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# Effects of different organic materials and reduced nitrogen fertilizer application on sorghum yield and soil nutrients

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**Rapeseed and sorghum, important economic crops in China, generate abundant straw resources. However, studies examining the effects of straw return combined with reduced nitrogen fertilization on soil quality are still insufficient to meet the precise fertilization needs, necessitating further research. This study employed two treatments: rapeseed straw plus sorghum straw (LT) and rapeseed green manure plus sorghum straw (YGT) returned to the soil. Nitrogen was applied at three rates: 0%, 70% of the conventional amount (0.7CK) and the conventional fertilization (CK). Meanwhile, conventional fertilization was used as a control. Over three consecutive years, this experiment investigated the impact of these treatments on sorghum yield and soil nutrient properties, evaluating overall soil quality and individual soil fertility components. Straw return significantly improved soil quality, with enhancements ranging from 6.5 to 61.4% compared to the CK. The LT + 0.7CK and YGT + 0.7CK produced relatively higher yields, increasing by 10.9% and 10.49% respectively over the CK. Moreover, the comprehensive soil quality of these two treatments is also relatively high, and the comprehensive soil quality of both is at the same level. However, the absence of rapeseed yield in the YGT + 0.7CK treatment during the rapeseed season suggests that LT + 0.7CK is a more economically viable fertilization approach. Soil fertility evaluations indicated that the LT + 0.7CK treatment did not meet the third-level farmland nutrient standards for available potassium, organic matter, total phosphorus, and total potassium. Future fertilization strategies should continue incorporating organic fertilizers and further research to enhance soil phosphorus and potassium contents, thus improving fertilization schemes. This study provides valuable insights for the sustainable utilization of straw resources and the reduction of chemical fertilizers in the Yangtze River Basin.**

**Keywords** Rapeseed straw, Sorghum straw, Rapeseed green manure, Yangtze River Basin, Soil nutrients, Sorghum yield

Soil degradation is a significant global threat affecting agriculture production and human living conditions, with an estimated 19.65 million $km^2$ of degraded soil worldwide[1]. In 1991, the International Soil Reference and Information Centre (ISRIC), supported by the United Nations Environment Program and the Food and Agriculture Organization, assessed the status of human-induced soil degradation globally, categorizing it into five major types: soil hydraulic erosion, soil wind erosion, chemical deterioration, physical deterioration, and biological degradation[2]. Excessive fertilization, a key driver of chemical deterioration, not only results in low fertilizer efficiency but also causes a series of issues such as reduction in soil organic matter, soil acidification, and pollution[3–5].

As the world's largest consumer of fertilizers, China uses one-third of the global total, equivalent to the combined usage of the USA and India. Currently, the fertilizer application per square kilometer in China stands at 32.85 tons, substantially higher than the global average of 12 tons per square kilometer, 2.6 times that of the

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USA, and 2.5 times that of the EU[6,7]. The excessive use of fertilizers poses a severe threat to the sustainable development of agriculture in China. Consequently, China has implemented a policy to reduce fertilizer use, aiming to ensure the sustainable development of its arable land and providing valuable experiences for managing soil degradation in other regions of the world[8,9].

Current researches on reducing fertilizer use primarily includes strategies such as crop rotation, formula fertilization, precision fertilization, and straw return[10–12]. Straw return combined with reduced fertilizer application has emerged as an effective method for decreasing nitrogen use while also enhancing soil organic matter content[13,14]. As the largest renewable resource on Earth, crop straw is abundantly available and low-cost, presenting significant potential for widespread application. Therefore, the impact of straw return combined with reduced fertilizer application on soil and crop yields has been a hot topic among scholars. Wang et al.[15] showed that in Northeast China, maintaining corn yields at the same level as conventional fertilization while reducing nitrogen application by 20% when returning crushed full amount of straw directly to the field also increased soil pH, organic matter, total nitrogen, and total phosphorus ($P < 0.05$). Researches by Wang et al.[16] indicated that reduced fertilization combined with the return of wheat and corn straw decreased the incidence of wheat crown rot, enhanced the diversity of endophytic bacteria, and altered the community structure and functions of endophytes. Waqas et al.[17] found that covering soil with sorghum straw can reduce soil bulk density and increase soil porosity. Although many studies have been conducted on straw return and nitrogen reduction, variations in planting systems, regional climates, and soil fertility across China mean that the optimal combination of straw return and reduced fertilizer application has not been fully quantified and requires further research. Current research on straw return primarily focuses on major crops such as wheat, corn, and rice, with limited studies on other crops, which somewhat restricts further resource utilization of straw[18,19].

