Effects of Equal-Nitrogen Combined Organic Fertilizer Application on Crop Yield and Nutrient Balance in Karst Peak-Cluster Depression Farmland (Postprint)

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Abstract

Based on a long-term located fertilization experiment of maize/soybean intercropping initiated in 2006 in the karst peak-cluster depression region of Guangxi, monitoring data from 2010-2014 were selected to investigate the effects of different proportions of organic manure replacing inorganic nitrogen fertilizer on crop yields and soil nutrients in the maize/soybean intercropping system under equal nitrogen input conditions, providing a theoretical basis for efficient fertilization and improved soil fertility in karst peak-cluster depression farmland. The experiment consisted of four treatments: control (no fertilizer, CK), balanced chemical fertilizer application (NPK), organic manure replacing 30% of chemical fertilizer nitrogen (C7M3, calculated based on nitrogen content, with insufficient PK supplemented by inorganic fertilizer, total fertilizer amount same as NPK treatment, organic manure was cattle manure, hereinafter the same), and organic manure replacing 60% of chemical fertilizer nitrogen (C4M6, calculated based on nitrogen content, with insufficient PK supplemented by inorganic fertilizer), with four replicates per treatment. Soil samples were collected after soybean harvest in 2010, 2012, and 2014 to determine soil nutrient status. The results showed: 1) Soil organic matter, total nitrogen, available phosphorus, and available potassium contents in fertilization treatments were all higher than those in CK treatment, among which organic matter content in C4M6 treatment was significantly higher than that in NPK treatment ($P<0.05$), and total nitrogen, available phosphorus, and available potassium contents increased with increasing organic manure application rate. 2) Long-term different fertilization treatments resulted in maize and soybean yields being 4.15-4.36 times and 2.47-2.58 times those of the no-fertilizer treatment, respectively. The yield increase effect of different fertilization treatments was C4M6>NPK>C7M3, but differences among fertilization treatments were not significant (P>0.05). 3) In the long-term no-fertilizer CK treatment, maize yield showed a decreasing trend with experimental years, with a decrease of 5.45 g · m^{2} · a^{1}, while soybean yield showed an increasing trend, with an increase of 1.50 g · m^{2} · a^{1}. In long-term fertilization treatments, both maize and soybean yields showed an overall increasing trend. 4) In fertilization treatments, potassium deficit occurred in the maize season (except for NPK treatment), while nitrogen deficit occurred in the soybean season. Considering both crop seasons, only C4M6 showed potassium deficit, with a deficit amount of 7.9 kg · hm^{2}. Phosphorus surplus was relatively large in all fertilization treatments, being 81.2 kg · hm^{2} (NPK), 83.4 kg · hm^{2} (C7M3), and 74.8 kg · hm^{2} (C4M6), respectively. In summary, under the maize/soybean intercropping system in karst peak-cluster depressions, based on crop yield and apparent soil nutrient balance characteristics, it is proposed that organic manure can replace part of chemical fertilizer application, with fertilization measures of appropriately "reducing nitrogen, stabilizing phosphorus, and increasing potassium" in the maize season, and "stabilizing nitrogen, reducing phosphorus, and reducing potassium" in the soybean season.

Full Text

Preamble

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Effect of Partial Replacement of Inorganic N with Organic Manure on Crop Yield and Soil Nutrient Balance in Arable Ecosystem in Karst Peak-Cluster Depression

