plant residues, and microorganisms contain potassium that, upon decomposition, releases nutrients into soil. Since potassium transfers slowly in subsoil, this caused some accumulation in the 20–40 cm layer.

In the 0–20 cm layer, compared with CT, NP, and CK treatments, CTS, NPS, and S treatments significantly increased organic matter (4.76%-27.21%) and total nitrogen (3.55%-23.94%) contents in both rice and rape seasons across all sites. Total potassium showed site-specific variations, decreasing by 4.44%-11.85% in the rice season at all sites, but increasing by 5.64% and 3.12% in the rape season at Wuxue and Jingzhou while decreasing by 8.17% at Wuhan, possibly due to short return duration and differential transformation among potassium forms.

Compared with NT and NPK treatments, NTS and NPKS treatments produced similar effects, increasing organic matter, total nitrogen, and total potassium by 6.75%-35.07%, 1.80%-32.03%, and 10.12%-29.52%, respectively.

No-tillage alone showed limited improvement in total nutrients. NT treatment significantly decreased organic matter (6.69% in rice, 8.51% in rape), total potassium (7.94% in rice, 15.05% in rape), and total nitrogen in the rape season (5.58%). Compared with CTS treatment, NTS treatment showed no significant changes in organic matter or total nitrogen, possibly related to soil compaction and nutrient loss under no-tillage.

In the 20-40 cm layer, all treatments increased organic matter content to some degree (3.33%-43.10%) in both seasons, while total nitrogen and total potassium showed inconsistent patterns.

The results indicate that straw return increases organic matter and total nitrogen contents in both 0-20 cm and 20-40 cm layers (with better improvement in the 0-20 cm layer), while total potassium shows inconsistent patterns. No-tillage effects on organic matter, total nitrogen, and total potassium vary across soil layers.

2.3 Effects of Conservation Tillage on Soil pH and Available Nutrients

Soil pH ranged from 4.81-5.91 at Wuxue, 5.93-6.76 at Jingzhou, and 6.24-6.72 at Wuhan, indicating acidic to neutral slightly acidic conditions (Figure 1 [Figure 1: see original paper]). Across all treatments, pH was significantly lower in the 0-20 cm layer than in the 20-40 cm layer. Compared with CT, NP, and CK treatments, both NTS and NPKS treatments decreased pH in both layers, with significant differences at Wuxue and inconsistent patterns at Wuhan and Jingzhou (significant at Wuhan in 0-20 cm and at Jingzhou in 20-40 cm). These results suggest that straw return and no-tillage reduce soil pH, consistent with Meng et al.

As shown in Table 6 , available phosphorus, available nitrogen, and available potassium contents were significantly higher in the 0-20 cm layer than in the 20-40 cm layer at Wuxue and Wuhan, while available potassium showed inconsistent patterns between layers at Jingzhou.

In the 0-20 cm layer, compared with CT, NP, and CK treatments, CTS, NPS, and S treatments significantly increased available nitrogen (5.97%-33.93%) and available potassium (8.71%-121.49%) in both seasons across all sites, with available phosphorus also increasing significantly at Jingzhou in the rice season and at Wuhan (20.95%-65.82%). Compared with NT and NPK treatments, NTS and NPKS treatments increased available nitrogen and available potassium by 9.05%-37.00% and 11.35%-133.04%, respectively, with available phosphorus increasing significantly by 27.25%-39.81% at Wuxue and Jingzhou but showing minimal change at Wuhan.

No-tillage effects differed from straw return effects. Compared with CT treatment, NT treatment showed no significant changes in available nitrogen, phosphorus, or potassium. However, compared with CTS treatment, NTS treatment significantly increased available phosphorus in both seasons at Wuxue (14.90% and 17.78%) and available nitrogen in the rice season (31.38%), with no significant changes in available potassium or rape-season available nitrogen. Overall, no-tillage showed relatively smaller effects on available nutrients compared with straw return.

In the 20-40 cm layer, straw return generally increased available nitrogen

(11.15%-50.64%), available phosphorus (25.30%-150.00%), and available potassium (10.81%-233.93%), though less significantly than in the 0-20 cm layer, consistent with Zhang et al. No-tillage showed no significant changes in available nutrient contents.