China is the world's largest producer and consumer of distilled spirits, and sorghum, a key raw material for these beverages, is widely cultivated in the country. The Southwest region, one of the main sorghum-growing areas in China, spans an area of 210.0 km$^2$, accounting for 29.6% of the national planting area[20]. This region is also a major growing area for rapeseed, one of the top four global oilseed crops and a primary source of edible vegetable oil and plant protein. As one of the main producers of rapeseed, China's rapeseed planting area reached 72,666 km$^2$ in 2023, with rapeseed straw resources being extremely abundant. Studies indicate that in China, the nutrient resources from rapeseed straw account for 7.6% of the nutrient resources from straw, second only to rice, wheat, and corn[19]. In this region, the cropping pattern of rapeseed followed by sorghum is also widely distributed. Based on this, the current study, conducted in Chongqing, located in the Southwest region within the Yangtze River Basin, employed two straw return modes: rapeseed straw plus sorghum straw, and rapeseed green manure plus sorghum straw, with conventional fertilizer levels and 70% of the conventional fertilizer amount. After three consecutive years of trials, this study explores the effects of different treatments on soil nutrients and sorghum yield, aiming to provide references for the resource utilization of straw and reduction of fertilizer application in the Yangtze River Basin.

## Materials and methods

### Research area overview

The test site is located in the Qijiang District, Chongqing Municipal Academy of Agricultural Sciences (28°42′50"N, 106°35′6"E). The terrain is higher in the south and west, lower in the north and east, with eleevated edges and lower hinterland, mainly consisting of mountains. The region is a humid subtropical climate zone, characterized by the subtropical East Asian monsoon. The annual average temperature is 17.8 ℃, the average annual rainfall is 1060.8 mm, and the frost-free period is 365 days.

### Experimental materials

The sorghum (*Sorghum bicolor L.*) and rapeseed (*Brassica campestris L.*) varieties used in the experiment are "Dadi 199" and "Jinpi Nuo 1," respectively. The pH of the experimental soil is 4.39; Total nitrogen is 0.72 g·kg$^{-1}$; The available phosphorus is 13.22 mg·kg$^{-1}$; Nitrate nitrogen is 0.82 mg·kg$^{-1}$; The ammonium nitrogen is 14.32 mg·kg$^{-1}$. The nitrogen, phosphorus, potassium, and carbon contents of sorghum straw is 0.75%, 0.54%, 1.33%, and 49.17%, respectively. The nitrogen, phosphorus, potassium, and carbon content of rapeseed straw is 0.69%, 0.06%, 1.20%, and 44.20%, respectively. The nitrogen, phosphorus, potassium, and carbon contents of rapeseed green manure is 1.40%, 0.44%, 2.67%, and 36.10%, respectively.

### Experimental design

The experiment is designed to investigate the effects of different straw return methods and reduced fertilizer applications on soil properties and crop yields. The treatments are as follows: Conventional Fertilization (CK), Rapeseed straw + Sorghum straw return (LT), Rapeseed straw + Sorghum straw return with 70% of conventional chemical fertilization (LT + 0.7CK), Rapeseed straw + Sorghum straw return with conventional fertilization (LT + CK), Rapeseed green manure + Sorghum straw return (YGT), Rapeseed green manure + Sorghum straw return with 70% of conventional chemical fertilization (YGT + 0.7CK), Rapeseed green manure + Sorghum straw return with conventional fertilization (YGT + CK). Three replicates were set for each treatment, and the experiment was conducted using a completely randomized design, with a total of 21 experimental communities set up. The area of each community is 95m$^2$. The straw return dates for rapeseed and sorghum straw are May 20 and September 26, respectively, each year after which the straw is crushed and incorporated into the soil. The rapeseed green manure is incorporated into the soil after crushing at the flowering stage on March 28 each year, with no crop harvested from the rapeseed in those treatments. The depth of crushing and returning to the field is 0–20 cm. The amount of straw returned to the field and the nutrient content brought into the soil by each treatment are shown in Table 1. Fertilization is divided into two stages. During the sorghum season, the nitrogen, phosphorus, and potassium application rates for conventional fertilization are 27 t·km$^{-2}$, 13.5 t·km$^{-2}$,

| Types of straw | Treatments | N ($t·km^{-2}·a^{-1}$) | P ($t·km^{-2}·a^{-1}$) | K ($t·km^{-2}·a^{-1}$) | SOC ($t·km^{-2}·a^{-1}$) | Straw quantity ($t·km^{-2}·a^{-1}$) |
|---|---|---|---|---|---|---|
| Rapeseed straw | LT | 1.73 | 0.15 | 3.01 | 110.72 | 250.50 |
| | LT + CK | 4.28 | 0.37 | 7.45 | 274.27 | 620.52 |
| | LT + 0.7CK | 3.85 | 0.34 | 6.70 | 246.93 | 558.66 |
| Sorghum straw | LT | 5.34 | 3.85 | 9.48 | 350.38 | 712.59 |
| | LT + CK | 5.55 | 4.00 | 9.84 | 363.96 | 740.21 |
| | LT + 0.7CK | 5.53 | 3.98 | 9.81 | 362.78 | 737.80 |
| Sorghum straw | YGT | 5.07 | 3.65 | 8.99 | 332.22 | 675.65 |
| | YGT + CK | 5.84 | 4.20 | 10.36 | 382.87 | 778.66 |
| | YGT + 0.7CK | 5.63 | 4.05 | 9.98 | 368.89 | 750.24 |
| Rapeseed green fertilizer | YGT | 2.52 | 0.79 | 4.81 | 65.02 | 180.12 |
| | YGT + CK | 5.68 | 1.78 | 10.83 | 146.37 | 405.46 |
| | YGT + 0.7CK | 5.59 | 1.76 | 10.67 | 144.27 | 399.63 |

