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The Role of Rapeseed Straw in Soil Fertility and Crop Productivity

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Abstract This study explores the effects of rapeseed straw return on soil fertility and crop productivity, highlighting its potential for sustainable management in agriculture. The findings reveal that straw return, combined with phosphorus fertilizer and biochar, significantly improves nutrient cycling and increases dry matter accumulation and yields of subsequent crops. Additionally, straw return demonstrates long-term advantages in enhancing microbial diversity and optimizing soil physical properties. However, the effectiveness of straw return is influenced by decomposition rate, environmental conditions, and may under certain conditions increase greenhouse gas emissions, underscoring the need for further optimization to enhance agricultural sustainability. This study provides scientific support for the sustainable agricultural application of straw return, emphasizing the importance of optimized management to balance production and environmental benefits.
Keywords Rapeseed straw; Soil fertility; Soil structure; Crop productivity; Microbial activity; Sustainable agriculture

1 Introduction

Rapeseed (*Brassica napus* L.) is a significant crop globally, primarily cultivated for its oil-rich seeds. It ranks as the third most important edible oilseed after soybean and palm oil, contributing substantially to the global edible oil supply (Fu et al., 2016; Yadav et al., 2022). In China, rapeseed accounts for about 20% of the world's production, with stable yields and improvements in seed quality over the past decade (Hu et al., 2017). Rapeseed is the main oil crop in Cixi City and also the main production area of rapeseed in Ningbo City. The annual planting area of rapeseed is 4000 hectares, accounting for about 50% of the rapeseed planting area in Ningbo City, and it is also a high-yield area in Ningbo City (Figure 1). Despite its importance, the handling of rapeseed straw, a byproduct of rapeseed cultivation, remains a challenge. Traditionally, rapeseed straw is either burned or left to decompose in the fields, practices that can lead to environmental issues such as air pollution and loss of soil organic matter (Yang et al., 2020). However, recent studies suggest that rapeseed straw can be a valuable resource for enhancing soil fertility and crop productivity when managed appropriately (Mitra and Mandal, 2012; Su et al., 2014; Zhang et al., 2023).

Figure 1 Pictures of the peak flowering period and pod setting period of rapeseed at planting base in Cixi City

Soil fertility is a cornerstone of sustainable agriculture, directly influencing crop productivity and ecosystem health. Fertile soils provide essential nutrients, support robust microbial activity, and maintain favorable physical properties, all of which are critical for optimal plant growth. Enhancing soil fertility through organic amendments, such as straw incorporation, can lead to increased crop yields and improved soil health. For example, the return of straw combined with phosphorus application has been shown to significantly increase crop productivity and soil bacterial diversity in rape-rice rotation systems (Zhang et al., 2023). Similarly, the use of organic and inorganic nutrients along with straw mulch has resulted in higher yields in rapeseed and subsequent crops, demonstrating the residual benefits of improved soil fertility (Mitra and Mandal, 2012). Moreover, practices like straw mulching can adjust soil micro-climate, thereby enhancing the productivity of crops such as winter oilseed rape (Su et al., 2014). Despite these benefits, the optimal management practices for rapeseed straw to maximize its positive impact on soil and crop productivity are not well established. Understanding the specific effects of rapeseed straw on soil properties and crop performance is essential for developing sustainable agricultural practices.

This study explores the impact of returning rapeseed straw to the field on soil fertility and crop productivity, with a particular focus on its role in nutrient supply, soil structure, and crop performance. It will evaluate both the immediate and long-term effects of rapeseed straw, examining various aspects such as nutrient cycling, soil microbial activity, and soil physical and chemical properties, aiming to provide valuable insights for optimizing the sustainable agricultural use of rapeseed straw. The study is expected to support agricultural practices that achieve high yields while promoting soil health, benefiting both farmers and the environment.

2 Characteristics of Rapeseed Straw

2.1 Chemical composition analysis

Rapeseed straw is composed of various chemical constituents that play a significant role in its utilization and decomposition. The primary components include cellulose, hemicellulose, and lignin. Studies have shown that the incorporation of rapeseed straw into soil can significantly increase the levels of nitrogen (N), phosphorus (P), and potassium (K) in the soil, which are essential nutrients for plant growth (Wang et al., 2022; Wei et al., 2022; Song et al., 2023). Additionally, the application of rapeseed residue has been found to increase soil organic matter and microbial biomass, further enhancing soil fertility (Yang et al., 2020).