These results demonstrate that straw return increases available nutrient contents in both layers (with better improvement in 0-20 cm), particularly for available potassium, while no-tillage effects are not significant.

2.4 Effects of Conservation Tillage on Integrated Soil Fertility Coefficient

Comprehensive analysis using the Nemerow index method (Table 7) revealed that integrated fertility coefficients (IFI) were higher in the rape season than in the rice season and significantly higher in the 0-20 cm layer than in the 20-40 cm layer across all sites.

Compared with CT, NP, and CK treatments, CTS, NPS, and S treatments increased IFI values in all layers (3.68%-17.28%). Similarly, NTS and NPKS treatments increased IFI values by 6.49%-27.69% compared with NT and NPK treatments, with more pronounced increases in the 0-20 cm layer.

No-tillage effects differed from straw return effects. Compared with CT treatment, NT treatment showed no significant IFI changes in the rice season but significantly decreased IFI by 3.10% and 6.76% in the 0-20 cm and 20-40 cm layers, respectively, in the rape season. Compared with CTS treatment, NTS treatment significantly increased IFI by 13.70% in the 20-40 cm layer in the rice season and by 2.90% in the 0-20 cm layer in the rape season.

These findings indicate that straw return effectively improves integrated soil fertility in all layers, while no-tillage alone shows limited improvement. However, NTS treatment demonstrates good improvement effects. Among all treatments, NTS and NPKS treatments produced the best soil fertility improvement (7.56%-25.93%) compared with controls (CT, NP, and CK).

Straw return treatments increased nutrient contents in the 0-20 cm layer, with available potassium showing the highest increase amplitude. This may occur because potassium in rice and rape is primarily distributed in leaves and straw, with relatively higher concentrations than nitrogen and phosphorus. Straw decomposition under microbial activity returns organic matter, nitrogen, phosphorus, potassium, and other nutrients to soil, increasing nutrient contents. Potassium in straw exists mainly in ionic form and is easily dissolved, replenishing available potassium components (water-soluble and exchangeable potassium). Straw decomposition also releases organic acids, anions, and alkaline metals that promote mineral potassium release and transformation. Therefore, straw return has the best relative effect on available potassium. Additionally, organic acids from straw decomposition promote transformation of insoluble phosphorus to soluble forms, indirectly increasing phosphorus availability. Soil nitrogen exists mainly as organic nitrogen, and straw addition stimulates heterotrophic microbial decomposition, increasing nitrogen availability. The superior improvement in the 0–20 cm layer compared with the 20–40 cm layer may result from nutrient input concentration in the surface layer, causing nutrient enrichment.

No-tillage effects on soil fertility were not significant and showed seasonal differences under rice-rape rotation. This may occur because no-tillage altered soil physical properties, affecting other soil characteristics. In this study, NT increased bulk density (1.00%) and decreased total porosity (0.66%) in the rape season, with no significant changes in the rice season, consistent with Xue et al. Soil physical properties are key factors affecting soil structure, aeration, and water/nutrient retention. Increased bulk density enhances soil loss, causing nutrient loss. Additionally, soil enzymes respond sensitively to crop rotation and tillage practices, and environmental influences may cause differential enzyme activities. These factors may contribute to inconsistent no-tillage effects on soil fertility. In contrast, NTS and NPKS treatments showed better improvement effects, possibly because added straw benefits soil fauna and microorganisms, loosening soil and reducing bulk density. Straw also moderates soil temperature changes, facilitating nutrient transformation. Therefore, combining straw return with no-tillage or fertilization positively maintains and improves soil fertility.

Conclusions

1) Straw return reduces soil bulk density and increases total porosity, improving soil physical properties. It also increases nutrient contents in the 0–20 cm layer, particularly available potassium.
2) No-tillage effects on soil physical properties differ between rice and rape seasons under rice-rape rotation, with limited effects on soil nutrients. However, no-tillage combined with straw return (NTS) shows good improvement effects on soil nutrient contents.
3) Compared with control treatments, straw return improves integrated soil fertility levels (with significantly better fertility in the 0–20 cm layer than in the 20–40 cm layer), with NTS and NPKS treatments showing the best improvement effects (7.56%–25.93%). No-tillage alone has limited effects on soil fertility improvement.

