Post-print: Dynamics of Soil Organic Carbon and Crop Yield Under Long-term Fertilization in Xinjiang Grey Desert Soil

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Abstract

To clarify the evolution characteristics of soil organic carbon and crop yields in Xinjiang grey desert soil under long-term different fertilization regimes, and based on a long-term monitoring experiment for grey desert soil fertility initiated in 1990, six treatments were selected: control (CK, no fertilizer), nitrogen-phosphorus fertilizer (NP), balanced nitrogen-phosphorus-potassium fertilization (NPK), NPK combined with conventional organic manure (NPKM), NPK combined with high-rate organic manure (hNPKM, with organic manure application rate being double that of NPKM), and NPK combined with straw return (NPKS). The evolution characteristics of soil organic carbon and wheat and maize yields under different treatments were analyzed, and the relationships between carbon input and organic carbon and crop yields were explored. The results showed: 1) Under long-term exhaustive cropping (CK) and continuous application of NP or NPK fertilizers, the organic carbon content in grey desert soil continued to decline, with annual decrease rates of 0.094 g · kg 1, 0.043 g · kg 1, and 0.053 g · kg 1, respectively, indicating that chemical fertilizer application (NP, NPK) could not maintain soil organic carbon content and was not conducive to soil fertility preservation. Under NPKM and hNPKM treatments, soil organic carbon increased significantly, with annual increases of 0.360 g · kg 1 and 0.575 g · kg 1, respectively, demonstrating that increasing organic manure application is an important measure for rapidly improving grey desert soil fertility. Under the straw return treatment (NKPS), soil organic carbon increased by 0.006 g · kg 1 annually; compared with the NPK treatment, although straw return did not substantially increase soil organic carbon, it maintained soil fertility. 2) Compared with CK, long-term combined application of chemical and organic fertilizers (NPKM, hNPKM) significantly increased crop yields ($P<0.05$). Compared with NP and NPK, long-term combined chemical and organic fertilizer application significantly increased wheat yield ($P<0.05$), but the difference in maize yield with chemical fertilizer treatments was not significant ($P>0.05$). The highest increase in maize yield was achieved with balanced fertilization (NPK), reaching 220 kg · hm 2 · a 1. The coefficient of variation for wheat yield (29.1%~43.9%) was higher than that for maize yield (19.0%~32.7%). The wheat yield increase magnitude under the chemical fertilizer combined with straw return (NPKS) treatment was close to that under the high-rate organic manure application (hNPKM) treatment, indicating that the role of straw return in crop yield increase cannot be ignored. 3) Carbon input showed a significant linear positive correlation with soil organic carbon and wheat and maize yields ($P<0.05$). Based on the above analysis, increasing soil carbon input (organic manure or straw) remains the most fundamental soil fertility improvement measure in grey desert soils of arid regions.

Full Text

Evolution of Soil Organic Carbon and Crop Yield Under Long-Term Fertilization in Xinjiang Grey Desert Soils

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Abstract

To clarify the evolution characteristics of soil organic carbon (SOC) and crop yield in Xinjiang grey desert soils under long-term different fertilization regimes, this study analyzed SOC content and yield trends of wheat and maize based on a long-term fertility monitoring experiment initiated in 1990. Six treatments were selected: control (CK, no fertilizer), nitrogen-phosphorus fertilizer (NP), balanced nitrogen-phosphorus-potassium fertilizer (NPK), NPK combined with constant manure (NPKM), NPK combined with high manure (hNPKM, with manure application rate double that of NPKM), and NPK combined with straw return (NPKS). The relationships between carbon input and SOC as well as crop yield were investigated. The results showed that: (1) Under continuous cropping without fertilization (CK) or continuous application of NP or NPK fertilizers, SOC content in grey desert soil decreased continuously at annual rates of 0.094 $g \cdot kg^{-1}$, 0.043 $g \cdot kg^{-1}$, and 0.053 $g \cdot kg^{-1}$, respectively, indicating that chemical fertilizer application (NP, NPK) could not maintain SOC content and was unfavorable for soil fertility preservation. Under NPKM and hNPKM treatments, SOC increased significantly at annual rates of 0.360 $g \cdot kg^{-1}$ and 0.575 $g \cdot kg^{-1}$, respectively, demonstrating that increased manure application is an important measure for rapidly improving grey desert soil fertility. Under straw return treatment (NPKS), SOC increased at a modest annual rate of 0.006 $g \cdot kg^{-1}$, suggesting that while straw return did not substantially increase SOC compared with NPK treatment, it helped maintain soil fertility. (2) Compared with CK, long-term combined application of chemical and organic fertilizers (NPKM, hNPKM) significantly increased crop yields ($P < 0.05$). Compared with NP and NPK treatments, combined chemical-organic fertilization significantly increased wheat yield ($P < 0.05$), but the difference in maize yield was not significant ($P > 0.05$). The highest maize yield increase was achieved under balanced NPK fertilization, reaching 220 $\mathrm{kg \cdot hm^{-2} \cdot a^{-1}}$. The coefficient of variation for wheat yield (29.1%-43.9%) was higher than that for maize yield (19.0%-32.7%). The wheat yield increase under NPKS treatment was comparable to that under high manure application (hNPKM), indicating that the effect of straw return on crop yield enhancement cannot be ignored. (3) Carbon input showed significant linear positive correlations with SOC and wheat and maize yields ($P < 0.05$). Based on these analyses, increasing soil carbon input (through manure or straw) remains the most fundamental measure for soil fertility improvement in grey desert soils of arid regions.