The chemical composition of rapeseed straw influences its biodegradability and effectiveness as a soil amendment. High levels of cellulose and hemicellulose make it a good source of organic carbon, which can improve soil structure and fertility (Jin et al., 2019; Deng et al., 2021). The presence of lignin, however, can slow down the decomposition process, making it necessary to use decomposition agents to accelerate the breakdown of the straw (Wang et al., 2022). The addition of biochar derived from rapeseed straw has also been shown to improve soil pH and nutrient availability, making it a valuable amendment for contaminated soils (Salam et al., 2019; Zong et al., 2021).

2.2 Biodegradability features

The decomposition rate of rapeseed straw varies under different environmental conditions. Factors such as soil moisture, temperature, and the presence of decomposition agents can significantly influence the rate at which the straw breaks down. For instance, the use of decomposition agents has been shown to enhance the fungal community diversity and accelerate the decomposition process, leading to improved soil quality and crop yields (Wang et al., 2022). Additionally, higher soil moisture levels can facilitate faster decomposition, as observed in studies where biochar application under high moisture conditions reduced the bioavailability of heavy metals and improved soil health (Salam et al., 2019).

The decomposition of rapeseed straw offers several environmental benefits. It enhances soil organic matter, which improves soil structure and water retention capacity (Jin et al., 2019; Deng et al., 2021). The process also increases microbial biomass and enzyme activity, contributing to better nutrient cycling and soil fertility (Yang et al., 2020). Moreover, the application of rapeseed straw can mitigate the risk of heavy metal contamination in soils by reducing the bioavailability and accumulation of toxic elements such as cadmium (Cd) and copper (Cu) (Zong et al., 2021).

2.3 Comparison with other crop residues
Rapeseed straw differs from other crop residues like wheat and corn in its chemical composition and nutrient content. While all three types of residues are rich in organic carbon, rapeseed straw has a higher nitrogen content, which can enhance its effectiveness as a soil amendment (Wei et al., 2022; Song et al., 2023). Additionally, the structural composition of rapeseed straw, with its higher lignin content, may require the use of decomposition agents to achieve similar decomposition rates as wheat and corn residues (Salam et al., 2019; Wang et al., 2022).

Rapeseed straw is highly suitable for soil amendment due to its ability to improve soil fertility and structure. Its application has been shown to increase soil organic matter, microbial biomass, and enzyme activity, making it a valuable resource for sustainable agriculture (Yang et al., 2020; Deng et al., 2021). In industrial applications, rapeseed straw can be used to produce biochar, which has been effective in immobilizing heavy metals and improving soil health in contaminated areas (Salam et al., 2019; Zong et al., 2021). The use of rapeseed straw in combination with other organic materials, such as biochar and nitrogen supplements, can further enhance its benefits for soil fertility and crop productivity (Jin et al., 2019; Khan et al., 2020).

3 Effects of Rapeseed Straw on Soil Fertility
3.1 Impact on soil nutrient content
Incorporating rapeseed straw into the soil significantly enhances the levels of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K). Studies have shown that straw incorporation increases the accumulation of these nutrients in subsequent crops, such as rapeseed, by substantial margins. For instance, the dry matter accumulation (DMA) and nutrient uptake in rapeseed were significantly higher with straw incorporation compared to control treatments without straw (Song et al., 2023). Additionally, the combined application of phosphorus fertilizer and straw return has been found to improve crop productivity and soil nutrient content, particularly enhancing the availability of P (Zhang et al., 2023).

The application of rapeseed residue also positively impacts the availability of micronutrients in the soil. The incorporation of organic materials, including rapeseed straw, has been shown to improve soil fertility by increasing the availability of micronutrients essential for plant growth. This is achieved through the enhancement of soil microbial activity, which plays a crucial role in nutrient cycling and availability (Liu et al., 2022; Wei et al., 2022).