References

[1] Ma Q H, Zhang G H, Geng R, et al. Present condition analysis of sloping farmland soil fertility in the water erosion zone of China[J]. Journal of Soil and Water Conservation, 2016, 30(5): 190–196

[2] Wang S L, Wang H, Li J, et al. Effects of long-term straw mulching on soil organic carbon, nitrogen and moisture and spring maize yield on rain-fed

croplands under different patterns of soil tillage practice[J]. Chinese Journal of Applied Ecology, 2016, 27(5): 1530-1540

[3] Feng F X, Huang G B, Yu A Z, et al. Effects of different conservation tillage measures on winter wheat water use in Wuwei oasis irrigated area[J]. Chinese Journal of Applied Ecology, 2009, 20(5): 1060-1065

[4] Peng W D, Chu C X, Zhong Y Q, et al. Effect of sweet corn straw returning to the field on soil fertility, yield and benefit[J]. Meteorological and Environmental Research, 2016, 7(4): 59-63

[5] Zhang R Z, Huang G B, Cai L Q, et al. Dry farmland practice involving multi-conservation tillage measures in the loess Plateau[J]. Chinese Journal of Eco-Agriculture, 2013, 21(1): 61-69

[6] Luo Z Z, Huang G B, Li G D, et al. Effects of conservation tillage on soil nutrients and enzyme activities in rainfed area[J]. Plant Nutrition and Fertilizer Science, 2009, 15(5): 1085-1092

[7] Xu Y C, Shen Q R, Lei B K, et al. Effect of long-term no-tillage and application of organic manure on some properties of soil fertility in rice/wheat rotation[J]. Chinese Journal of Applied Ecology, 2000, 11(4): 549-552

[8] Feng Y H, Zou Y B, Wang S H, et al. Impact of zero tillage on the soil characters and the growth and yield formation in direct seeding rice[J]. Crop Research, 2004, 18(3): 137-140

[9] Wu J F, Pan X H, Wang L, et al. Effects of continuous no-tillage on crop yield and soil fertility in double rice cropping system[J]. Scientia Agricultura Sinica, 2010, 43(15): 3159-3167

[10] Cao C M, Yan C S, Zhang Z M, et al. Discussion on the comprehensive evaluation of soil fertility[J]. Chinese Journal of Soil Science, 1983, (4): 13-15

[11] Yang F, Dong Y, Xu M G, et al. Effects of straw returning on the integrated soil fertility and crop yield in southern China[J]. Chinese Journal of Applied Ecology, 2012, 23(11): 3040-3044

[12] Jiang Z P, Huang S M, Wei G P, et al. Comprehensive evaluation and changes of paddy soil fertility under different continuous cropping and no-tillage modes[J]. Southwest China Journal of Agricultural Sciences, 2007, 20(6): 1250-1254

[13] Liu S P, Chen H Q, Nie X T, et al. Comprehensive evaluation of tillage and straw returning on soil fertility in a wheat-rice double cropping system[J]. Transactions of the CSAE, 2008, 24(5): 51-56

[14] Bao Y X, Xu M G, Lü F T, et al. Evaluation method on soil fertility under long-term fertilization[J]. Scientia Agricultura Sinica, 2012, 45(20): 4197-4204

[15] Jiang X B, Li Y S, Ouyang Z, et al. Effect of no-tillage on soil aggregate and organic carbon storage[J]. Chinese Journal of Eco-Agriculture, 2012, 20(3):

270–278

[16] Wu J, Cai L Q, Qi P, et al. Distribution characteristics of organic carbon and total nitrogen in dry farmland soil aggregates under different tillage methods in the loess plateau of central Gansu Province[J]. Chinese Journal of Eco-Agriculture, 2015, 23(3): 276–284

[17] Zhang B F, Zeng L S, Li J L, et al. Soil bulk density and porosity in greenhouse vegetables field under the optimized fertilization treatment[J]. Chinese Agricultural Science Bulletin, 2013, 29(32): 309–314

