Effects of Different Fertilization Practices on Dryland Fertility and Crop Yield in the Dongting Lake Region: Postprint

Authors: Chen Ge, Tang Chunchun, Li Zusheng, Huang Yunxiang, Zeng Xibai, Wen Jiong, Gao Xue, Zhang Qian

Date: 2017-11-09T00:00:00+00:00

Abstract

Using the long-term stationary experimental method, we investigated changes in crop yield and soil nutrients under a cotton-rapeseed rotation system for non-grain crops in the Dongting Lake region across different fertilization regimes: conventional farmer fertilization (TF), formula fertilization (NPK), and various organic-inorganic fertilizer proportioning modes [with organic fertilizer-derived nitrogen accounting for 50% (50%OM), 30% (30%OM), and 10% (10%OM) of total nitrogen in the formula fertilizer], aiming to provide references for rational fertilization under corresponding crop cultivation systems. The results showed that under the fertilization rates and organic-inorganic fertilizer ratios employed in this experiment, combined application of organic and chemical fertilizers significantly increased cotton and rapeseed yields, with the 50%OM treatment producing the highest yield. The yield ranking across treatments was 50%OM > 30%OM > 10%OM > NPK > TF > CK (no fertilization control). When organic nitrogen application accounted for 50% of total nitrogen (50%OM treatment), cotton and rapeseed yields were 24.52% and 29.57% higher than the NPK treatment, and 46.03% and 49.07% higher than the conventional fertilization (TF) treatment, respectively. Simultaneously, the inter-annual variation in crop yields under organic fertilizer treatments was less than 20%, significantly lower than that of the NPK, TF, and CK treatments, indicating that organic fertilizer application not only promotes high yields of upland crops but also ensures their yield stability. Combined application of organic and chemical fertilizers increased soil organic matter, total nitrogen, alkali-hydrolyzable nitrogen, and available potassium contents, with the 50%OM treatment showing the best effect, achieving increases of 57.5%, 38.2%, 65.1%, and 48.1% compared with pre-experiment levels, respectively. Soil available phosphorus content exhibited a trend of increasing with applied phosphorus amount. In contrast, soil organic matter and nutrient contents under the CK treatment showed a year-by-year decreasing trend. Changes in soil organic matter and nutrient contents (Y) with experimental years (X) across all treatments could be expressed by the equation Y=aX+b. In the high-fertility upland soils of the Dongting Lake region, rational organic-inorganic fertilizer application ratios are particularly important for ensuring high and stable yields of non-grain crops and improving cropland fertility, with the optimal effect achieved when organic fertilizer-derived nitrogen accounts for 50% of total nitrogen applied under the conditions of this experiment.

Full Text

Influence of Different Fertilization Modes on Soil Fertility and Crop Yield in Dongting Lake Upland Areas

CHEN Ge[1,2], **TANG Chunchun**[1], **LI Zusheng**[1], **HUANG Yunxiang**[2], **ZENG Xibai**[3], WEN Jiong[1], GAO Xue[4], ZHANG Qian[3]

[1]Institute of Yueyang Agricultural Sciences / Experimental Station of Yueyang Agricultural Environment, Ministry of Agriculture, Yueyang 414000, China
[2]College of Resources and Environment, Hunan Agricultural University, Changsha 410000, China
[3]Institute of Environment and Sustainable Agricultural Development, Chinese Academy of Agricultural Sciences, Beijing 100081, China
[4]Tibet Academy of Agricultural and Animal Husbandry, Lhasa 850002, China