**Table 1**. The amount of straw returned to the field and the nutrient content brought into the soil by straw. *Nitrogen fertilizer is calculated as pure nitrogen. Phosphate fertilizer is calculated as $P_2O_5$. Potassium fertilizer is calculated as K.

and 19.5 $t·km^{-2}$ respectively; During the rapeseed season, the nitrogen, phosphorus, and potassium application rates for conventional fertilization are 17.5 $t·km^{-2}$, 8 $t·km^{-2}$, and 6.5 $t·km^{-2}$, respectively. Nitrogen, phosphorus, and potassium fertilizers are applied with nitrogen split as base fertilizer: top dressing (seedling stage) at a 6:4 ratio and phosphorus and potassium applied as a one-time base dressing. In different treatments, except for different amounts of nitrogen fertilizer, the number of other fertilizers used is the same. In different treatments, sorghum is sown around May 25th each year with a planting density of $1.82*10^7$ plants per square kilometer. Rapeseed is planted in early October every year, with a planting density of $1.11*10^7$ plants per square kilometer.

### Soil sample collection, analysis, and yield calculation

After three continuous years, soil samples are collected just before the sorghum harvest in September 2023. Samples were taken from each plot using a five-point sampling method, and five samples from each plot were mixed and bagged for transport back to the lab. Samples were air-dried, sieved, and tested for chemical properties. Sampling depths were 0–10 cm and 10–20 cm, with a total of 42 samples collected across the 21 experimental communities. The determination methods for soil samples are shown in Appendix Table 2. The calculation method for production is based on actual receipt.

### Index calculation

Soil quality is assessed using a comprehensive evaluation method. A continuous membership function standardize the indices for soil factors, while an "S" shaped function calculates the membership values[18].

$$(X) = \begin{cases} 1 & (X \geq X_{max}) \\ 0.9 * \frac{X - X_{min}}{X_{max} - X_{min}} + 0.1 & (X_{max} > X > X_{min}) \\ 0.1 & (X \leq X_{min}) \end{cases} \quad (1)$$

* $X_{max}$, $X_{min}$ are the thresholds for soil quality assessment indicators, representing the maximum and minimum values of the measured soil indicators, respectively.

$$SQI = \sum_{i=1}^{n} W_i \times F(X_i) \quad (2)$$

*SQI = Soil Quality Index.

*Wi = Weight vector for quality factors (average correlation coefficient of a given indicator with other indicators relative to the total average of all evaluation indicators. F(Xi) = Membership value of each quality indicator.

### Data analysis

Differences in nutrient content and yield among treatments are analyzed using one-way ANOVA. Differences in nutrient content at different depth are tested using independent sample T-tests. Correlations between nutrient properties and yield across treatments are assessed through correlation analysis. Data is analyzed using SPSS 20.0, and graphs were plotted using Origin 8.0.

## Results and analysis

### Yield characteristics of sorghum under various treatments

As shown in Fig. 1, compared to the LT treatment, sorghum yield increased by 23.18% and 30.34% under the LT + CK treatment and LT + 0.7CK treatment, respectively. Similarly, compared to the YGT treatment, yields

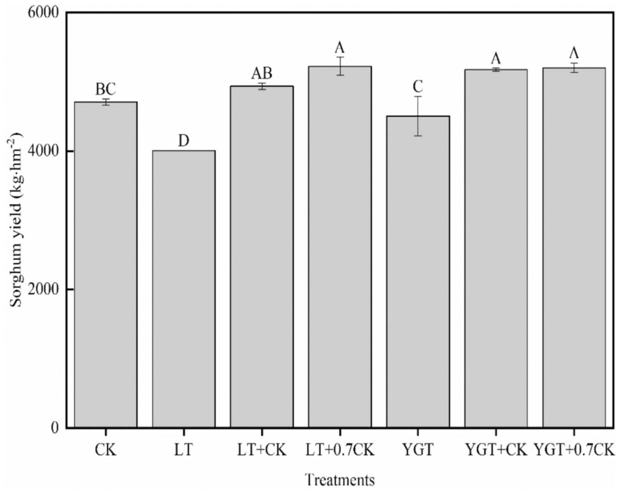


**Fig. 1**. Characteristics of sorghum yield under different treatments.

increased by 14.81% and 15.47% under the YGT + CK treatment and YGT + 0.7CK treatment, respectively. The analysis indicates that in both two-season straw return with concurrent fertilizer application and rapeseed green manure plus sorghum straw return with chemical fertilizer, the highest yields were achieved when the chemical fertilizer applied was at 70% of the full rate. Additionally, both the LT + 0.7CK and YGT + 0.7CK treatments significantly outperformed the CK treatment, with yield increases of 10.92% and 10.49%, respectively. Although the sorghum yield from the LT + 0.7CK treatment was higher than that from the YGT + 0.7CK treatment, the difference was not statistically significant.