Keywords: Long-term fertilization; Grey desert soil; Soil organic carbon; Crop yield evolution; Carbon input

Introduction

Soil fertility and crop yield improvement have always been the focus of agricultural research. Soil organic carbon (SOC) is a primary indicator of soil fertility and a representative metric in soil science research, playing a crucial role in ecosystem productivity, agroecosystem function, and farmland fertility. SOC maintains suitable soil physicochemical properties and provides carbon sources for crop growth, making it essential for ensuring land productivity and food security. Xinjiang grey desert soil covers an area of 1.7895 million hectares and represents the main zonal soil in northern Xinjiang as well as important agricultural soil in the Tianshan North Slope Economic Belt. Due to its distribution in arid and semi-arid regions, soil infertility is a major limiting factor for high and stable crop yields, making rapid improvement of SOC in grey desert soils critical for promoting agricultural development in Xinjiang.

Numerous studies have shown that reasonable agricultural practices such as organic manure application, chemical fertilizer use, or straw return can increase farmland SOC. The famous long-term experiments at Rothamsted (UK, started 1843) and Morrow (USA, started 1888) have reported that long-term chemical fertilizer (N, P, K) application increased SOC compared with control plots, and combined chemical-organic fertilization significantly improved SOC content and crop yield. Similar results have been confirmed in China through long-term fertility monitoring experiments in red soil, black soil, Lou soil, and cinnamon soil. Regarding the relationship between SOC and crop yield, Qiu et al. simulated the effects of changing SOC baseline values on crop yields across six cropping patterns in China, finding that each 1 $\mathrm{g(C) \cdot kg^{-1}}$ increase in SOC increased crop yields by 176-454 $\mathrm{kg \cdot hm^{-2}}$ depending on the region. These studies have clarified the effects of organic and chemical fertilizers on SOC and productivity.

Although some research exists on organic carbon and yield changes under different soil types and fertilization measures, results cannot cover all soil types due to regional differences, soil baseline values, or variations in experimental methods and monitoring periods. Additionally, the lack of long-term experimental data in arid regions has limited research on the evolution of fertilization effects on organic carbon and yields in Xinjiang oasis grey desert soils. This study, based on the long-term Xinjiang grey desert soil fertility and fertilizer effect experiment, analyzed SOC and yield evolution trends under different long-term fertilization conditions, quantitatively described the relationships between carbon input differences caused by chemical fertilizer, organic manure, and straw return and their effects on SOC and crop yields, providing a basis for selecting appropriate soil fertility improvement measures for Xinjiang grey desert soils.

1.1 Study Area Description

The long-term fertilization experiment is located in the National Modern Agricultural Science and Technology Demonstration Garden of Xinjiang Academy of Agricultural Sciences, 25 km north of Urumqi, Xinjiang (N43°95$ ‘26’ ‘, *E*87°46’ 45’ ’ $). The experimental area belongs to a typical Central Asian arid region mountain-oasis ecosystem, with an elevation of 600 m, mean annual precipitation of 310 mm, mean annual evaporation of 2,570 mm, and aridity index of 8.29. The mean annual temperature is 7.7 °C, average sunshine duration is 2,590 h, and frost-free period is 156 days. The experimental soil is grey desert soil, with initial basic physicochemical properties shown in Table 1 .