Abstract

A long-term field experiment was conducted under a cotton-rapeseed rotation system in upland areas of Dongting Lake to investigate the effects of different fertilization modes on soil fertility and crop yield. The treatments included no fertilization (CK), conventional farmer fertilization (TF), formula fertilization (NPK), and three combined organic-inorganic fertilization regimes where organic fertilizer nitrogen accounted for 10% (10%OM), 30% (30%OM), and 50% (50%OM) of total nitrogen in the formula fertilizer. The results demonstrated that combined organic-inorganic fertilization significantly increased cotton and rapeseed yields, with the highest yields observed under the 50%OM treatment. The yield ranking from highest to lowest was: 50%OM > 30%OM > 10%OM > NPK > TF > CK. Specifically, the 50%OM treatment increased cotton and rapeseed yields by 24.52% and 29.57% compared to NPK, and by 46.03% and 49.07% compared to TF, respectively. Furthermore, the inter-annual variation in crop yields under organic fertilization treatments was less than 20%, substantially lower than that under TF, NPK, and CK treatments, indicating that organic-inorganic fertilization not only promoted high yields but also ensured stable production. Combined fertilization increased soil organic matter, total nitrogen, alkali-hydrolyzable nitrogen, and available potassium contents, with the 50%OM treatment showing the greatest improvements of 57.5%, 38.2%, 65.1%, and 48.1% over initial levels, respectively. Soil available phosphorus content tended to increase with phosphorus input, while the CK treatment showed declining trends in all soil fertility parameters. Changes in soil organic matter and nutrient contents (Y) over experimental years (X) followed linear relationships described by Y = aX + b. These findings highlight that rational organic-inorganic fertilization is crucial for maintaining high and stable yields of non-grain crops and improving soil productivity in the fertile upland soils of Dongting Lake region, with optimal results achieved when organic nitrogen accounts for approximately 50% of total nitrogen application.

Keywords: Cotton-rapeseed rotation; Long-term static experiment; Organic-inorganic fertilization; Crop yield; Soil fertility

1. Materials and Methods

1.1 Experimental Site Conditions

The long-term monitoring experiment was established at the Yueyang Agricultural Environment Scientific Observation Experimental Station of the Ministry of Agriculture in Yueyang City, Hunan Province, which serves as a provincial cultivated land quality monitoring site. The geographic coordinates are 113°5 15 E, 29°16 0 N, with an elevation of approximately 40 m. The site is located in the subtropical zone of the middle Yangtze River region, characterized by a warm and humid climate with ample sunlight and appropriate rainfall. The average annual temperature is 17.0 °C, average annual precipitation is 1,400 mm, and annual sunshine duration ranges from 1,722 to 1,816 h. The main upland crops in this region include rapeseed, cotton, and maize, with cotton still occupying a substantial planting area despite recent reductions. The experimental soil is a fluvo-aquic soil developed from Dongting Lake sediments, with a clay loam texture. Initial soil properties were: pH 5.7, organic matter 19.3 $g \cdot kg^{-1}$, total nitrogen 1.36 $g \cdot kg^{-1}$, alkali-hydrolyzable nitrogen 119.6 $mg \cdot kg^{-1}$, available phosphorus 18.6 $mg \cdot kg^{-1}$, and available potassium 58.39 $mg \cdot kg^{-1}$.

1.2 Experimental Design

Based on the predominant upland cropping systems in the Dongting Lake plain region, the long-term experiment focused on cotton and rapeseed—the two most historically significant and widely planted upland crops—using a double-cropping system with cotton in spring and rapeseed in autumn. The crop varieties were 'Xiangyou 16' rapeseed and 'Xiangzamian 3' cotton, provided by the Yueyang Agricultural Sciences Institute. Following Hunan Provincial Department of Agriculture guidelines and local fertilization practices, six treatments were established: CK (no fertilization); 10%OM (10% organic fertilizer + chemical fertilizer); 30%OM (30% organic fertilizer + chemical fertilizer); 50%OM (50% organic fertilizer + chemical fertilizer); TF (conventional fertilization); and NPK (formula fertilization). Each plot measured 8 m × 5 m, with no replicates, and plots were separated by cement ridges. All treatments except TF and CK received equal total nutrient amounts. The organic-inorganic treatments were calculated based on the NPK treatment' s nitrogen rate, with organic fertilizer applied according to the specified proportions and adjusted for phosphorus and potassium contributed by the organic source. Detailed nutrient application rates for each treatment are presented in .