## Soil physicochemical properties under different treatments

Soil nutrients levels across all measured indices (Fig. 2a–c), organic matter (Fig. 2d), and available nutrients (Fig. 2e–i) were consistently higher in the 0–10 cm soil layer than in the 10–20 cm layer. In treatments with two-season straw return, soil total nitrogen (Fig. 3), ammonium nitrogen, nitrate nitrogen, and alkaline nitrogen (Fig. 3) exhibited an increasing trend with greater chemical fertilizer use. Among these, the LT + 0.7CK treatment, which yielded higher, showed significantly greater increases in soil total nitrogen, ammonium nitrogen, nitrate nitrogen, and alkaline nitrogen by 59.73%, 45.33%, 21.85%, and 63.95%, respectively, compared to the conventional fertilization (CK).

The content of soil exchangeable potassium and total potassium decreased initially and then increased with rising amounts of chemical fertilizer used. Notably, the high-yielding LT + 0.7CK treatment had 3.55% lower exchangeable potassium and 27.74% lower total potassium compared to CK. Soil total phosphorus and available phosphorus generally decreased with increasing fertilizer rates, where the LT + 0.7CK treatment recorded a slight increase in available phosphorus by 0.69% but a decrease in total phosphorus by 12.35% compared to CK. Soil organic matter content first increased and then decreased with higher fertilizer application, with the LT + 0.7CK treatment showing a notable increase of 24.74% compare to CK.

In treatments involving rapeseed green manure combined with sorghum straw return, soil total nitrogen content, ammonium nitrogen, nitrate nitrogen, alkaline nitrogen, available phosphorus, and organic matter increased initially and then decreased with increasing chemical fertilizer usage. The high-yielding YGT + 0.7CK treatment displayed higher values in these parameters compared to CK, with increases of 79.85%, 75.29%, 33.79%, 71.84%, and 27.26% respectively, although available phosphorus decreased by 4.31%. Both total phosphorus and potassium followed a trend of initial decline followed by an increase with greater fertilizer use, with the YGT + 0.7CK treatment recording decreases of 30.95% and 36.12% in total phosphorus and potassium, respectively. However, exchangeable potassium increased with more fertilizer, decreasing by 3.20% in the YGT + 0.7CK treatment compared to CK. Overall, the LT + 0.7CK treatment had lower total phosphorus, total potassium, and exchangeable potassium than CK; similarly, the YGT + 0.7CK treatment showed lower levels of total phosphorus, total potassium, available phosphorus, and exchangeable potassium compared to CK.

## Correlation analysis between soil properties and sorghum yield

Figure 4 illustrates the significant correlations between various soil nutrients and sorghum yield. Positive correlations are observed with ammonium nitrogen, nitrate nitrogen, alkaline nitrogen, total nitrogen, and soil organic matter. Conversely, total phosphorus, available phosphorus, total potassium, and exchangeable potassium were negatively correlated with sorghum yield.

## Evaluation of individual soil fertility and overall soil quality

The organic matter and total phosphorus contents across the treatments were 53.95%-63.82% and 0.16%-27.83% lower than the third-level agricultural field standards (Soil Nutrient Grading Standards for the Second Soil Survey in China), respectively. While the nitrogen content in the CK (control) and LT (low treatment)