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Abstract: Based on a long-term experiment on maize-soybean relay intercropping system in the karst peak-cluster depression in Guangxi, the effects of organic nitrogen (manure) in place of chemical nitrogen (fertilizer) on crop yield and soil nutrient balance were investigated. The experiment was started in 2006, and the data were collected in 2010–2014. Four treatments with four repetitions were designed in the study –including CK (no fertilizer), NPK (chemical fertilizer in maize at N 200 kg · hm^{2}, P O 90 kg · hm^{2}, K O 120 kg · hm^{2}; and in soybean at N 22.5 kg · hm^{2}, P O 60 kg · hm^{2}, K O 67.5 kg · hm^{2}), C7M3 (the total amounts of N, P and K were same as NPK treatment, in which 70% N was from chemical fertilizer and 30% N from organic cattle manure), and then C4M6 (60% N was from organic cattle manure and 40% N from chemical fertilizer, the amounts of P and K were the same as the treatment NPK). The results showed that: 1) compared with CK, treatments of NPK, C7M3 and C4M6 all increased soil organic matter (SOM), total nitrogen (TN), available phosphorus (AP) and available potassium (AK). Furthermore, SOM content in C4M6 was significantly higher than that in NPK ($P < 0.05$). The contents of TN, AP and AK increased with increasing organic manure supplement. 2) The yields of maize and soybean in the fertilizer treatments were respectively 4.15–4.36 and 2.47–2.58 times higher than that in CK. Crop yield order in fertilizer treatments was C4M6 > NPK > C7M3, but there was no significant difference among treatments ($P > 0.05$). 3) For CK treatment, maize yield decreased by 5.45 g·m ^{2}· a ^{1}, while soybean yield increased by 1.50 g·m ^{2}·a ^{1} during experimental period. The yields of both maize and soybean increased under long-term fertilization as the experiment went on. 4) In the experiment, K deficit was observed in organic manure treatments and CK during maize growth period, but N deficit appeared in all treatments during soybean growth period. In the maize-soybean relay intercropping system, K deficit of 7.9 kg·hm ^{2}·a ^{1} was observed only in C4M6. P surplus was observed for all fertilizer treatments with surplus amounts of 81.2 kg(P)·hm ^{2}, 83.4 kg(P)·hm ^{2} and 74.8 kg(P)·hm ^{2} in NPK, C7M3 and C4M6 treatments, respectively. In summary, based on the characteristics of nutrient balance and crop yield, that partial replacement of chemical nitrogen fertilizer by cattle manure was reasonable. We recommend that farmers should "reduce N, maintain P and increase K" during maize growth period, but should "maintain N and reduce P and K" in soybean growth period in maize-soybean agricultural ecosystem in karst peak-cluster depression areas.

Keywords: Karst peak-cluster depression; Maize-soybean relay intercropping; Replacement of chemical fertilizer with organic manure; Crop yield; Nutrient balance

Peak-cluster depression is the main type of karst landform in Guangxi, most extensively and continuously distributed in the northwestern part of the region. The ecological environment in peak-cluster depression areas is extremely fragile, characterized by shallow soil layers where agricultural disturbances easily trigger soil erosion and leakage, leading to rocky desertification and ecosystem degradation. Consequently, farmland in this region is predominantly low-to-medium yield with nutrient deficiency or imbalance. Maintaining stable or increased crop production while preserving land use sustainability is particularly crucial for agricultural production in northwestern Guangxi peak-cluster depression areas. Applying organic manure increases soil organic matter and carbon-nitrogen storage, serving as an important measure to improve soil physicochemical properties and enhance soil fertility. Meanwhile, combined application of organic and inorganic fertilizers integrates the quick-acting nature of chemical fertilizers with the persistent effects of organic manure, playing a significant role in improving land productivity and soil properties. Research by Lin et al. demonstrated that both organic and chemical fertilizers continuously increased soil organic carbon and nitrogen content, with organic fertilizer showing superior effects that increased with application rate. Gao et al. analyzed 25 years of maize yield data under long-term fertilization in black soil regions, finding that chemical fertilizer alone or combined with organic fertilizer significantly increased maize yield compared to no fertilization, with organic-inorganic combined application showing an overall upward yield trend, though no significant difference was observed between equal nitrogen input from chemical fertilizer versus chemical-organic combinations. Chen et al. investigated the effects of different proportions of organic nitrogen replacing chemical nitrogen on wheat growth and nitrogen use efficiency in yellow-brown soil areas, finding that 25% organic nitrogen replacement yielded the best results. Investigations revealed that fertilizer input in Guangxi peak-cluster depression agriculture is dominated by nitrogen fertilizer, with insufficient organic manure application and even less combined organic-chemical fertilization. Meanwhile, with the development of local livestock, sericulture, and processing industries for sugarcane, cassava starch, and jasmine tea, large quantities of organic wastes such as livestock manure, sugarcane filter mud, cassava peels, cassava starch residue, and jasmine residue are generated. These organic waste resources have not been scientifically and rationally utilized, causing safety hazards such as farmland and groundwater pollution.