1.2 Experimental Design

The long-term fertility monitoring experiment was initiated in 1990, with the study period covering 1990–2013 (24 years). The experiment included 12 fertilization treatments ranging from no fertilizer to continuous chemical fertilizer and chemical fertilizer combined with organic manure. This study selected six treatments for sampling and analysis. Specific annual nutrient inputs are shown in Table 2 . Nitrogen, phosphorus, and potassium fertilizers were applied as urea (46.0% N), diammonium phosphate (18.0% N, 20.1% P), and potassium sulfate (44.8% K), respectively. Based on actual agricultural production practices, fertilizer application rates were divided into two periods: 1990–1994 and 1995–present. The organic manure used was decomposed sheep manure containing 8.0 $g \cdot kg^{-1}$ N, 2.3 $g \cdot kg^{-1}$ P, and 3.0 $g \cdot kg^{-1}$ K. For the straw return treatment, all aboveground biomass was crushed and returned to the field after harvest each year.

1.3 Field Management

Each experimental plot measured 34.9 m × 13.4 m (468 m^2). Precast reinforced concrete panels were buried 70 cm deep between plots, with 10 cm exposed above ground plus earthen ridges to prevent water seepage and fertilizer leakage. Due to historical constraints, the long-term experiment was not replicated. However, given the large plot size, each treatment was divided into three subplots for sampling to compensate for the lack of replication.

Irrigation and fertilization methods: Before 2008, furrow irrigation was used; since 2008, drip irrigation has been adopted. For chemical fertilizers, 60% of total nitrogen and 100% of phosphorus and potassium were applied as basal fertilizer, broadcast uniformly on the surface before deep plowing and sowing. The remaining 40% of nitrogen was top-dressed during the first spring irrigation. Since 2008, this portion has been applied in split doses through drip irrigation. Organic manure was generally applied in autumn. Straw was returned by crushing all aboveground biomass after harvest and incorporating it through deep plowing.

Cropping system: Before 1999, a maize-spring wheat-winter wheat rotation was used. In 1999, one cotton season was planted, and 2000-2008 returned to the maize-spring wheat-winter wheat rotation. Since 2009, the rotation has been cotton-maize-winter wheat. Therefore, the main crops were wheat and maize, which were the focus of this study for yield and soil changes.

Sowing and harvest times: Winter wheat was sown in mid-September and harvested around July 20 of the following year. Spring wheat was sown around March 20 and harvested around July 25. Maize was sown around April 25 and harvested around September 20.

Crop varieties: Local dominant cultivars were used, generally updated versions of the same series. Winter wheat varieties included ‘Xindong 17’ , ‘Xindong 18’ , and ‘Xindong 28’ ; spring wheat varieties were ‘Xinchun 2’ , ‘Xinchun 8’ , and ‘Xinchun 18’ ; maize varieties were ‘SC704’ , ‘Xinyu 7’ , and ‘Xinyu 12’ .

1.4 Soil Sampling and Analysis

Soil samples were collected annually after crop harvest using a diagonal sampling method. A 5-cm diameter stainless steel auger was used to collect soil from 0-20 cm and 20-40 cm depths, with five sampling points mixed per subplot. After collection, crop roots and stones were removed, and samples were air-dried and ground to pass a 0.25-mm sieve for SOC determination. SOC was measured using the potassium dichromate volumetric method (DB/6500 B11 1440-87). Data were analyzed using SPSS software for ANOVA and Duncan’s new multiple range test for multiple comparisons. Microsoft Excel was used for basic data calculations and graphing.

1.5 Calculation Methods for Carbon Input from Crop Residues, Manure, and Straw

Carbon input calculations followed the method of Jiang (2013):

1) **Crop residue carbon input**
   Wheat root residue carbon input $[\mathrm{t(C)} \cdot \mathrm{hm}^{-2}] = [(\mathrm{Yg} + \mathrm{Ys}) \times 30\%/70\%$

× (1 - Rs) + Ys × Rs] × (1 - 0.14) × 0.399/1,000
Maize root residue carbon input [$t(C) \cdot hm^{-2}$] = [(Yg + Ys) × 26%/74% × (1 - Rs) + Ys × Rs] × (1 - 0.14) × 0.444/1,000

Where: Yg is grain yield; Ys is straw yield; Rs is stubble retention coefficient (18.3% for wheat CK, 13.1% for other wheat treatments, and 3% for all maize treatments); 30% and 26% are the proportions of photosynthetic carbon allocated to underground parts for wheat and maize, respectively; 70% and 74% are the corresponding aboveground proportions; 73.5% and 85.1% are the proportions of wheat and maize root systems distributed in the 0–20 cm soil layer; 0.14 is air-dry moisture content; 399 and 444 are the oven-dry carbon contents ($g \cdot kg^{-1}$) for wheat and maize, respectively; 1,000 is the unit conversion factor.