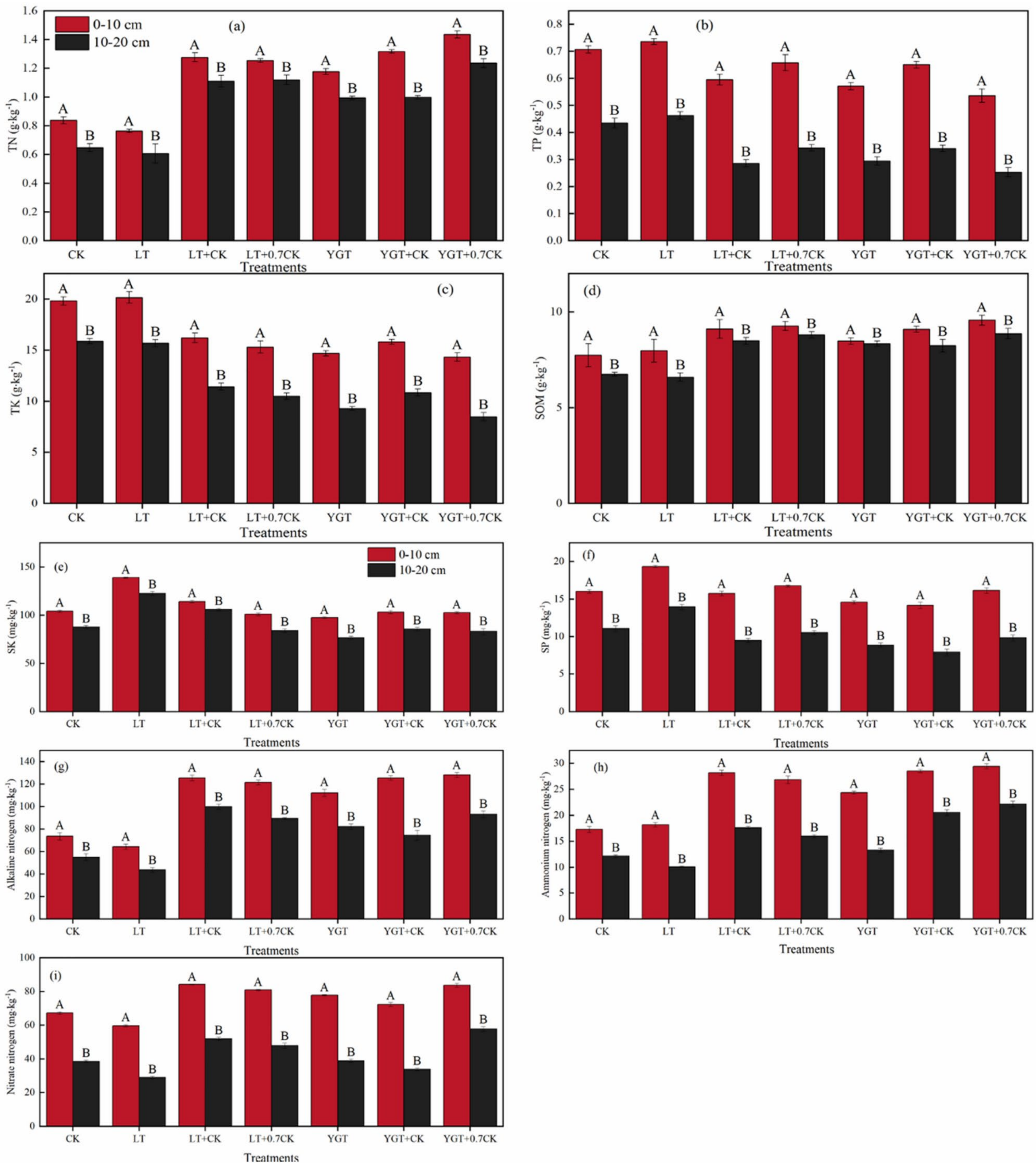


**Fig. 2**. Characteristics of soil physicochemical properties changes with depth under different treatments. In this figure, TN represents total nitrogen; TP stands for total phosphorus; TK represents total potassium; SOM stands for soil organic matter; SK represents exchangeable potassium; SP stands for available phosphorus.

was below the third-level agricultural field standard, all other treatments satisfied the third-level requirements for total nitrogen and alkali-hydrolyzable nitrogen. All treatments met the standards for available phosphorus. However, only CK and LT treatments reached the third-level standards for total potassium, with other treatments showing 7.96–24.01% lower levels. For exchangeable potassium, aside from the LT and LT + CK treatments, the remaining treatments had 4.01%-12.98% lower contents than the third-level agricultural field standards. Overall, the available potassium, organic matter, total phosphorus, and total potassium contents in the LT + 0.7CK and YGT + 0.7CK treatments with higher yields did not meet the third level nutrient standards for farmland.