3.2 Influence on soil organic carbon
Rapeseed straw incorporation contributes significantly to increasing soil organic carbon (SOC) stocks. The addition of organic residues such as rapeseed straw enhances the organic matter content in the soil, which is crucial for maintaining soil health and fertility. Studies have demonstrated that the application of rapeseed residue increases soil organic matter (OM) and microbial biomass carbon (MBC), which are key indicators of improved soil carbon stocks (Jin et al., 2019; Yang et al., 2020).

The long-term potential of rapeseed straw for carbon sequestration is notable. The incorporation of biochar derived from rapeseed residue has been shown to improve soil carbon sequestration by stabilizing organic carbon in the soil (Jin et al., 2019; Thers et al., 2019; Khan et al., 2022). The study found that converting rapeseed straw into high-temperature biochar and applying it to soil can reduce greenhouse gas emissions, such as N_2O. Compared to traditional farmland management, biochar treatment achieved a 73%~83% reduction in greenhouse gas emissions, primarily due to its effective carbon sequestration effect (Thers et al., 2019). This practice not only enhances soil fertility but also contributes to mitigating climate change by sequestering carbon over extended periods.

3.3 Effects on microbial activity and biodiversity
Rapeseed straw incorporation promotes the growth of beneficial soil microbial communities. The addition of organic materials such as rapeseed straw enhances microbial biomass and enzyme activities, which are critical for nutrient cycling and soil health. For example, the application of rapeseed residue has been shown to increase the activities of soil enzymes such as urease, acid phosphatase, and dehydrogenase, which are indicative of enhanced microbial activity (Yang et al., 2020; Liu et al., 2022).

The incorporation of rapeseed straw also positively impacts soil biodiversity and ecosystem stability. The combined application of biochar and organic fertilizers, including rapeseed straw, has been found to improve soil microbial community richness and diversity. Siebers et al. (2018) found that returning rapeseed straw to the field increased the relative abundance of certain beneficial bacteria and fungi in the soil, which positively impact plant growth (Figure 2). This enhancement of microbial diversity contributes to building a more stable and resilient soil ecosystem, which is crucial for achieving sustainable agricultural practices.