2) **Manure carbon input**
According to the *Chinese Organic Fertilizer Nutrient Manual*, sheep manure contains 188 $g \cdot kg^{-1}$ carbon with 50% moisture content. This study estimated that 80% of sheep manure was applied in the 0–20 cm tillage layer.
Manure carbon input [$t(C) \cdot hm^{-2}$] = Manure carbon content × (1 - W%) × Fresh manure weight/1,000
Where W% is manure moisture content.

3) **Straw carbon input**
Wheat straw carbon input = Wheat straw yield × (1 - 0.14) × 0.399
Maize straw carbon input [$t(C) \cdot hm^{-2}$] = Maize straw yield × (1 - 0.14) × 0.444
Where 0.399 and 0.444 are the average oven-dry organic carbon contents for wheat and maize, respectively, and 0.14 is air-dry moisture content.

Results

2.1 Effects of Long-Term Different Fertilization Treatments on SOC

SOC is an important indicator of soil fertility. Long-term application of chemical and organic fertilizers significantly altered SOC content. This study analyzed the evolution trend of SOC in the topsoil layer (0–20 cm) of grey desert soil under different fertilization treatments from 1990–2013. The results showed that SOC changes followed clear patterns [Figure 1: see original paper]. Under long-term no fertilization, continuous NP fertilizer, or NPK fertilizer application, SOC content fluctuated annually. Each monitoring result represented the balance between SOC input and output under different long-term fertilization conditions, so the most recent test results could indicate the cumulative effects of different fertilization practices on SOC. Using the initial SOC value of 8.800 $g \cdot kg^{-1}$ as the baseline, SOC content after 24 years decreased to 6.541 $g \cdot kg^{-1}$ under CK (annual decrease of 0.094 $g \cdot kg^{-1}$), while continuous NP and NPK treatments decreased to 7.772 $g \cdot kg^{-1}$ and 7.540 $g \cdot kg^{-1}$ (annual decreases of 0.043 $g \cdot kg^{-1}$ and 0.053 $g \cdot kg^{-1}$, respectively). SOC content under NP and NPK treatments was slightly higher than CK but not significantly different ($P > 0.05$). These results demonstrate that chemical fertilizer application (NP, NPK) could not maintain SOC content and was detrimental to soil fertility preservation.

Continuous NPK fertilizer combined with high or constant manure application significantly increased SOC values [Figure 1: see original paper]. SOC content under hNPKM and NPKM treatments increased from 8.800 $g \cdot kg^{-1}$ to 22.600 $g \cdot kg^{-1}$ and 17.430 $g \cdot kg^{-1}$, respectively, with annual increases of 0.575 $g \cdot kg^{-1}$ and 0.360 $g \cdot kg^{-1}$. Therefore, manure application had significant effects on improving fertility of grey desert soils with low SOC baseline values. After 24 years of NPK fertilizer combined with straw return, SOC content was 8.945 $g \cdot kg^{-1}$, an increase of 0.145 $g \cdot kg^{-1}$ from the initial value (annual increase of 0.006 $g \cdot kg^{-1}$). Compared with NPK treatment, straw return did not substantially increase SOC but compensated for the insufficient carbon input from NPK fertilizer alone, thereby maintaining soil fertility.

Linear regression analysis of the relationship between SOC content and fertilization years showed that long-term high or constant manure application significantly increased SOC, with a significant linear positive correlation with fertilization years ($P < 0.01$) at accumulation rates of 0.626 $g \cdot kg^{-1} \cdot a^{-1}$ and 0.305 $g \cdot kg^{-1} \cdot a^{-1}$, respectively . Manure application increased the accumulation rate, which improved with increasing manure application rate. The equations also showed that SOC content under CK treatment had a significant linear negative correlation with fertilization years ($P < 0.01$), decreasing at a rate of 0.056 $g \cdot kg^{-1} \cdot a^{-1}$. Correlations between SOC content and fertilization years under NP, NPK, and NPKS treatments were not significant ($P > 0.05$).