The fertilizers used were rapeseed cake as organic fertilizer, urea as nitrogen fertilizer, calcium superphosphate as phosphorus fertilizer, and potassium chloride as potassium fertilizer. Basal and topdressing ratios followed local practices: for rapeseed, all organic fertilizer and phosphorus, plus 25% of nitrogen and 50% of potassium were applied as basal fertilizer incorporated during soil preparation, with the remainder applied as topdressing near the root zone; for cotton, all organic fertilizer and phosphorus, plus 25% of nitrogen and 50% of potassium served as basal fertilizer, with the remaining nitrogen and potassium applied as flower-boll fertilizer near the root zone. Field management followed standard local practices. Crop schedules were: cotton sown in mid-April, transplanted in mid-May, and harvested in late October; rapeseed sown in late September, transplanted in early November, and harvested in early May of the following year.

1.3 Sampling and Analysis Methods

At maturity of each crop season, all plots were individually harvested for yield measurement and sampling. After cotton harvest each year, five random sampling points were selected in each plot to collect 0–20 cm topsoil samples. Samples were air-dried and sieved through 1 mm and 0.25 mm mesh for determination of soil organic matter and nutrient contents. Soil organic matter was determined by the potassium dichromate volumetric method, total nitrogen by the Kjeldahl method, alkali-hydrolyzable nitrogen by the diffusion method, available phosphorus by the Olsen method, and available potassium by 1 mol $\cdot$ L^{-1} NH_4OAc extraction-flame photometry [19].

1.4 Data Statistics and Methods

Data processing and graphing were performed using Microsoft Excel, and statistical analysis was conducted using SPSS software.

2. Results

2.1 Crop Yield Variations Under Different Fertilization Treatments

presents the inter-annual variations in rapeseed and cotton yields under different fertilization treatments. The multi-year average cotton yields under 10%OM, 30%OM, and 50%OM treatments were 114.1%, 112.9%, and 124.5% of the NPK treatment, respectively; 133.9%, 132.4%, and 146.0% of the TF treatment; and 475.9%, 470.6%, and 519.2% of the CK treatment. The NPK treatment yielded 117.3% of TF, while NPK and TF yielded 416.9% and 355.5% of CK, respectively. The unfertilized control produced significantly lower cotton yields than all fertilized treatments, showing an overall declining trend despite annual fluctuations, with a 48.3% reduction from 2008 to 2012. All fertilized treatments increased cotton yields over time, though NPK showed rapid growth in the first two years followed by stagnation and decline with prolonged experimentation. Among organic treatments, cotton yields in 2012 increased by 73.2%, 60.7%, and 56.2% over 2008 levels under 50%OM, 30%OM, and 10%OM treatments, respectively, all exceeding the 45.6% increase under TF. Organic fertilization treatments not only maintained higher cotton yields but also exhibited lower inter-annual yield variation coefficients, demonstrating that organic-inorganic fertilization promotes both high and stable cotton production, with 50%OM being the optimal regime. The TF treatment, while outperforming CK, yielded less than all other fertilized treatments, indicating that local conventional fertilization practices require improvement in both nutrient structure and application rate for better economic returns.

For rapeseed, yield rankings across treatments were: 50%OM > 10%OM > 30%OM > NPK > TF > CK. The 10%OM, 30%OM, and 50%OM treatments produced yields of 128.3%, 124.3%, and 129.6% of NPK; 147.6%, 143.0%, and 149.0% of TF; and 335.7%, 325.2%, and 338.9% of CK, respectively. NPK yielded 115.0% of TF, while NPK and TF yielded 261.6% and 227.4% of CK, respectively. The unfertilized control showed a continuous decline in rapeseed yield, while fertilized treatments decreased from 2008–2010 then increased from 2010–2012, with substantial inter-annual variation. All fertilized treatments significantly outperformed the control, with NPK and TF showing smaller differences between them but both underperforming compared to organic-inorganic combinations, among which 50%OM achieved the highest yields.

