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Optimal Soil, Climate, and Management Factors for Maximizing Crop Yield and Soil Nutrients in a Rice–Oilseed Rotation System with Straw Return

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Abstract: Straw return (SR) has been widely recommended as a conservation agricultural practice in China. However, the effects of SR on crop yield and soil properties are inconsistent across studies of rice–oilseed rape cropping systems in China. This study aimed to investigate the effects of SR on crop yield and soil nutrient content in a rice–oilseed rotation system, and to understand the mechanism of straw return on the difference in yield increases between rice and oilseed rape. Additionally, suitable climate factors, soil properties, and agricultural practices were identified to achieve maximum increases in yield and soil nutrients in a rice–oilseed rotation under SR. This paper is based on a meta-analysis of 1322 observations from 83 peer-reviewed studies to evaluate the effects of climate, initial soil conditions, and agricultural management practices on rice and oilseed rape yields and soil nutrients under SR. The results showed that the responses of oilseed rape and rice yield remained positive, with 12.37% and 6.54% increases, and were significantly higher under SR than the control (no SR). Moreover, SR significantly increased the contents of several soil nutrients (soil organic carbon (SOC), total nutrients, available nutrients) and microbial biomass carbon (MBC) and nitrogen (MBN). Interestingly, the increase in crop yields was attributed to the increase in SOC, total nitrogen, and available potassium. Additionally, the increase in yields was mainly affected by climate factors, initial soil properties, and agronomic practices. For example, both mean annual temperature (MAT) and mean annual precipitation (MAP) had a positive correlation with crop yield increases under SR ($p < 0.01$). Initial soil conditions such as low SOC and total nitrogen content were more suitable for increased rice yield under SR, while the opposite was true for increased oilseed rape yield. Without fertilization, the SR did not significantly improve crop yield and soil nutrients, while it was more pronounced with N fertilization at 150–180 kg hm^{-2}. The positive effect of SR on crop yields is more evident with plowing tillage, whereas the SR caused the highest increase in soil nutrients with the no-tillage condition. These findings have important implications for further improving crop yield, SOC, and soil nutrients in the Chinese rice–oilseed cropping system through straw return.

Keywords: meta-analysis; MBC; rice–oilseed rape; straw return; SOC content; soil nutrients

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1. Introduction

Upland rice rotation is an essential cropping system in the world, especially in Asia [1,2], covering an estimated area of 26.7 million hectares [3]. Rice is the most important staple crop, accounting for 30.1% of the sown area and 35.0% of the total grain production [4]. On the other hand, oilseed rape (*Brassica napus* L.) is used to produce edible oils for human consumption and is a promising biodiesel crop. China is the largest oilseed rape producer, with a share of 17.4% of global oilseed rape acreage and 17.7% of global oilseed rape production [4]. Therefore, the sustainability of the rice–oilseed rape rotation system is vital to ensure food security.

With population growth and limited arable land, increasing rice and oilseed yield per unit area is essential to fulfilling dietary and edible-oil needs [5,6]. Increasing the land area used and crop intensity is another way to enhance crop productivity [7], but this type of cultivation inevitably produces more straw. According to statistics [4], total crop straw production reached 1.04 billion tons in 2015. Farmers used to burn the straw directly in the fields, which was a practical and simple practice, but it had serious environmental impacts [8,9]. In recent years, straw burning has been explicitly prohibited by law; therefore, effective straw management has become a crucial issue in China.