This study, based on a long-term fertilization experiment initiated in 2006, analyzed the effects of equal nitrogen input with different proportions of organic manure replacement on crop yield and nutrient balance in the traditional maize-soybean relay intercropping system in karst peak-cluster depression areas. The objective was to explore the effectiveness of organic manure nitrogen replacing chemical nitrogen fertilizer and provide data support for designing reasonable manure-chemical fertilizer ratios, thereby offering a scientific basis for local rural resource utilization of organic wastes.

1.1 Study Area Description

The experimental site is located at the Huanjiang Observation and Research Station for Karst Ecosystems, Chinese Academy of Sciences (24°43 N–24°45 N, 108°18 E–108°20 E), within a mid-subtropical monsoon climate zone. The multi-year average temperature is 19.9 °C, with annual accumulated temperature 10 °C of 6,300 °C and a frost-free period of 300–330 days. Annual precipitation averages 1,400 mm, with the rainy season from April to August accounting for over 70% of annual rainfall, and the dry season from September to March of the following year. Annual sunshine hours average 1,400 h, with total solar radiation of 400 kJ · cm ^{2}, of which effective radiation is 200 kJ · cm ^{2}. The study area features typical peak-cluster depression landscape developed on dolomite bedrock, with high surrounding terrain and low central areas, ranging from 647.2 m to 262 m in elevation. The predominant soil type is brown limestone soil with a thickness of 30–200 cm. Pre-experiment soil properties were: pH 7.13, organic matter (SOM) 43.04 g · kg ^{1}, total nitrogen (TN) 2.24 g · kg ^{1}, total phosphorus (TP) 1.35 g · kg ^{1}, and total potassium (TK) 13.39 g · kg ^{1}.

1.2 Experimental Design

The long-term experiment was established in 2006 using a randomized block design with six fertilization treatments, each replicated four times. Plots were separated by 20 cm thick cement boards buried at least 50 cm deep, with each plot measuring 4 m × 7.5 m. The cropping system was maize/soybean relay intercropping. Pre-cultivation vegetation was grassland dominated by *Artemisia hedinii* and *Microstegium vagans*. This study selected four treatments: CK, no fertilizer; NPK, inorganic fertilizer application with urea, calcium magnesium phosphate, and potassium chloride applied at rates of N 200.0 kg · hm ^{2}, P O 90.0 kg · hm ^{2}, and K O 120.0 kg · hm ^{2} in the maize season, and N 22.5 kg · hm ^{2}, P O 60.0 kg · hm ^{2}, and K O 67.5 kg · hm ^{2} in the soybean season; C7M3: 70% NPK + 30% farm manure (calculated by nitrogen content, with insufficient P and K supplemented by inorganic fertilizer, total fertilizer amount equal to treatment , using cattle manure); and C4M6: 40% NPK + 60% farm manure (calculated by nitrogen content, with insufficient P and K supplemented by inorganic fertilizer).

This analysis used monitoring data from 2010–2014. The spring maize variety was 'Ruidan 8' and summer soybean variety was 'Guichun 5'. Spring maize was planted in holes with 100 cm row spacing and 50 cm plant spacing (four rows per plot), with a drainage ditch opened in the middle 2 m of each plot. Soybean was typically intercropped in holes on both sides of maize rows about 20 days before maize harvest. Other agronomic practices such as intertillage, weeding, and pest control followed conventional methods.