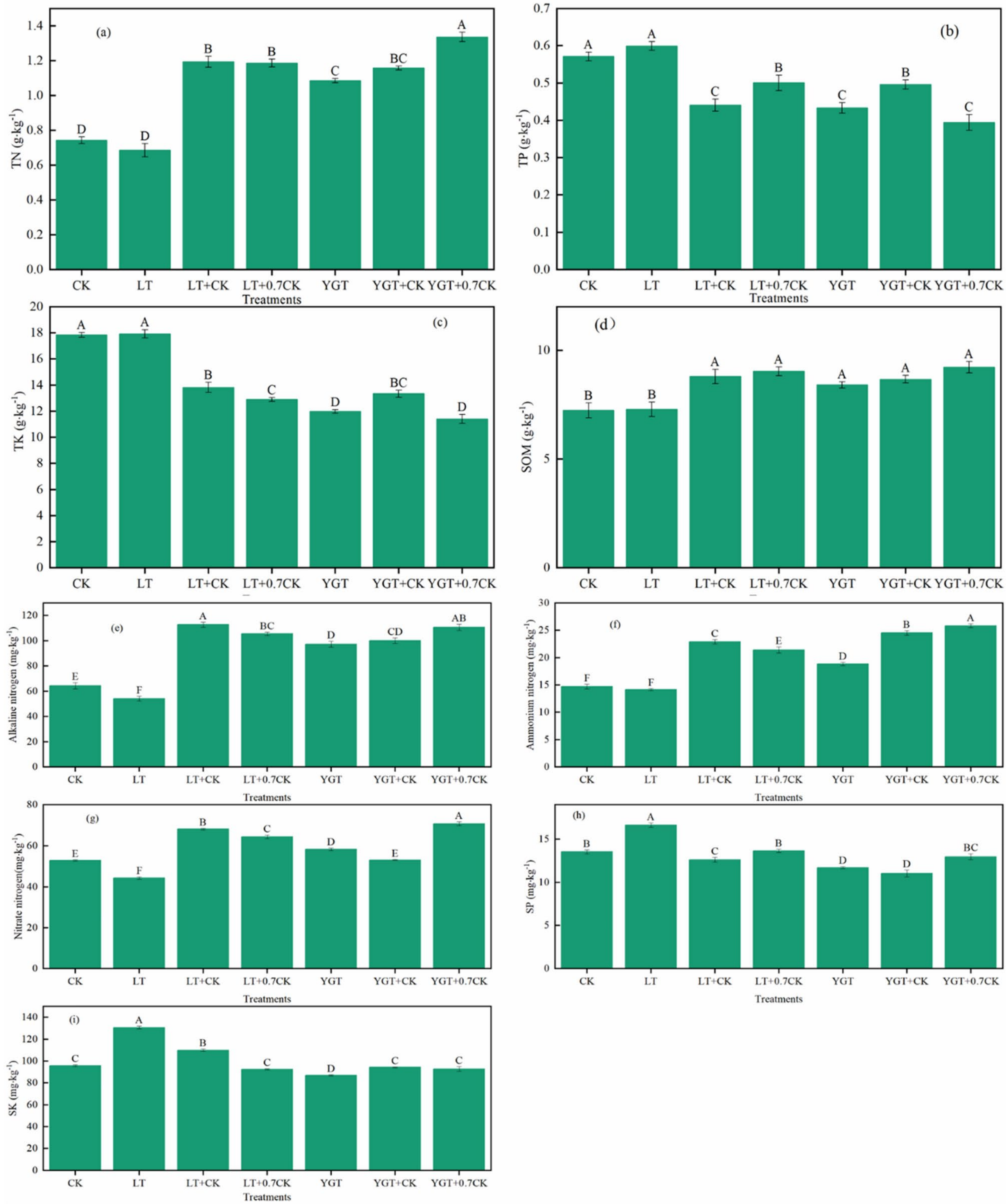


**Fig. 3**. Mean values of soil physicochemical properties under different treatments.

Figure 5 reveals that in the double-season straw return treatments, the soil quality index increases with higher nitrogen fertilizer use, showing an enhancement of 14.39%-61.39% over the control. In contrast, the oilseed rape green manure combined with sorghum straw return treatments exhibited an initial increase followed by a decrease in soil quality index with more nitrogen, achieving a 6.47%-54.70% higher index than the control. Overall, the soil comprehensive quality of LT + CK, LT + 0.7CK, and YGT + 0.7CK treatments was higher, with CK showing the lowest soil comprehensive quality index.