2.2 Variations in Soil Organic Matter and Total Nitrogen Contents

[Figure 1: see original paper] illustrates changes in soil organic matter content. Organic-inorganic fertilization treatments and TF showed increasing trends, NPK exhibited an initial increase followed by decline, while CK showed a decreasing trend. Soil organic matter content increased with organic fertilizer application rate, with mean values ranking as: 50%OM > 30%OM > TF > 10%OM > NPK, indicating substantial fertilization mode effects. By 2012, the unfertilized control had decreased organic matter by 0.4 $g \cdot kg^{-1}$ (2.1%), while NPK increased by 2.2 $g \cdot kg^{-1}$ (11.4%) despite receiving no organic amendments, likely due to root and residue inputs. Organic-inorganic treatments showed remarkable increases: 50%OM, 30%OM, TF, and 10%OM increased organic matter by 11.1, 9.8, 6.6, and 6.4 $g \cdot kg^{-1}$, representing gains of 57.5%, 50.8%, 34.2%, and 33.2%, respectively. Regression analysis revealed linear relationships between organic matter content (y) and experimental year (x): 10%OM: $y = 1.50x + 18.58$ ($R^2 = 0.8514$); 30%OM: $y = 2.14x + 18.74$ ($R^2 = 0.8649$); 50%OM: $y = 2.42x + 18.96$ ($R^2 = 0.8401$); TF: $y = 1.46x + 18.82$ ($R^2 = 0.8554$). No significant correlations were found for NPK and CK. These relationships indicate annual organic matter increases of 1.50, 2.14, 2.42, and 1.46 $g \cdot kg^{-1}$ for 10%OM, 30%OM, 50%OM, and TF treatments, respectively, demonstrating that annual increments rise with organic fertilizer proportion.

[Figure 2: see original paper] shows total nitrogen content variations. Mean total nitrogen contents ranked as: 50%OM > 30%OM > TF > 10%OM > NPK > CK. The 50%OM treatment exceeded 10%OM, NPK, and CK by 14.29%, 22.22%, and 25.71%, respectively, while 30%OM surpassed NPK and CK by 18.06% and 21.43%. By 2012, the unfertilized control had decreased total nitrogen by 0.09 $g \cdot kg^{-1}$ (6.6%), likely due to low biomass production and insufficient natural nitrogen replenishment. NPK treatment showed minimal change (+0.05 $g \cdot kg^{-1}$) over five years, while organic-inorganic treatments increased substantially: 50%OM, 30%OM, and 10%OM increased by 0.52, 0.48, and 0.18 $g \cdot kg^{-1}$ (38.2%, 35.3%, and 13.2%), respectively, confirming that total nitrogen content rises with organic fertilizer application. Regression analysis for the 30%OM treatment yielded: y = 0.11x + 1.37 (R^2 = 0.6607), indicating an annual increase of 0.11 $g \cdot kg^{-1}$.

Soil organic matter and total nitrogen showed strong consistency across treatments. Over five years, both parameters exhibited similar trends, increasing with organic fertilizer rate and remaining significantly higher under organic-inorganic treatments compared to NPK and CK. The unfertilized control maintained low levels with gradual decline. Initial soil C/N ratio was 8.2; after five years, TF treatment reached 10.2, organic-inorganic treatments averaged 9.4, and NPK reached 8.8, while CK was 8.6. These results demonstrate that organic-inorganic fertilization more effectively replenishes soil organic matter, enhances nutrient supply capacity, and regulates nutrient release intensity and rate to provide balanced mineral nutrition throughout crop growth stages.

2.3 Variations in Soil Available Nutrient Contents

Nitrogen is one of the most active nutrient elements in soil, and alkali-hydrolyzable nitrogen content largely reflects soil nitrogen supply intensity [5]. As shown in [Figure 3: see original paper], CK treatment exhibited a declining trend, decreasing by 8.0% over five years, while all fertilized treatments increased to varying degrees. From 2008–2010, NPK treatment showed the fastest increase (39.2%), whereas organic-inorganic treatments increased more gradually. After 2011, NPK' s growth slowed while organic-inorganic treatments accelerated. By 2012, organic-inorganic treatments (10%OM, 30%OM, 50%OM) increased alkali-hydrolyzable nitrogen by 61.2–77.9 $mg \cdot kg^{-1}$ (51.2%-65.1%), NPK increased by 59.7 $mg \cdot kg^{-1}$ (49.9%), and TF increased by 44.4 $mg \cdot kg^{-1}$ (37.1%). After five years, organic-inorganic treatments showed the greatest increases, followed by NPK, with TF showing the smallest increase among fertilized treatments.