2.2 Evolution of Crop Yield Under Long-Term Different Fertilization Treatments

From 1990–2013, the experimental area planted 12 wheat seasons and 8 maize seasons. Analysis of yield evolution characteristics showed that, compared with CK, long-term chemical fertilizer or chemical-organic fertilizer application significantly increased crop yields, with yield changes following a linear increasing trend, while unfertilized crop yields showed a slow decreasing trend [Figure 2: see original paper].

Analysis of yield variation coefficients under different treatments showed that, under continuous long-term fertilization, wheat yield variation coefficient (29.1%-43.9%) was higher than maize yield variation (19.0%-32.7%). Additionally, organic and chemical fertilizers had different effects on crop yield change rates. The yield change rate for wheat under high manure application was higher than under chemical fertilizer, while for maize, balanced fertilization showed the maximum yield change rate .

ANOVA for non-replicated experiments showed different yield change patterns between wheat and maize. In wheat seasons, CK produced the lowest yield. NP, NPK, and NPKS treatments were significantly higher than CK ($P < 0.05$), while organic fertilizer treatments (hNPKM, NPKM) were significantly higher than

NP, NPK, and NPKS ($P < 0.05$). Analysis of annual yield increases showed wheat yield increases of 153.1 $kg \cdot hm^{-2}$, 175.2 $kg \cdot hm^{-2}$, 163.7 $kg \cdot hm^{-2}$, 180.8 $kg \cdot hm^{-2}$, and 179.2 $kg \cdot hm^{-2}$ for NP, NPK, NPKM, hNPKM, and NPKS treatments, respectively . Combined organic material application increased wheat yield substantially, particularly noteworthy was that wheat yield increase under NPKS treatment was comparable to high manure application, indicating that straw return effects on crop yield enhancement cannot be ignored. Yield variation coefficients for fertilization treatments ranged from 44.1% to 49.7%. Wheat yield under CK decreased by 4.71 $kg \cdot hm^{-2}$ annually, though not significantly ($P > 0.05$).

Maize yield showed different patterns. Fertilization treatments were significantly higher than CK ($P < 0.05$), but differences between chemical fertilizer (NP, NPK) and organic fertilizer treatments (NPKM, hNPKM, NPKS) were not significant. Comparison of annual maize yield increases showed the ranking: NPK > hNPKM > NPKS > NPKM > NP > CK, with balanced fertilization showing the highest increase. NPK, hNPKM, and NPKS treatments showed significant linear increases ($P < 0.05$) with variation ranges of 0.4%-2.7%, while NP and NPKM treatments showed increasing trends (annual increases of 123.0 $kg \cdot hm^{-2} \cdot a^{-1}$ and 170.0 $kg \cdot hm^{-2} \cdot a^{-1}$, respectively) that were not significant ($P > 0.05$). Unfertilized maize yield decreased by 6.2 $kg \cdot hm^{-2} \cdot a^{-1}$, also not significant ($P > 0.05$) .

2.3 Differences in Carbon Input Among Fertilization Treatments and Their Relationships with SOC and Crop Yield

Fertilization contributions to crop yield were significant. While forming economic yield, crops return consumed soil nutrients through biological yield (straw return) and underground root residues. Therefore, even without organic fertilizer application, residue return can supplement some soil fertility losses, creating large gradients in carbon input differences among fertilization measures. Table 5 shows average annual carbon inputs under different fertilization treatments from 1990-2013. CK treatment had significantly lower annual carbon input than other treatments, related to low crop biomass and consequently low underground root residue amounts. Compared with no fertilization and NPK fertilizer, organic fertilizer treatments had annual carbon inputs 6.24-10.3 times and 2.94-4.86 times higher, respectively. Although NPKS treatment had annual carbon inputs 4.89 and 2.35 times higher than no fertilization and chemical fertilizer treatments, respectively, crop yields were not significantly different from NP and NPK treatments , possibly because straw carbon decomposition rates are high, resulting in loss before conversion to stable carbon forms.

Using CK as reference, relative yields of wheat and maize under fertilization treatments (yield differences from CK) were plotted against carbon input values [Figure 3a: see original paper]. Results showed significant linear positive correlations between annual relative carbon input and relative average yields of both maize and wheat: y_{wheat} = 136.5x + 3,323.9 ($R^2 = 0.57$*), y_{maize}*

$= 138.1x + 3{,}290.4$ ($R^2 = 0.79$). This indicates similar relative yield increases for wheat and maize under the same carbon input conditions. Further analysis of the relationship between carbon input and SOC showed that SOC content increased significantly with carbon input, following a linear positive correlation: $y = 2.37x + 5.53$ ($R^2 = 0.983$, $P < 0.01$) [Figure 3b: see original paper], indicating that SOC content in grey desert soils depends on the cumulative effects of SOC input, and carbon input differences are the fundamental cause of SOC content variations.