1.3 Sample Collection and Measurement

Following the monitoring requirements of the Chinese Ecosystem Research Network (CERN), crop yields were obtained through sampling at each harvest. At maize harvest, 10 plant samples were taken from each plot as one composite sample; at soybean harvest, 15 plant samples were taken from each plot as one composite sample. Grain was manually threshed, sun-dried, and weighed after air-drying. Moisture content was measured to calculate crop yield, and straw was oven-dried to calculate straw biomass. Soil samples were collected after soybean harvest in 2010, 2012, and 2014. Eight topsoil samples (0–20 cm) were randomly collected from each plot and combined into one composite sample. Approximately 200 g of each composite sample was air-dried and passed through 20-mesh and 100-mesh sieves for nutrient analysis. Conventional analytical methods were used to determine soil organic matter (potassium dichromate external heating method), total nitrogen (Kjeldahl digestion-flow injection analysis), available phosphorus (sodium bicarbonate extraction-molybdenum antimony colorimetry), available potassium (ammonium acetate extraction-atomic absorption spectrometry), and pH (potentiometric method with soil:water ratio of 1:2.5).

1.4 Calculation and Analysis Methods

Soil nutrient apparent balance (kg • hm ^{2}) = Total input from organic and chemical fertilizers -Crop nutrient uptake. Plant nutrient contents of maize and soybean were calculated as the average of plot measurements from 2010–2014. Plant nutrient uptake was calculated based on average grain and straw yields over the years. This study did not consider nutrient inputs through seeds, crop root stubble, precipitation, biological nitrogen fixation, or dry/wet deposition, nor nutrient losses through ammonia volatilization, N O emissions, or leaching.

Microsoft Excel 2010 and DPS software were used for data plotting and statistical analysis, respectively. One-way ANOVA (LSD) was primarily used with significance level set at = 0.05.

2.1 Effects of Equal Nitrogen Combined with Organic Fertilizer on Soil Nutrient Content Changes

Combined application of organic nitrogen fertilizer increased soil organic matter content (Table 1). Comparing average soil organic matter from 2010, 2012, and 2014, no significant differences were observed among the 30% organic nitrogen (C7M3), chemical fertilizer (NPK), and no fertilizer (CK) treatments ($P > 0.05$), while the 60% organic nitrogen addition (C4M6) significantly increased soil organic matter content ($P < 0.05$). Total nitrogen content showed no significant differences among the four treatments ($P > 0.05$), but was lowest in CK and highest in C4M6. Soil available phosphorus and available potassium contents increased with increasing organic fertilizer application, following the order C4M6 > C7M3 > NPK > CK. Available phosphorus in fertilized treatments was significantly higher than in the unfertilized treatment, being approximately 3.1–3.4 times higher, with no significant differences among fertilized treatments. Available potassium in C4M6 was significantly greater than in NPK and CK, with no significant difference from C7M3; C7M3 had higher available potassium than NPK, but the difference was not significant ($P > 0.05$). These results indicate that organic fertilizer replacing part of chemical fertilizer can maintain available nutrient levels comparable to pure chemical fertilizer application, with an increasing trend. Analysis of multi-year data showed that soil pH in unfertilized and chemical fertilizer treatments decreased annually, while pH in organic fertilizer treatments showed an increasing trend, though differences among treatments were not significant. Overall, organic nitrogen replacing part of chemical nitrogen was beneficial for soil nutrient accumulation.

2.2 Average Crop Yields Under Equal Nitrogen Combined with Organic Fertilizer

Long-term fertilization significantly increased crop yields ($P < 0.01$) in the karst peak-cluster depression (Figure 1 [Figure 1: see original paper]). Statistical analysis of five-year crop yields revealed that average maize yields under NPK, 30% organic nitrogen (C7M3), and 60% organic nitrogen (C4M6) treatments were

4.24, 4.15, and 4.36 times higher than the unfertilized control (CK), respectively. Corresponding soybean yields were 2.56, 2.47, and 2.58 times higher than CK. These results demonstrate that fertilizer application has an extremely significant yield-increasing effect in karst peak-cluster depression areas. Yields varied slightly among fertilization treatments, but differences were not significant ($P > 0.05$), indicating that on karst brown limestone soil, a certain amount of organic nitrogen can replace part of the chemical nitrogen fertilizer while maintaining comparable yields.