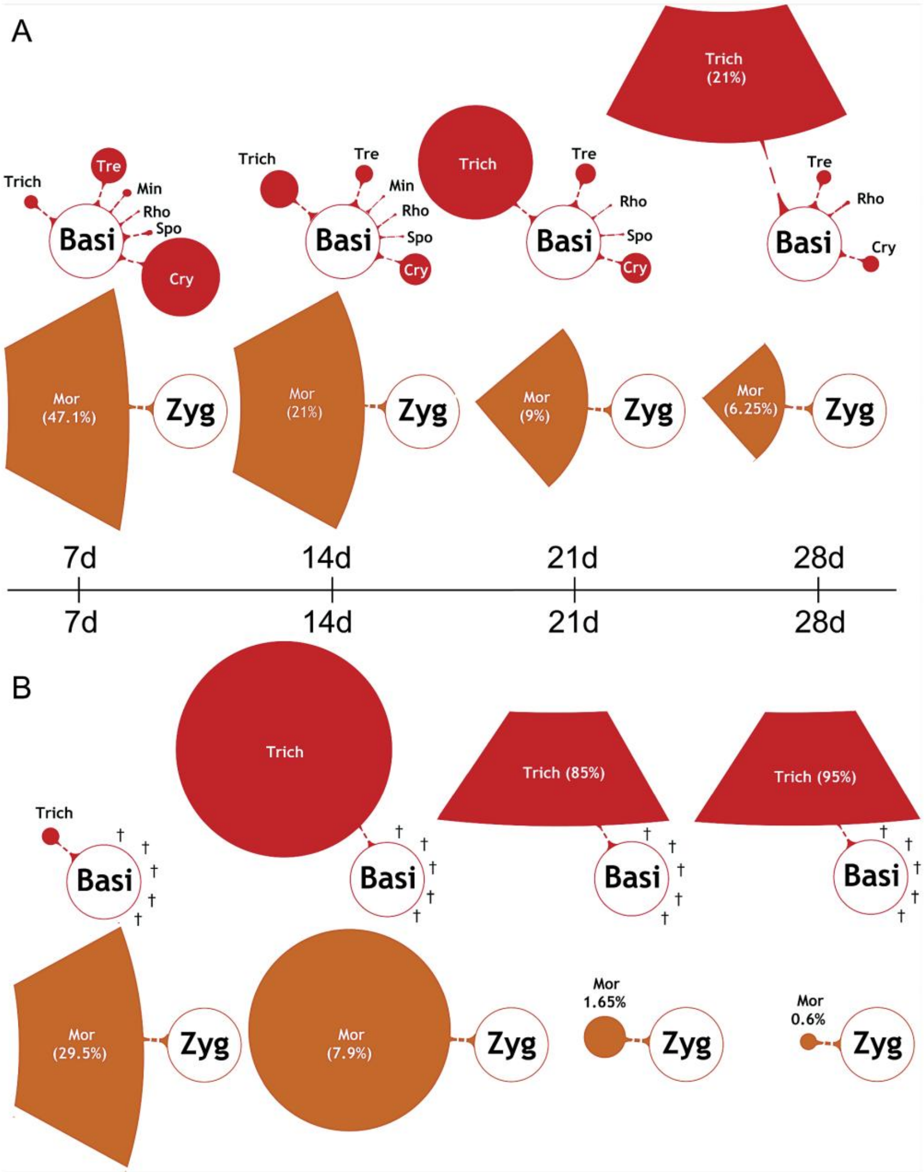

Figure 2 Changes in the community composition of Basidiomycota and Zygomycota. Basidiomycota (Basi) and Zygomycota (Zyg) OTU abundances derived from internal transcribed spacer (ITS) region sequencing in A. control soil samples and B. during RS-EX exposure (7, 14, 21, 28 d). Filled circle sizes indicate average OTU abundances. Highly abundant taxa are depicted by circle sections, and abundances given in %. Open circles indicate higher-order taxa (circle sizes not in scale). Extinction of OTUs is depicted by crosses. Trich, *Trichosporon*; Mor, *Mortierella* (Adopted from Siebers et al., 2018)

Image caption: The figure shows changes in the community composition of Basidiomycota and Zygomycota fungal phyla in soil following treatment with rapeseed straw extract (RS-EX). The results indicate that RS-EX treatment significantly reduced the relative abundance of *Mortierella*, a major member of Zygomycota, from 47.1% at the start of treatment to nearly extinction. Meanwhile, *Trichosporon*, within Basidiomycota, proliferated rapidly after treatment, occupying approximately 95% of the fungal community. This shift reveals the strong selective effect of RS-EX on fungal communities, indicating that RS-EX treatment leads to the disappearance of susceptible fungi like *Mortierella* while promoting the dominance of more resistant fungi such as *Trichosporon* in the soil (Adapted from Siebers et al., 2018)

4 Role of Rapeseed Straw in Enhancing Crop Productivity

4.1 Influence on subsequent crop yields

The incorporation of rapeseed straw into the soil has been shown to significantly enhance subsequent crop yields by improving soil nutrient recycling. For instance, the application of phosphorus combined with straw return in a rape-rice rotation system increased rapeseed grain yields by up to 32.69% and rice yields by up to 17.31% compared to treatments without straw return (Zhang et al., 2023). According to our long-term observation results, after returning rapeseed straw to the field, the subsequent crop rice grows vigorously, has a clear appearance, and significantly increases yield (Figure 3). Similarly, long-term straw return in upland crops has been associated with increased soil organic carbon (SOC) stocks, which in turn supports higher crop productivity (Hagos et al., 2020). The addition of organic materials, including straw, has also been found to stabilize crop yields and improve soil nutrient content in winter rapeseed and maize rotations (Wei et al., 2022).

The residual effects of rapeseed straw incorporation extend beyond immediate nutrient recycling, influencing crop performance in subsequent seasons. Annual straw incorporation in a rice-rapeseed rotation system significantly increased dry matter accumulation and nutrient uptake in rapeseed, indicating a positive residual effect on crop performance (Song et al., 2023). Additionally, the use of biochar derived from rapeseed straw has been shown to improve soil properties and enhance rapeseed yield, although these benefits may diminish over time (Jin et al., 2019).