Regression analysis between experimental year (x) and alkali-hydrozable nitrogen content (y) yielded: 10%OM: y = 16.28x + 99.62 (R^2 = 0.9765), with annual increase of 16.28 $mg \cdot kg^{-1}$; 30%OM: y = 18.78x + 97.94 (R^2 = 0.9799), 18.78 mg·kg^{-1}; 50%OM: y = 21.31x + 97.93 (R^2 = 0.9633), 21.31 mg·kg^{-1}; TF: y = 12.08x + 104.48 (R^2 = 0.9718), 12.08 mg·kg^{-1}; NPK: y = 15.65x + 109.63 (R^2 = 0.9140), 15.65 mg·kg^{-1}. The CK regression showed R^2 below the reliability threshold of 0.6580. These results confirm that organic-inorganic treatments produced greater annual alkali-hydrolyzable nitrogen increases than NPK, which in turn exceeded TF.

Phosphorus has low mobility in soil and tends to accumulate. As shown in [Figure 4: see original paper], CK treatment decreased available phosphorus from 18.65 mg·kg^{-1} in 2008 to 6.3 mg·kg^{-1} in 2012 (66.2% reduction). Fertilized treatments showed gradual increases, with NPK producing the highest values in the first four years but falling below 50%OM in the fifth year. Chemical fertilizer rapidly increased available phosphorus initially, but the gap with organic-inorganic treatments narrowed and was eventually surpassed with continued experimentation. Available phosphorus increased with phosphorus input rate, with 10%OM, 30%OM, 50%OM, and TF showing similar growth trends and minimal differences. Regression analysis yielded: 10%OM: y = 0.94x + 18.07 (R^2 = 0.8476), annual increase 0.94 mg·kg^{-1}; 30%OM: y = 1.10x + 17.54 (R^2 = 0.8807), 1.10 mg·kg^{-1}; 50%OM: y = 1.53x + 16.78 (R^2 = 0.8791), 1.53 mg·kg^{-1}; TF: y = 10.70x + 17.20 (R^2 = 0.6350), low correlation; NPK: y = 1.23x + 18.21 (R^2 = 0.7335), 1.23 mg·kg^{-1}; CK: y = -2.99x + 20.98 (R^2 = 0.9872), annual decrease 2.99 mg·kg^{-1}. Thus, annual available phosphorus increases ranked: 50%OM > NPK > 30%OM > 10%OM, while CK declined continuously.

[Figure 5: see original paper] shows available potassium variations. CK treatment decreased by 15.9% over five years, while all fertilized treatments increased. Over five years, 50%OM, 30%OM, 10%OM, and TF increased by 17.8, 15.7, 15.4, and 11.6 mg·kg^{-1}, respectively, and NPK increased by 15.3 mg·kg^{-1}. Differences among fertilized treatments were modest, with 50%OM showing the highest increase (48.1%). Regression analysis yielded: 10%OM: y = 7.02x + 52.72 (R^2 = 0.8807), annual increase 7.02 mg·kg^{-1}; 30%OM: y = 6.95x + 53.22 (R^2 = 0.9182), 6.95 mg·kg^{-1}; 50%OM: y = 7.46x + 53.83 (R^2 = 0.9105), 7.46 mg·kg^{-1}; TF: y = 4.66x + 56.01 (R^2 = 0.9802), 4.66 mg·kg^{-1}; NPK: y = 5.96x + 55.80 (R^2 = 0.8187), 5.96 mg·kg^{-1}. These results indicate annual available potassium increases ranked: 50%OM > 10%OM > 30%OM > NPK, while CK declined.