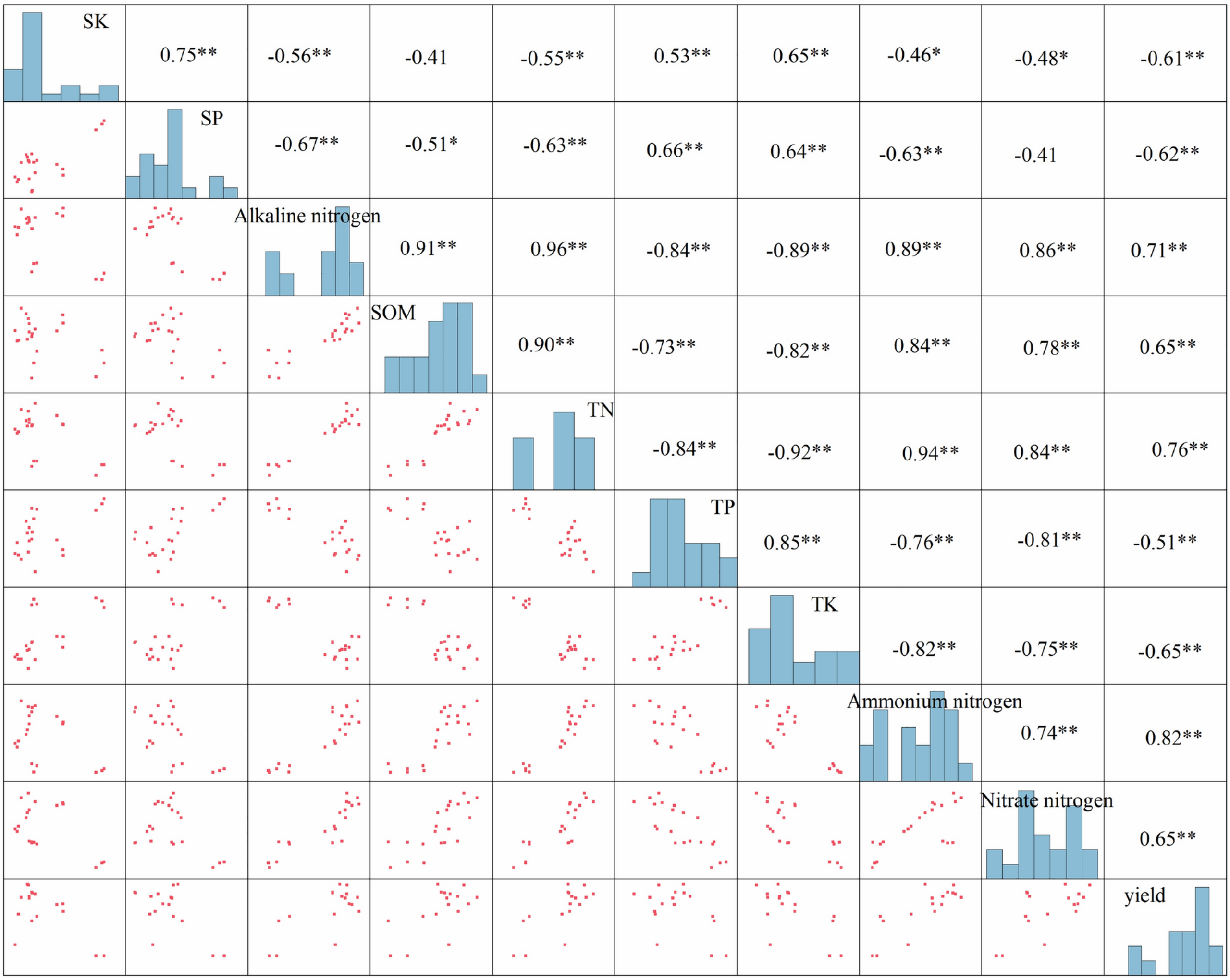


**Fig. 4.** Binary scatter matrix of soil properties and sorghum yield with correlation coefficient graph.

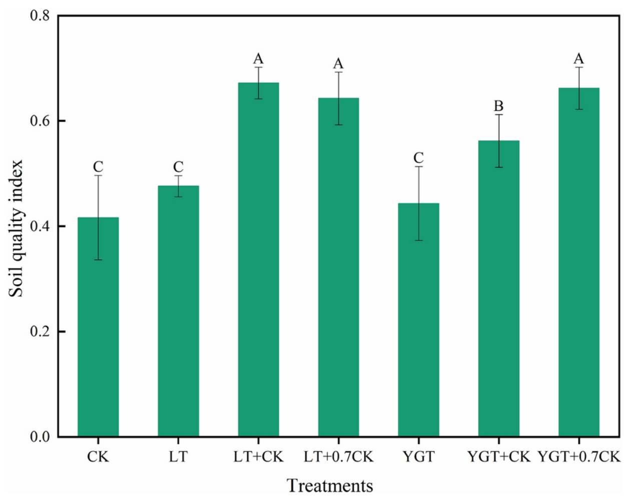


**Fig. 5.** Comprehensive soil quality.

## Discussion

### Impact of different straw return methods on crop yield

This study investigated the effects of different straw return methods on crop yield, specifically comparing two-season straw return treatment (LT) and oilseed rape green manure combined with sorghum straw treatment (YGT) to conventional fertilization (CK). The highest yields were observed with a 30% reduction in chemical nitrogen application for both LT and YGT compared to CK. Notably, the concentrations of total phosphorus, available phosphorus, and organic matter were lower in the LT + CK treatment than those in the LT + 0.7CK treatment when 70% of full nitrogen was applied. Similarly, in the YGT + CK treatment, the levels of available phosphorus, alkaline nitrogen, organic matter, total nitrogen, ammonium nitrogen, and nitrate nitrogen were all lower compared to the YGT + 0.7CK treatment. This may be due to the excessive application of nitrogen fertilizer, which accelerates the mineralization of organic matter, resulting in a decrease in soil organic matter content[21–23]. The decrease in soil organic matter content can lead to a deterioration of soil fertility and structure, thereby exacerbating the loss of soil nutrients and reducing their effectiveness[24,25]. The over-application of nitrogen reduces the availability of crucial nutrients like organic matter, phosphorus, and nitrogen, which are essential for crop yield. This reduction likely contributes to the observed decrease in crop yield as nitrogen application increases[18,26].

The treatments LT + 0.7CK and YGT + 0.7CK demonstrated crop yield increases of 10.92% and 10.49%, respectively, compared to CK. This improvement is likely due to the enhanced soil quality resulting from straw return. In these high-yield treatments, the levels of soil organic matter, ammonium nitrogen, nitrate nitrogen, alkaline nitrogen, and total nitrogen were all higher than in the CK treatment. Soil organic carbon plays a critical role in influencing soil quality by indirectly improving soil structure, moisture content, nutrient availability, ion exchange capacity, and microbial activity and diversity[27–29]. It also serves as an essential nutrient source for crop growth, thereby playing a vital role in crop yield formation. Nitrogen fertilizer is crucial for plant growth and maintaining photosynthetic capacity[30]. Studies have shown that, within a certain range, an increase in soil nitrogen can lead to increased crop yields[31,32]. Although the total phosphorus content was lower in the LT + 0.7CK treatment compared to CK, the available phosphorus content was still higher, indicating that straw return can enhance the effectiveness of phosphorus fertilizers[33,34]. Research by Indoshi et al[35] research shows that returning straw to the field can also improve soil water and heat conditions, thereby promoting root growth and development. Therefore, returning straw to the field can increase the total amount and effectiveness of soil nutrients, and improve soil water and heat conditions, which may explain the observed increase in crop yield.