4.2 Effects on crop growth parameters

Rapeseed straw incorporation can stimulate root growth and enhance soil exploration, leading to improved nutrient uptake and crop growth. The application of biochar, a by-product of rapeseed straw, has been found to increase soil enzymatic activities and improve nitrogen assimilation, which in turn promotes root development and nutrient absorption (Khan et al., 2022). Furthermore, the use of organic materials, including straw, has been shown to enhance root biomass and soil nutrient availability, supporting better root growth and soil exploration (Wei et al., 2022).

The incorporation of rapeseed straw into the soil has been demonstrated to enhance above-ground biomass production. For example, straw mulching and reduced slow-release fertilizer treatments significantly increased rapeseed biomass and yield under varying climate conditions (Feng et al., 2020). Additionally, the application of biochar and nitrogen supplements has been shown to improve leaf and stem biomass, as well as photosynthetic efficiency, leading to higher overall biomass production (Khan et al., 2020).

4.3 Long-term benefits on crop productivity

Long-term incorporation of rapeseed straw contributes to sustained soil health and crop yield stability. Studies have shown that straw return combined with appropriate fertilization practices can increase SOC stocks and improve soil fertility, leading to stable and enhanced crop yields over extended periods (Hagos et al., 2020). The use of biochar derived from rapeseed straw has also been found to improve soil properties and support long-term crop productivity, although the effects may vary depending on soil type and initial SOC content (Jin et al., 2019).

Figure 3 The growth and appearance of the subsequent crop rice

The incorporation of rapeseed straw into agricultural practices contributes to sustainability by enhancing soil fertility, reducing the need for chemical fertilizers, and promoting nutrient recycling. The use of organic materials, including rapeseed straw, has been shown to improve soil nutrient content and support sustainable crop production practices (Wei et al., 2022). Additionally, the recycling of bioenergy by-products, such as biochar from rapeseed straw, can further enhance soil fertility and crop growth, contributing to more sustainable agricultural systems (Kataki et al., 2018).

5 Methods to Enhance the Efficiency of Rapeseed Straw Utilization

5.1 Optimal treatment and application methods

Pre-treatment techniques such as incorporating decomposition agents can significantly enhance the breakdown of rapeseed straw, leading to improved soil fertility and crop productivity. For instance, the application of decomposition agents has been shown to increase the diversity of fungal communities and improve soil quality, which in turn boosts cotton yield parameters (Wang et al., 2022). Additionally, annual straw incorporation combined with nitrogen fertilizer application in rice seasons has been found to significantly increase dry matter accumulation and nutrient uptake in subsequent rapeseed crops (Song et al., 2023).

Effective application strategies include combining straw return with appropriate fertilization regimes. For example, phosphorus application during the rapeseed season combined with straw return has been shown to improve crop productivity and soil bacterial diversity in rape-rice rotation systems (Zhang et al., 2023). Similarly, straw mulching with nitrogen fertilizer has been found to enhance soil nutrients, enzyme activities, and crop yield (Akhtar et al., 2019). These strategies not only improve soil fertility but also optimize nutrient use efficiency, leading to better crop performance.

5.2 Technologies for improving effective utilization

The production and application of biochar from rapeseed straw can significantly improve soil fertility and crop growth. Studies have shown that the co-application of biochar and nitrogen can enhance soil organic carbon, total nitrogen accumulation, and photosynthesis in rapeseed plants (Khan et al., 2020). This integrated approach not only compensates for nitrogen input but also increases nitrogen utilization efficiency, making it a sustainable practice for crop production.

Innovative composting and fermentation techniques can further enhance the utilization of rapeseed straw. For instance, the incorporation of straw with nitrogen fertilization has been found to inhibit nitrogen leaching, thereby increasing yield and efficiency in maize seasons (Meng et al., 2021). Additionally, the use of rapeseed residue in paddy fields has been shown to increase soil organic matter, microbial biomass, and enzyme activity, while also mitigating cadmium pollution risks (Yang et al., 2020). These methods not only improve soil health but also contribute to environmental sustainability.

5.3 Sustainable approaches for proper utilization of rapeseed straw

Integrating rapeseed straw utilization into crop rotation systems can lead to sustainable agricultural practices. For example, the use of straw return in rape-rice rotation systems has been shown to increase crop productivity and soil bacterial diversity (Zhang et al., 2023). Similarly, the incorporation of straw in rice-rapeseed rotation systems has been found to significantly improve dry matter accumulation and nutrient uptake in rapeseed crops (Song et al., 2023). These practices ensure the efficient use of resources and maintain soil fertility over the long term.