3. Discussion

3.1 Effects of Fertilization on Upland Non-Grain Crop Yields

Crop yield represents the integrated performance of soil fertility, climatic conditions, and management practices [20], with fertilization being a critical measure for ensuring high and stable production. Previous long-term experiments have shown that both organic amendments and chemical fertilizers effectively increase crop yields with comparable effects [21], and that long-term chemical fertilization sustains high yields in cereal crops, while combined organic-inorganic fertilization represents a sustainable model for stable, high yields [22]. Our results confirm that while all fertilization treatments improved cotton and rapeseed yields, substantial differences existed among treatments, with 50%OM producing the highest yields. Interestingly, 10%OM outperformed 30%OM, indicating that yield does not necessarily increase linearly with organic fertilizer proportion. The TF treatment produced the lowest yields among fertilized treatments, likely because it neither accounted for indigenous soil nutrient supply nor crop nutrient requirements. This pattern differs from rice-based systems where yields typically increase with organic fertilizer proportion [20-23], and the >15% yield difference between TF and NPK exceeds that observed in rice-dominated systems. These discrepancies suggest that in the cotton-rapeseed system of Dongting Lake region, farmers' fertilization practices are less optimized than in rice systems, and crops respond more strongly to improved nutrient management, offering greater potential yield gains from rational fertilization.

Inter-annual yield variations revealed distinct patterns. CK cotton yields decreased by 48.3% by year five, while 50%OM, 30%OM, 10%OM, and TF increased by 73.2%, 60.7%, 56.2%, and 45.6%, respectively, with organic treatments showing lower inter-annual variation coefficients. NPK cotton yields grew rapidly initially but stagnated and declined with time. CK rapeseed yields fell by 52.8% by year five. From 2008-2010, organic-inorganic treatments decreased by 30.0%-38.5%, while NPK and TF decreased by 48.3% and 49.2%; from 2010-2012, organic-inorganic treatments increased by 41.9%-68.5%, NPK by 40.0%, and TF by only 20.1%. These variations were partially weather-driven: in 2010, low temperature and rain during late rapeseed growth impaired pod development, while in 2011, early and intense precipitation caused boll rot and abscission in cotton, reducing yields. Two key features emerged: (1) under identical weather conditions, both annual yields and yield increases ranked organic-inorganic > NPK > TF > CK; and (2) inter-annual yield fluctuations under TF or NPK exceeded those in rice-based systems. These results demonstrate that organic-inorganic fertilization not only enhances cotton and rapeseed yields but also substantially improves yield stability.

3.2 Effects of Fertilization on Upland Soil Organic Matter and Nutrient Contents

The effects of long-term organic and chemical fertilization on soil organic matter vary with soil type, fertilizer type, and rotation system [24-25]. Studies have shown that long-term fertilization omission decreases soil organic matter, while chemical fertilization increases root residues and thus modestly elevates organic matter, and organic fertilization maintains or increases organic matter levels. In southern subtropical regions, long-term experiments indicate that double-cropping rice systems maintain organic matter at 30-36 $g \cdot kg^{-1}$, while rice-upland rotations maintain about 25 $g \cdot kg^{-1}$ [15,21,24]. In contrast, our upland system maintained only 23.2 $g \cdot kg^{-1}$ under TF, 21.7 $g \cdot kg^{-1}$ under NPK, and approximately 24.9 $g \cdot kg^{-1}$ under organic-inorganic treatments, suggesting that moisture regime substantially influences organic matter levels. Among organic-inorganic ratios, higher organic proportions resulted in faster organic matter accumulation, confirming that organic inputs promote soil organic matter enhancement in proportion to application rate.