Discussion

3.1 Changes in SOC

The significant SOC increase under long-term manure or straw application has been proven in many studies. In this experiment, SOC content increased significantly under manure application and straw return, consistent with existing literature. Therefore, combined chemical-organic fertilization technology is the primary measure for improving grey desert soil fertility. However, whether chemical fertilizer alone can increase SOC remains controversial. Li et al. studied the effects of different fertilization on soil profile SOC in Fukang grey desert soils, finding that after 20 years of fertilization, all fertilization treatments had SOC contents 14%-56% higher than initial values, while unfertilized treatment decreased by 33%. Whitbread et al. also showed that long-term chemical fertilizer application increased crop yield and consequently underground crop residues, leading to higher SOC than unfertilized treatments. However, different results exist. Zhang et al. studied total SOC changes under long-term fertilization in black soil, grey desert soil, and red soil, finding that NP treatment maintained initial values in all three soils, while after 16 years, NPK treatment maintained SOC in black soil, decreased SOC significantly in grey desert soil, and increased SOC significantly in red soil. These differences may relate to soil type, regional ecological and climatic conditions, soil baseline values, and experimental observation periods. In this experiment, NP or NPK fertilization showed slow SOC decreases, while chemical fertilizer significantly increased crop yield, implying that root-derived residue carbon was insufficient to compensate for carbon losses in grey desert soils and could not maintain soil fertility. Additionally, Li et al. showed that wheat straw return significantly increased SOC in grey desert soils, while in this study, NPKS treatment increased SOC compared with initial soil and NPK treatment but not significantly. Therefore, under similar soil types and climatic conditions, straw return methods significantly affect SOC change trends, warranting further research.

3.2 Crop Yield Changes

Soil fertility improvement is ultimately reflected in crop productivity enhancement. Wang collected data from 24 long-term experiments across 18 provinces from 1979-2008, analyzing fertilization effects on SOC and crop productivity.

The results showed that in 106 upland and 50 paddy samples, chemical fertilizer application increased SOC by 1.00 $g \cdot kg^{-1}$, 1.25 $g \cdot kg^{-1}$, and 2.17 $g \cdot kg^{-1}$ for wheat, maize, and rice, respectively, corresponding to average yield increases of 173.5%, 204.0%, and 45.0%. This indicates that chemical fertilizer increased SOC content and promoted crop yield increases. Zhang et al. and Yang et al. obtained similar results analyzing wheat and maize yields under long-term different fertilization in southern red soil uplands and northern loess soils. This experiment showed similar evolution trends of organic carbon and yield in grey desert soils compared with red soil or loess soils, but differed in that chemical fertilizer application continuously increased crop yield while SOC content decreased, implying that crop yield formation in grey desert soils consumes organic carbon.

Increasing SOC through organic material application (manure, straw return) has been proven an important farmland fertility measure in research and practice worldwide. However, in Xinjiang' s arid oasis grey desert soils, evaluation of long-term differential fertilization effects on SOC remains inconsistent, mainly regarding: (1) whether chemical fertilizer application can increase SOC while improving yield, and (2) whether straw return can significantly increase SOC content. Using monitoring data from 1990-2013 from the Xinjiang grey desert soil long-term experiment, this study examined SOC and crop yield changes under long-term no fertilization, chemical fertilizer, and organic fertilizer applications. The results showed that no fertilization or NP/NPK chemical fertilizer application decreased SOC by 0.056-0.002 $g \cdot kg^{-1}$, long-term manure application increased SOC by 0.305-0.626 $g \cdot kg^{-1}$ annually, and straw return increased SOC by 0.004 $g \cdot kg^{-1}$ annually. These results provide references for objectively evaluating the effects of chemical and organic fertilizers on SOC in grey desert soils.

Land productivity shows good correlation with SOC content. SOC content results from the balance between mineralization and accumulation of exogenous carbon input and has a significant linear relationship with carbon input. Although fertilization systems differ in agricultural production, carbon input under different fertilization conditions can be calculated by measuring organic manure carbon content and root residue carbon content to analyze relationships between carbon input and crop yield. In this study, wheat and maize yields showed good linear relationships with carbon input, making them reference indicators for predicting crop yields under certain conditions.

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