Eco-friendly practices such as straw mulching and reduced nitrogen fertilization can help reduce the environmental impact of rapeseed straw utilization. For instance, straw mulching combined with slow-release fertilizers has been shown to improve water use efficiency and reduce nutrient loss in rapeseed crops (Feng et al., 2020). Additionally, optimizing straw input and management practices can help mitigate greenhouse gas emissions and promote sustainable agricultural production (Li et al., 2023). These practices not only enhance crop productivity but also contribute to climate change mitigation.

6 Case Study

6.1 Effects of straw incorporation and potassium fertilization on soil stability in rice-oilseed rape rotation

In the rice-oilseed rape rotation system of southern China, soil structure stability and fertility directly impact agricultural productivity and ecological sustainability. However, due to a lack of organic matter and inadequate fertilizer management, soil structure degradation has become a significant issue. Consequently, straw incorporation and appropriate potassium fertilization have been widely adopted as effective measures to improve soil quality (Hagos et al., 2020).

A multi-year field study analyzed the effects of straw incorporation and potassium fertilization on soil aggregate stability and nutrient content (Xue et al., 2022). The results indicated that straw incorporation significantly increased soil organic carbon (SOC) levels and iron oxide concentrations, especially in soil aggregates larger than 0.25 mm, which contribute to enhanced soil aggregate stability. This practice effectively reduced SOC loss in rice-oilseed rape rotation, showing higher aggregate stability after the harvest of oilseed rape. In contrast, the direct impact of potassium fertilization was limited, mainly influencing processes related to SOC transformation and microbial activity. Scanning electron microscopy further demonstrated the improvement in soil structure under straw incorporation treatment, showing a rougher surface with increased porosity (Figure 4), enhancing soil's water retention and nutrient-holding capacity. The study concluded that straw incorporation, as a soil improvement measure, offers significant advantages for boosting soil fertility and promoting sustainable agriculture.