Continuous five-year fertilization omission decreased soil total nitrogen, indicating that natural nitrogen inputs cannot compensate for crop uptake under these conditions [26-28]. NPK increased total nitrogen by only 3.7% over initial levels, TF by 8.1%, while organic-inorganic treatments (averaging 50%OM, 30%OM, and 10%OM) increased by 28.9%. These substantial differences confirm that our nitrogen application rates were generally appropriate and consistent with previous research [26-28]. Organic fertilization more effectively increased soil nitrogen than chemical fertilization alone, reaffirming that combined application promotes nitrogen accumulation and improves soil fertility. The CK treatment showed declining available nitrogen, phosphorus, and potassium, while all fertilized treatments increased these nutrients, underscoring fertilization' s importance. Chemical nitrogen rapidly transforms to ammonium and nitrate, potentially causing ammonia volatilization and nitrate leaching [26,29], resulting in low retention, whereas organic nitrogen mineralizes slowly and persists in soil [28-29]. The increases in available nutrients under our experimental conditions were smaller than those in rice-based systems at equivalent application rates, possibly due to lower nutrient availability and higher nutrient demand under upland conditions, though underlying mechanisms require further investigation.

4. Conclusions

1. Fertilization significantly increased rapeseed and cotton yields, with organic-inorganic combinations outperforming NPK and TF treatments. The 50%OM treatment produced the highest yields, while the unfertilized control showed continuous yield decline.
2. Organic-inorganic fertilization increased soil organic matter, total nitrogen, available potassium, and alkali-hydrolyzable nitrogen contents, with 50%OM showing the greatest improvements. Soil available phosphorus correlated positively with phosphorus input, while the unfertilized control exhibited declining nutrient levels.
3. Based on these results, combined organic-inorganic fertilization is recommended for cotton-rapeseed rotation in the Dongting Lake region, with organic fertilizer providing approximately 50% of total nutrient input for optimal outcomes.

References

[1] Shen S M. The scientific value of long-term soil fertility experiment[J]. Plant Nutrition and Fertilizer Science, 1995, 1(1): 1–9

[2] Sun B, Zhu Z L, Niu D. Long-term experimental research on long-term ecological processes in agro-ecosystems: A review[J]. Soils, 2007, 39(6): 849–854

[3] Galantini J, Rosell R. Long-term fertilization effects on soil organic matter quality and dynamics under different production systems in semiarid Pampean soils[J]. Soil and Tillage Research, 2006, 87(1): 72–79

[4] Yang S M, Li F M, Suo D R, et al. Effect of long-term fertilization on soil productivity and nitrate accumulation in Gansu oasis[J]. Agricultural Sciences in China, 2006, 5(1): 57–67

[5] Xu Z X. Effects of long-term different fertilizer or manure application on crop yield and soil fertility[J]. Journal of Zhejiang Agricultural Science, 2007(4): 439–441

[6] Zhang Q C, Wang G H. Yield of inbred rice and hybrid rice and soil nutrient balance under long-term fertilization[J]. Plant Nutrition and Fertilizer Science, 2006, 12(3): 340–345

[7] Tang J W, Lin Z A, Xu J X, et al. Effect of organic manure and chemical fertilizer on soil nutrient[J]. Soil and Fertilizer Sciences in China, 2006(3): 44–47

[8] Shen H, Cao Z H. Effect of long-term fertilization on soil available carbon pool and available ratio of soil carbon under different agroecosystems[J]. Tropical and Subtropical Soil Science, 1998, 7(1): 1–5

[9] Saleque M A, Abedin M J, Bhuiyan N I, et al. Long-term effects of inorganic and organic fertilizer sources on yield and nutrient accumulation of lowland rice[J]. Field Crops Research, 2004, 86(1): 53–65

[10] Ragasits I, Debreczeni K, Berecz K. Effect of long-term fertilisation on grain yield, yield components and quality parameters of winter wheat[J]. Acta Agronomica Hungarica, 2000, 48(2): 155-163

[11] Sun H D, Zhu P, Liu S H, et al. The monitoring research of influence on fertility of black soil and crop yield by using organic and inorganic fertilizers[J]. Plant Nutrition and Fertilizer Science, 2002, 8(S1): 110–116