2.3 Temporal Changes in Crop Yields Under Equal Nitrogen Combined with Organic Fertilizer

Yield trend lines, fitted using linear regression of interannual yield fluctuations ($y = kx + b$), can quantify yield changes over time, where slope k represents the rate of yield change. Changes in unfertilized treatment yields essentially reflect variations in soil baseline fertility under long-term no-fertilization conditions. As shown in Figure 2 [Figure 2: see original paper], long-term unfertilized (CK) maize yield exhibited a decreasing trend (negative k value) with a decline rate of 5.45 g · m^{2} · a^{1}, due to continuous soil nutrient depletion and gradually decreasing supply capacity. Unfertilized soybean yield remained relatively stable (positive k value) with an increase of 1.50 g · m^{2} · a^{1}, primarily because soybean root nodules can fix atmospheric nitrogen to provide nitrogen nutrition for growth, and soybean residues left in the field can increase soil nutrients and organic matter, thereby improving soil fertility.

Long-term fertilized treatments showed increasing trends for both maize and soybean yields. The magnitude of increase (k value) in the maize season followed the order: NPK > C7M3 > C4M6, while in the soybean season it was: C7M3 > NPK > C4M6. However, yield changes among fertilized treatments were not significantly different, indicating that balanced chemical fertilization and combined organic nitrogen application are effective approaches for maintaining high yields of maize and soybean in karst peak-cluster depressions, and that organic manure combined with nitrogen fertilizer can serve as a long-term effective fertilization measure.

2.4 Soil Nutrient Apparent Balance Under Combined Organic Nitrogen Fertilizer

In the maize season, long-term no-fertilization resulted in deficits of N, P, and K nutrients, with annual deficits of 30.5 kg · hm^{2}, 13.8 kg · hm^{2}, and 21.1 kg · hm^{2}, respectively (Table 2). The long-term inorganic fertilizer (NPK) treatment showed surpluses of N, P, and K. In the 30% organic nitrogen replacement (C7M3) treatment, N and P showed surpluses that were 2.9 kg · hm^{2} and 2.0 kg · hm^{2} higher than NPK, respectively, while K showed a deficit of 4.5 kg · hm^{2}. In the 60% organic nitrogen replacement (C4M6) treatment, N and P also showed surpluses, while K showed a deficit of 19.5 kg · hm^{2}. These results indicate that organic nitrogen replacement has positive effects on soil N and P replenishment in the maize season, but organic manure replacement leads to K deficits that increase with organic fertilizer amount.

In the soybean season, the CK treatment showed deficits of N, P, and K (Table 2). In fertilized treatments, P and K showed surpluses, with C7M3 having surpluses nearly equivalent to NPK and C4M6 showing slightly lower surpluses (1.0 kg · hm^{2} and 4.6 kg · hm^{2} lower, respectively). Nitrogen showed deficits in all fertilized treatments, with C4M6 and NPK having similar deficits (48.6 kg · hm^{2}) and C7M3 having a slightly lower deficit (46.6 kg · hm^{2}). The N deficit in fertilized treatments was 1.58–1.65 times that of the unfertilized treatment, while soybean yield was more than double that of the unfertilized treatment. This may be because fertilization promoted nitrogen fixation by soybean root nodules, positively contributing to increased soybean yield.

From a single-season perspective, soil showed deficits of different elements: K deficit in the maize season and N deficit in the soybean season. Crop rotation has complementary and improving effects on soil nutrient deficits. Analyzing the annual nutrient budget across the maize-soybean rotation, CK showed deficits of N, P, and K, while among fertilized treatments only C4M6 showed K deficit (7.9 kg · hm^{2} · a^{1}), with all others showing surpluses, particularly large P surpluses.