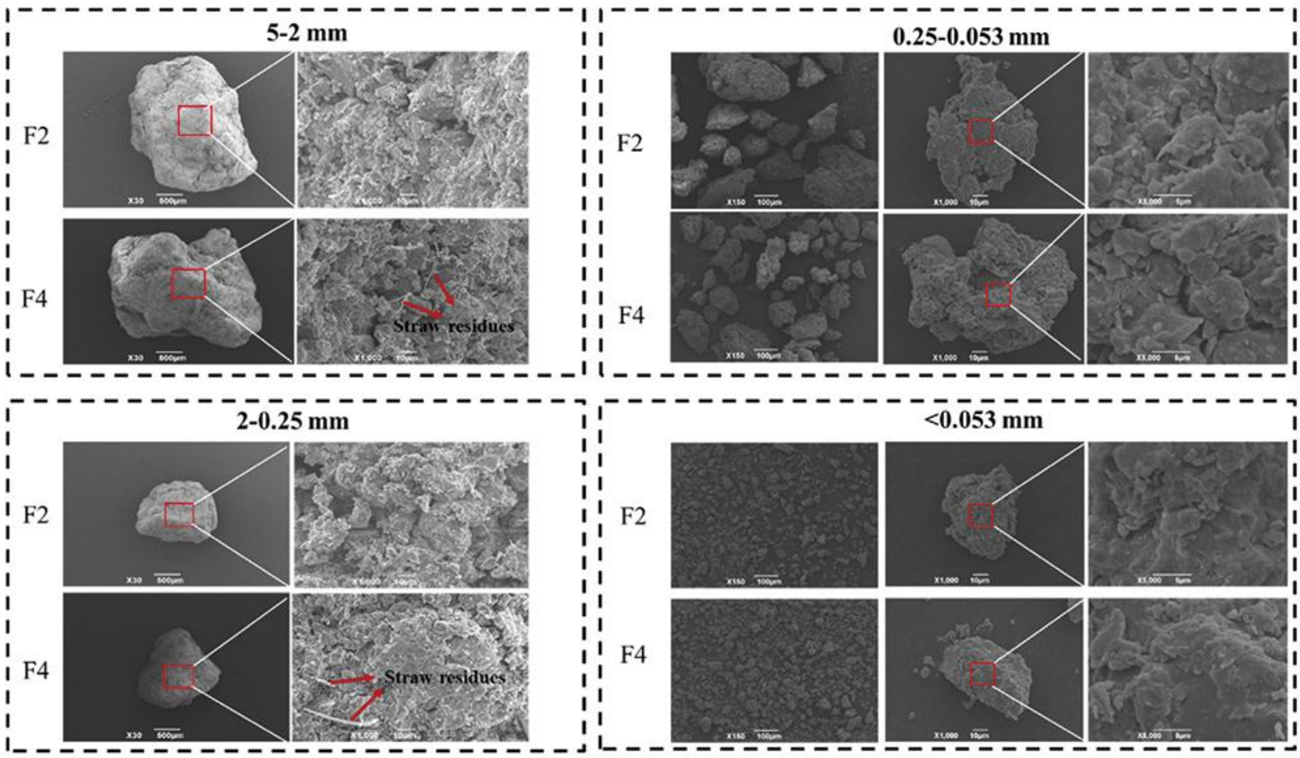

Figure 4 Scanning electron micrograph showing the structure and morphology of aggregates under no straw returned and straw returning treatments. F2, mineral nitrogen, phosphorus and potassium; F4, mineral nitrogen, phosphorus and potassium with straw returning (Adopted from Xue et al., 2022)

Image caption: The figure shows that in the treatment without straw returning (F2), soil aggregates have smaller particles, fewer pores, and a more compact arrangement; whereas in the straw-returning treatment (F4), aggregates have larger particles, significantly more pores, smoother surfaces, and contain some undecomposed straw residues. The results indicate that straw returning improves the structure and stability of soil aggregates by increasing organic matter and promoting microbial activity (Adapted from Xue et al., 2022)

6.2 Enhancing crop yield through straw incorporation and phosphorus fertilization

In the rapeseed-rice rotation system widely cultivated in the Yangtze River basin, the low utilization efficiency of phosphorus fertilizer has led to insufficient soil nutrient accumulation or phosphorus runoff, impacting both crop growth and environmental quality. With the promotion of straw incorporation techniques, combining this approach with appropriate phosphorus application has become a viable method to enhance soil fertility and boost crop yields (Yang et al., 2020; Zhang et al., 2023).

In a three-year experiment, Zhang et al. (2023) investigated the effects of combining straw incorporation with various phosphorus fertilization strategies on crop yield and soil health in a rapeseed-rice rotation system. The results indicated that alternating the incorporation of rice and rapeseed straw and applying 120 kg/ha of phosphorus fertilizer during the rapeseed season (T2P3 treatment) significantly improved crop yields, with a 15% increase in rapeseed yield and a 17% increase in rice yield. Additionally, the T2P3 treatment markedly enhanced the available phosphorus content in the soil and optimized the soil microbial community structure, particularly promoting the growth of phosphate-solubilizing bacteria such as *Pseudomonas* and *Bacillus subtilis*. Compared to traditional seasonal fertilization (T2P2), the T2P3 treatment improved soil fertility and biodiversity while reducing phosphorus fertilizer usage, demonstrating the feasibility of this optimized strategy. This study provides scientific evidence for phosphorus management and straw utilization in the region.

7 Challenges and Limitations

7.1 Decomposition rate and nutrient release

The decomposition rate of rapeseed straw and the subsequent release of nutrients are critical factors influencing its effectiveness in improving soil fertility and crop productivity. The presence of arbuscular mycorrhizal fungi (AMF) has been shown to significantly promote the degradation of rapeseed straw and enhance the release of essential nutrients such as nitrogen, phosphorus, and potassium (Guo et al., 2023). However, the rate of decomposition can vary significantly depending on environmental conditions and the presence of microbial communities. For instance, the application of decomposition agents can alter the fungal community structure, thereby affecting the rate of straw decomposition and nutrient release (Wang et al., 2022). Additionally, long-term studies have shown that the effects of straw return on soil organic carbon (SOC) storage can be inconsistent, with some soils showing greater increases in SOC stocks than others (Hagos et al., 2020). This variability poses a challenge in predicting the exact benefits of rapeseed straw incorporation in different soil types and climatic conditions.