[12] Wang J F, Xing S Z. Negative effects of application chemical fertilizers on farmland and the control measures[J]. Agro-Environmental Protection, 1998, 17(1): 40–43

[13] Lin Z A, Zhao B Q, Yuan L, et al. Effects of organic manure and fertilizers long-term located application on soil fertility and crop yield[J]. Scientia Agricultura Sinica, 2009, 42(8): 2809–2819

[14] Shi X J, Mao Z Y, Zhao B Q, et al. On-site experimental study on the effects of rice straw returning on the fertility of purplish paddy soil and rice yields[J]. Plant Nutrition and Fertilizer Science, 2002, 8(S1): 16–20

[15] Wang S J, Chen Y, Li S Y. Balance of soil organic matter in a long-term triple cropping system in paddy fields[J]. Acta Pedologica Sinica, 2002, 39(1): 9–15

[16] Liu Y, Wang Y Q, Zhang X M, et al. Effect of Chinese milk vetch planting on soil fertility and rice yield[J]. Anhui Agricultural Science Bulletin, 2007, 13(1): 98–99

[17] Wang K F, Wang K R, Peng N, et al. Yield trends and reasons for their change in red-soil rice field with long-term organic matter circling[J]. Journal of Agro-Environment Science, 2007, 26(2): 743–747

[18] Li H, Ma C B, Lu J W, et al. Increasing effect of N, P and K fertilizer on rapeseed in different regions of China[J]. Scientia Agricultura Sinica, 2013, 46(9): 1837–1847

[19] Lu R K. Analytical Methods of Soil Agricultural Chemistry[M]. Beijing: Agricultural Science and Technology Press, 2000

[20] Sun Y J, Yang Z Y, Sun Y Y, et al. Effects of water-nitrogen management patterns and phosphorus and potassium fertilizer combined application on grain yield and quality of hybrid rice Gangyou 725 in rapeseed (wheat)-rice planting area of Chengdu plain[J]. Plant Nutrition and Fertilizer Science, 2014, 20(1): 17–18

[21] Zhang G R, Li J M, Xu M G, et al. Effects of chemical fertilizer and organic manure on rice yield and soil fertility[J]. Scientia Agricultura Sinica, 2009, 42(2): 543–551

[22] Liao Y L, Zheng S X, Nie J, et al. Effects of long-term application of fertilizer and rice straw on soil fertility and sustainability of a reddish paddy soil productivity[J]. Scientia Agricultura Sinica, 2009, 42(10): 3541–3550

[23] Huang Q R, Hu F, Li H X, et al. Crop yield response to fertilization and its relations with climate and soil fertility in red paddy soil[J]. Acta Pedologica Sinica, 2006, 43(6): 926–933

[24] Huang J, Gao J S, Zhang Y Z, et al. Change characteristics of rice yield and soil organic matter and nitrogen contents under various long-term fertilization regimes[J]. Chinese Journal of Applied Ecology, 2013, 24(7): 1889–1894

[25] Wu L Z, Cai Z C. Estimation of the change of topsoil organic carbon of croplands in China based on long-term experimental data[J]. Ecology and Environment, 2007, 16(6): 1768–1774

[26] Wang N N, Huang Q H, Xu M G, et al. The inter-annual characteristics of nitrogen recovery efficiency of double cropping rice system on paddy soil under long-term fertilization[J]. Plant Nutrition and Fertilizer Science, 2013, 19(2): 297–303

[27] Cai Z J, Sun N, Wang B R, et al. Effects of long-term fertilization on pH of red soil, crop yields and uptakes of nitrogen, phosphorous and potassium[J].

Plant Nutrition and Fertilizer Science, 2011, 17(1): 71-78

[28] Shen S M. Contribution of nitrogen fertilizer to the development of agriculture and its loss in China[J]. Acta Pedologica Sinica, 2002, 39(S1): 12-25

[29] Richter J, Roelcke M. The N-cycle as determined by intensive agriculture —Examples from central Europe and China[J]. Nutrient Cycling in Agroecosystems, 2000, 57(1): 33-46

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