[18] Kan W J, Wu Q T. A quantitative method of comprehensive evaluation of soil fertility[J]. Chinese Journal of Soil Science, 1994, 25(6): 245–247

[19] Wu J, Cai L Q, Luo Z Z, et al. Effects of conservation tillage on soil physical properties of rainfed field of the loess plateau in central of Gansu[J]. Journal of Soil and Water Conservation, 2014, 28(2): 112–117

[20] Chen X W, Zhang X P, Liang A Z, et al. Effects of tillage mode on black soil' s penetration resistance and bulk density[J]. Chinese Journal of Applied Ecology, 2012, 23(2): 439–444

[21] Zhang J, Zhang R Z, Zuo X A. Effects of conservative tillage on physical and chemical characteristics under a pea-wheat rotation system in the loess plateau[J]. Journal of Desert Research, 2016, 36(1): 137–143

[22] Meng H Q, Liu J, Xu M G, et al. Evolution of pH in topsoils of typical Chinese croplands under long-term fertilization[J]. Acta Pedologica Sinica, 2013, 50(6): 1109–1116

[23] Zhang P, Chen X L, Wei T, et al. Effects of straw incorporation on the soil nutrient contents, enzyme activities, and crop yield in a semiarid region of China[J]. Soil and Tillage Research, 2016, 160: 65–72

[24] Lu X H, Wu L H, Pang L J, et al. Distribution of N, P and K in rice plant under a long-term located plastic film mulching cultivation[J]. Chinese Journal of Soil Science, 2010, 41(1): 145–149

[25] Mengel K, Uhlenbecker K. Determination of available interlayer potassium and its uptake by ryegrass[J]. Soil Science Society of America Journal, 1993, 57(3): 761–766

[26] Zhang H M, Xu M G, Shi X J, et al. Rice yield, potassium uptake and apparent balance under long-term fertilization in rice-based cropping systems in southern China[J]. Nutrient Cycling in Agroecosystems, 2010, 88(3): 341–349

[27] Yang K L, Yang S J, Xin X C. Effect of maize straw returning to soil on phosphorus availability[J]. Journal of Anhui Agricultural Sciences, 2012, 40(28): 13782–13783

[28] Kaewpradit W, Toomsan B, Cadisch G, et al. Mixing groundnut residues and rice straw to improve rice yield and N use efficiency[J]. Field Crops Research, 2009, 110(2): 130–138

[29] Pan J L, Dai W A, Shang Z H, et al. Review of research progress on the influence and mechanism of field straw residue incorporation on soil organic matter and nitrogen availability[J]. Chinese Journal of Eco-Agriculture, 2013, 21(5): 526–535

[30] Mu P, Zhang E H, Wang H N, et al. Effects of continuous returning straw to maize tilth soil on chemical character and microbial biomass[J]. Journal of Soil and Water Conservation, 2011, 25(5): 81–85

[31] Yao X M, Zhou Z C, Tian X H, et al. Effects of long-term all straw return to field with machine on the stratifications of soil nutrients[J]. Chinese Journal of Soil Science, 2015, 46(1): 198–202

[32] Xue B, Yin Z Y, Xiao Q, et al. Effects of long-term straw returning on soil fertility under rice rape rotation system[J]. Chinese Agricultural Science Bulletin, 2017, 33(7): 134–141

[33] Page K, Dang Y, Dalal R. Impacts of conservation tillage on soil quality, including soil-borne crop diseases, with a focus on semi-arid grain cropping systems[J]. Australasian Plant Pathology, 2013, 42(3): 363–377

[34] Shen Y T, Guo C J, Jin S, et al. Effect of soil bulk density on nutrient loss of black soil slope[J]. Journal of Soil and Water Conservation, 2016, 30(1): 26–30

[35] Yang Z D, Cai L Q, Zhang R Z, et al. Soil enzymatic activities under different tillages practricess in dryland[J]. Chinese Journal of Soil Science, 2008, 39(3): 514–517

Note: Figure translations are in progress. See original paper for figures.