7.2 Potential negative effects

While rapeseed straw can improve soil fertility, it may also have potential negative effects, such as allelopathy, which can inhibit the growth of subsequent crops. Studies have found that aqueous extracts of rapeseed straw significantly affect the seed germination and seedling growth of crops such as oats, maize, and sunflowers. However, higher concentrations of the extract inhibit root and stem growth in sunflowers, while lower concentrations have a promoting effect on maize. This allelopathic inhibitory effect is most pronounced in sunflowers, with relatively lesser effects on maize and oats (Gao et al., 2020). The incorporation of rapeseed straw has been associated with changes in soil microbial communities, which can lead to the production of allelopathic compounds that negatively affect plant growth (Jin et al., 2021).

Additionally, the application of straw can result in increased greenhouse gas emissions, including methane and nitrous oxide, which contribute to global warming (Li et al., 2023). These emissions are particularly concerning in paddy-upland cropping systems, where the combination of straw and high moisture levels can exacerbate the release of these gases (Salam et al., 2019). Therefore, careful management practices are required to mitigate these potential negative effects and ensure the sustainable use of rapeseed straw in agriculture.

7.3 Practical challenges in large-scale application

The large-scale application of rapeseed straw in agricultural systems presents several practical challenges. One major issue is the logistics of collecting, transporting, and evenly distributing the straw across large fields. This process can be labor-intensive and costly, particularly in regions with limited mechanization (Song et al., 2023).

Additionally, the incorporation of straw into the soil requires specific equipment and techniques to ensure proper mixing and decomposition, which may not be readily available to all farmers (Sonwani et al., 2019; Liu et al., 2020).

Another challenge is the variability in the effectiveness of straw incorporation depending on the cropping system, soil type, and environmental conditions. For example, the benefits of straw return in terms of soil nutrient content and crop yield can differ significantly between rice-rape rotation systems and upland cropping systems (Hagos et al., 2020; Zhang et al., 2023). These practical challenges highlight the need for tailored management practices and support systems to facilitate the widespread adoption of rapeseed straw incorporation in diverse agricultural settings.

8 Concluding Remarks

The integration of rapeseed straw into agricultural practices has shown significant benefits for soil fertility and crop productivity. Studies have demonstrated that straw return, when combined with appropriate fertilization, enhances soil nutrient content, microbial diversity, and crop yields. For instance, phosphorus application during the rapeseed season combined with straw return significantly improved crop productivity and soil bacterial diversity in rape-rice rotations. Similarly, annual straw incorporation with nitrogen fertilizer in rice seasons positively influenced dry matter and nutrient accumulation in subsequent rapeseed crops. Moreover, straw residue incorporation was found to enhance soil microbial biomass and carbon-nitrogen dynamics, particularly in high fertility soils. The use of decomposition agents with straw return also improved soil fungal community diversity and soil quality, leading to better cotton yields. Long-term straw management practices, coupled with potassium fertilization, were shown to increase crop yields and improve soil properties and microbial communities in rice-oilseed rape rotations. Straw mulching with nitrogen fertilizer improved soil nutrients, enzyme activities, and crop productivity in semi-arid conditions.

Future research should focus on optimizing straw management practices to maximize their benefits while minimizing potential negative impacts such as greenhouse gas emissions. Studies should explore the long-term effects of different straw incorporation rates and combinations with various fertilizers on soil health and crop productivity across diverse agro-ecological zones. Investigating the interactions between straw return and soil microbial communities in greater detail could provide insights into enhancing soil fertility sustainably. Additionally, research should aim to develop region-specific guidelines for straw management that consider local soil types, climate conditions, and cropping systems. The potential of straw return to mitigate climate change through carbon sequestration should also be a key area of investigation, with a focus on balancing productivity gains with environmental sustainability.

The role of rapeseed straw in improving soil fertility and crop productivity is well-supported by current research. The integration of straw return into agricultural practices offers a sustainable approach to enhance soil health, increase crop yields, and support long-term agricultural productivity. However, careful management is required to optimize these benefits and mitigate any adverse environmental impacts. Continued research and innovation in this field will be crucial to developing effective and sustainable straw management strategies that can be tailored to specific agricultural contexts.

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Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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