### Impact of different fertilization practices on soil properties

This study demonstrated that straw return could increase the nitrogen content and soil organic matter, consistent with findings by Li et al.[36] and Huang et al.[33]. This increase is attributed to the rich organic carbon and nitrogen content in the straw itself, which directly augments the soil organic matter content through decomposition[37]. At the same time, the increase in organic matter can further improve soil structure, improve soil water and heat conditions, promote the increase of microbial activity, thereby reducing soil nutrient leaching and increasing the availability and effectiveness of soil nutrients[16,35,38]. However, the study found that in the straw return treatments, LT + 0.7CK and YGT + 0.7CK, the levels of total phosphorus, total potassium, and available potassium, as well as the total phosphorus in the YGT + 0.7CK treatment, were lower than those in the CK treatment. This contrasts with the findings of Huang et al.[33]. The discrepancy may be due to the higher crop yields in the LT + 0.7CK and YGT + 0.7CK treatments, which would have resulted in greater nutrient uptake from the soil, thus leading to these lower nutrient concentrations[18,39]. And in the straw returning treatment, when the application rate of chemical nitrogen fertilizer exceeded 70% of conventional fertilization, there was no significant change in soil comprehensive quality in the LT treatment. In the YGT treatment, the soil comprehensive quality showed a decreasing trend. This may be due to the excessive input of nitrogen fertilizer exacerbating the decomposition of organic matter in the soil[23].

Furthermore, individual soil fertility evaluations revealed that the available potassium, organic matter, total phosphorus, and total potassium in the high-yield treatments of LT + 0.7CK and YGT + 0.7CK were below the level of third-grade farmland, with the organic matter content notably below the standard for all-season farmland, indicating a clear deficiency. Soil organic matter, phosphates, and potash play crucial roles in enhancing the soil nutrients effectiveness, root growth, photosynthesis, and crop resilience[17,40,41]. Future research could focus on conservation tillage, the application of soil conditioners, and precision fertilization to increase the content and reduce the leaching of phosphorus and potassium nutrients[10,42].

As soil depth increases, nutrient content tends to decrease. This is because the surface soil typically has a lower bulk density, which allows for better aeration and receives more light and moisture, all of which promote the decomposition and transformation of straw in the soil[43,44]. The decomposition of straw not only directly increases nutrient content but also improves soil structure and promotes microbial activity, helps prevent nutrient leaching[30,45]. Hence, nutrient levels are generally higher in the surface soil.

The study indicates that the yields of sorghum and the soil qualities in the LT + 0.7CK and YGT + 0.7CK treatments were similar. However, the green manure returns of oilseed rape results in the loss of one crop season's yield, and studies have shown that the farmers' acceptance of fertilization practices is directly correlated with economic income[46,47]. Therefore, overall, the LT + 0.7CK treatment was the most effective in this study, representing the optimal fertilization strategy.

The experimental results indicated that the LT + 0.7CK treatment resulted in the highest sorghum production and superior soil quality. However, the study also found that the content of phosphorus and potassium fertilizers was lower than those in CK, falling below the standard for third-grade farmland construction. The study did not further investigate the enhancement of phosphorus and potassium fertilizer content and efficacy, which somewhat limits the broader applicability of these findings[48]. Future research should therefore focus on increasing the soil content of phosphorus and potassium fertilizers and refining fertilization strategies to enhance soil quality and crop yields in the Yangtze River basin[49,50].

## Conclusion

In treatments involving two-season straw return and combined oilseed rape green manure with sorghum straw return, the highest sorghum yield and overall soil quality were achieved with a 30% reduction in the application chemical nitrogen fertilizer. Among them, LT + 0.7CK not only had the same soil improvement benefits as YGT + 0.7CK, but also had higher economic benefits than YGT + 0.7CK, making it a better fertilization treatment in this study. However, the levels of available potassium, organic matter, total phosphorus, and total potassium in LT + 0.7CK treatment did not meet the third-level nutrient standards for farmland. Therefore, further research is needed to refine the fertilization plan and provide better guidance for the resource utilization of straw.

## Data availability

The datasets generated for this study are available on request to the corresponding author.

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The plants involved in this study are cultivated crops in agriculture, and the experiments comply with Chinese and international guidelines and legislation.

## Author contributions
R.S.W designed and performed the experiment, analyzed the data, and wrote the manuscript, C.G. W., J.B.L., T. L. and Y. J.C. participated in sample collection and measurement, R.S. W., C.G. W., and B. L. processed the data and analyzed the results, R.S.W., L.C. and Y.M. L. performed writing—review and edited final manuscript. All authors reviewed the article and approved the submitted version.

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## Declarations

## Competing interests
The authors declare no competing interests.

## Additional information
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