Crop yields in unfertilized soil reflect the combined performance of soil baseline fertility and environmental conditions, which can indicate soil fertility status. In the unfertilized treatment, maize yield decreased over time at a rate of 5.45 g · m^{2} · a^{1}. In contrast, soybean yield in the unfertilized treatment increased over time. Studies have shown that soybean N sources are primarily from biological nitrogen fixation, followed by soil N, which may explain why soybean yield maintained an upward trend despite the apparent decline in soil baseline fertility. This also explains why the N apparent deficit was greater in fertilized treatments than in unfertilized treatments while yields were more than double.

Fertilization facilitates rapid nutrient supply and is an important measure for increasing crop yields, with rational fertilization being crucial for maintaining sustainable farmland productivity. Li et al. found in fluvo-aquic soil that balanced NPK application and NPK combined with organic manure could maintain sustained high yields. Hao et al. also found in black soil that balanced fertilization (NPK) and organic manure combined with NPK (MNPK) showed overall increasing yield trends. Zhang et al. demonstrated in karst regions that fertilization not only significantly increased maize yield but also had the same yield-increasing effect on soybean. This study found that fertilized treatments significantly increased both maize and soybean yields, being 4.15–4.36 and 2.47–2.58 times higher than unfertilized treatments, respectively, with no significant differences among fertilized treatments ($P > 0.05$). In the short term, yields of both crops under fertilization showed upward trends over time. These results indicate that balanced chemical fertilization (NPK) and balanced organic nitrogen application are effective measures for increasing crop yields in karst peak-cluster depressions, and that chemical fertilizer (NPK) combined with organic nitrogen can achieve the same yield-increasing effect as chemical fertilizer alone, suggesting that from a yield perspective, partial organic nitrogen replacement is feasible.

The essence of farmland nutrient balance is the equilibrium between nutrient consumption by crops and nutrient input from fertilization, with its surplus or deficit being a primary driver of temporal and spatial changes in soil nutrients and an important factor for measuring agricultural sustainability. In this study, N and P showed surpluses in fertilized treatments during the maize season, while K showed deficits in organic manure treatments that increased with organic fertilizer amount, suggesting K may be the limiting element among the three fertilization treatments. The 60% manure replacement treatment contained more organic fertilizer, providing K more slowly and persistently, resulting in the highest available potassium content that was significantly higher than the NPK treatment. This may explain why C4M6 maintained the highest yield despite showing K deficit. Therefore, for the maize season alone, N and P inputs could be appropriately reduced while maintaining current K levels in the short term.

In the soybean season, P and K showed surpluses while N showed apparent deficits in fertilized treatments. The nutrient balance calculation method used in this study ignored nitrogen fixation by soybean root nodules. Zhang et al. reported that 50% or more of soybean N requirements come from biological nitrogen fixation. In this study, unfertilized soybean yield showed an increasing trend, while fertilized treatments significantly outyielded unfertilized treatments. This suggests that in the soybean season, P and K inputs could be appropriately reduced while maintaining N input.

Considering the effects of both crops on soil nutrient apparent balance, rational intercropping or rotation utilizing different crop nutrient requirements and residual fertilizer effects from previous crops can balance soil nutrient surpluses and deficits within a cropping cycle. In this study, N surplus in the maize season could meet soybean N demand before nodule formation, while K surplus in the soybean season could compensate for K deficit in the maize season, thereby improving N and K use efficiency, reducing surpluses, and decreasing N and K losses. Soil nutrient balance principles allow for certain deficits or surpluses. The K deficit in C4M6 was only 7.9 kg · hm ^{2} · a ^{1}, about 10 times smaller than the allowable deficit reported by Lu et al. for several soil types, suggesting that the C4M6 fertilization level in this study could maintain K balance in the short term, though the specific allowable amount requires further research. P showed surpluses in both seasons, with annual surpluses greater than those reported by Hao et al. in black soil under conventional chemical fertilizer and chemical-organic combined treatments (33.4 kg · hm ^{2} and 61.2 kg · hm ^{2}, respectively). Therefore, phosphorus fertilizer input should be appropriately reduced in karst peak-cluster depressions.

In the ecologically fragile karst peak-cluster depression region with shallow soil layers, maintaining sustainable farmland productivity is particularly important, requiring attention to both crop yield and soil environmental changes. Statistical data from three time periods showed that NPK chemical fertilizer combined with organic manure improved soil nutritional conditions to varying degrees. The 60% manure replacement treatment had significantly higher organic matter content than the 30% manure and pure chemical fertilizer treatments, with total nitrogen, available phosphorus, and available potassium contents increasing with organic fertilizer amount, indicating that organic manure addition improved soil baseline fertility. In the short term, soil pH differences among fertilization treatments were not significant, suggesting that manure replacement of partial chemical fertilizer had little short-term effect on soil acidity. Five-year crop yield data showed that the 60% manure replacement treatment outyielded pure chemical fertilizer treatment, with lower N and P surpluses, indicating that C4M6 maintained high yields while reducing N and P loss risks. If 95–105% of average yield is targeted as the organic replacement rate goal, C7M3 yield was 97.6% of NPK treatment, which is comparable. Therefore, from an agricultural sustainability perspective, manure replacement of partial chemical fertilizer is a feasible measure in karst peak-cluster depressions.

In summary, based on crop relay intercropping, soybean nitrogen fixation, and the slow-release effect of phosphorus fertilizer, fertilization measures of "reduce N, maintain P, and increase K" in the maize season and "maintain N, reduce P, and slightly reduce K" in the soybean season are recommended for karst peak-cluster depressions. Utilizing organic manure to replace part of chemical fertilizer can improve soil fertility and nutrient utilization efficiency by increasing soil organic matter and total nitrogen.

Based on the Huanjiang Station long-term experiment, studying the effects of different manure replacement rates of chemical nitrogen on crop yield and soil nutrient balance in maize/soybean relay intercropping systems led to the following conclusions: 1) From 2010–2014, fertilized treatments had higher soil organic matter, total nitrogen, available phosphorus, and available potassium than unfertilized treatments, with C4M6 showing significantly higher organic matter than NPK ($P < 0.05$). Total nitrogen, available phosphorus, and available potassium increased with organic manure application rate, demonstrating that organic manure replacement of partial chemical nitrogen improved soil nutrient content and fertility. 2) Long-term different fertilization treatments significantly increased crop yields in karst peak-cluster depression brown limestone soil, with maize and soybean yields being 4.15–4.36 and 2.47–2.58 times higher than unfertilized treatments, respectively. Yield increase effects followed C4M6 > NPK > C7M3, but differences among fertilized treatments were not significant. Organic manure replacement of partial chemical nitrogen significantly increased crop yields, achieving the same yield-increasing effect as chemical fertilizer. 3) Different nutrient deficits were observed in different crop seasons under fertilization: K deficit in the maize season (except NPK treatment) and N deficit in the soybean season. Considering both seasons, only C4M6 showed K deficit (7.9 $\text{kg} \cdot \text{hm}^{2} \cdot \text{a}^{1}$). P surpluses were substantial: 81.2 $\text{kg} \cdot \text{hm}^{2} \cdot \text{a}^{1}$ (NPK), 83.4 $\text{kg} \cdot \text{hm}^{2} \cdot \text{a}^{1}$ (C7M3), and 74.8 $\text{kg} \cdot \text{hm}^{2} \cdot \text{a}^{1}$ (C4M6). 4) Under the maize/soybean relay intercropping system in karst peak-cluster depressions, based on crop yield and soil nutrient apparent balance characteristics, organic manure can replace part of chemical fertilizer application, with recommended fertilization measures of "reduce N, maintain P, and increase K" in the maize season and "maintain N, reduce P, and reduce K" in the soybean season.

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