Straw return (SR) as a novel approach for resource utilization is supported by relevant authorities, policies, and laws [10] and has been widely applied in China. For example, according to Li et al. [11], approximately 47% of straw is currently being returned to the soil. However, many farmers encounter many problems in the production process and are even reluctant to return straw to the field owing to its in-situ decomposition [12]. Therefore, scientists are striving to find ways to improve rice straw decomposition and nutrient cycling. For example, Wang et al. [13] found that microorganisms absorb a significant amount of nitrogen during the decomposition process, which affects seedling growth and yield. However, early nutrient deficiencies can be effectively mitigated by mixing fertilizer with straw to improve crop yields [13]. Lu [14] reported that long-term SR could improve soil health. Zhu et al. [15] showed that SR reduces soil temperature and retards crop growth. Similarly, excessive SR increased total N concentration under rainfall conditions, leading to N losses [16]. Li et al. [17] investigated the effects of long-term SR on crop yield as a function of initial soil pH and SR duration. Peng et al. [18] found that under different soil conditions (sandy loam and chalky loam soils), straw returning to fields has no significant effect on rice yield. Previous research has also shown that crop yield was not significantly affected by straw return with a higher rate of N fertilizer application in wheat [19]. Although the effects of SR have been extensively studied, the results are inconsistent or contradictory due to differences in soil conditions, management practices, and climatic conditions. Therefore, the yield response to SR in a rice–oilseed rotation should be evaluated together rather than separately [14].

Multiple meta-analyses have documented the impact that managing crop straw has on both crop productivity and soil characteristics. For example, one noteworthy finding from the study conducted by Islam et al. [10] is that the use of straw retention boosted the yields of both maize and wheat by 5.5% in a cropping system utilizing both crops. Additionally, Li et al. [20] found that straw retention resulted in a yield increase of 4.5% for rice and 4.2% for wheat in a cropping system that alternated between the two crops. Crops respond variably to SR regarding yield production under different rotation-based cropping systems. Therefore, integrative studies are necessary to reveal crop yield variation patterns and identify the main drivers of responses to SR.

However, to our knowledge, the integration of SR with the external climatic conditions, management practices, and soil properties on rice and oilseed rape yield and soil nutrients in the rice–oilseed rape cropping system have not been explored so far. We hypothesized that incorporating straw back into the soil could lead to an increase in crop yield and an improvement in soil nutrient levels. We carried out a study on the effects of SR on the rice–oilseed rape rotation system by conducting a meta-analysis of 83 published studies. Our analysis consisted of 1322 comparison pairs to evaluate the collective impact of SR on soil properties and crop yield. Our objectives were to (a) quantify the effects of SR on crop yield and soil nutrient content in a rice–oilseed rotation system; (b) examine changes in soil nutrients and crop yield under a range of climatic conditions, management practices, and initial soil properties; (c) explore how straw return can improve crop yields by improving soil nutrients in a rice–oilseed rape cropping system. The results of the systematic analysis in this study will provide worthwhile information on straw return as an effective agricultural management practice to improve crop productivity in rice–oilseed rape cropping systems. Moreover, this study will be helpful in developing new adaptive strategies for rice–oilseed rape cropping systems in the future.

2. Materials and Methods

2.1. Data Collection

We used the ISI Web of Science, Science Direct, and the China Knowledge Resource Integrated Database to search for peer-reviewed scientific journal articles (including master's and doctoral dissertations) on the effects of SR on crop yield and soil nutrients in rice–oilseed rape cropping systems in China. The main keywords used to search for related publications were "straw return" or "straw incorporation" or "straw mulching" and "yield" or "soil" till February 2022. Then, we checked for references to articles on the effect of straw on crop yield in rice–oilseed rape cropping systems to identify other relevant book chapters and peer-reviewed reports, resulting in 83 studies at 81 field trial sites (Figure 1). The rice–oilseed rape cropping system under straw return is described in Figure 1. The data were then obtained by screening according to the following conditions: (1) for trials in mainland China, including field studies of rice or oilseed rape growth only, rice or oilseed rape was planted last season, or the article states that the area is a rice–oilseed rape rotation area; furthermore, crop grains had to be harvested and weighed at physiological maturity; (2) strict treatments (SRs) and controls (straw not returned); (3) inclusion of at least one target variable, i.e., crop yield or soil nutrients; (4) test experiments should include at least three replicates per treatment; (5) data should have mean, sample size, and standard deviation/error. For some of the data presented as bar or line graphs in the literature, means and standard deviations were obtained by GetData GraphDigitizer software 2.26 (https://getdata-graph-digitizer.software.informer.com/, accessed on 8 January 2023). A total of 83 papers were finally screened. Among them, there are 7 master's and 2 doctoral dissertations.

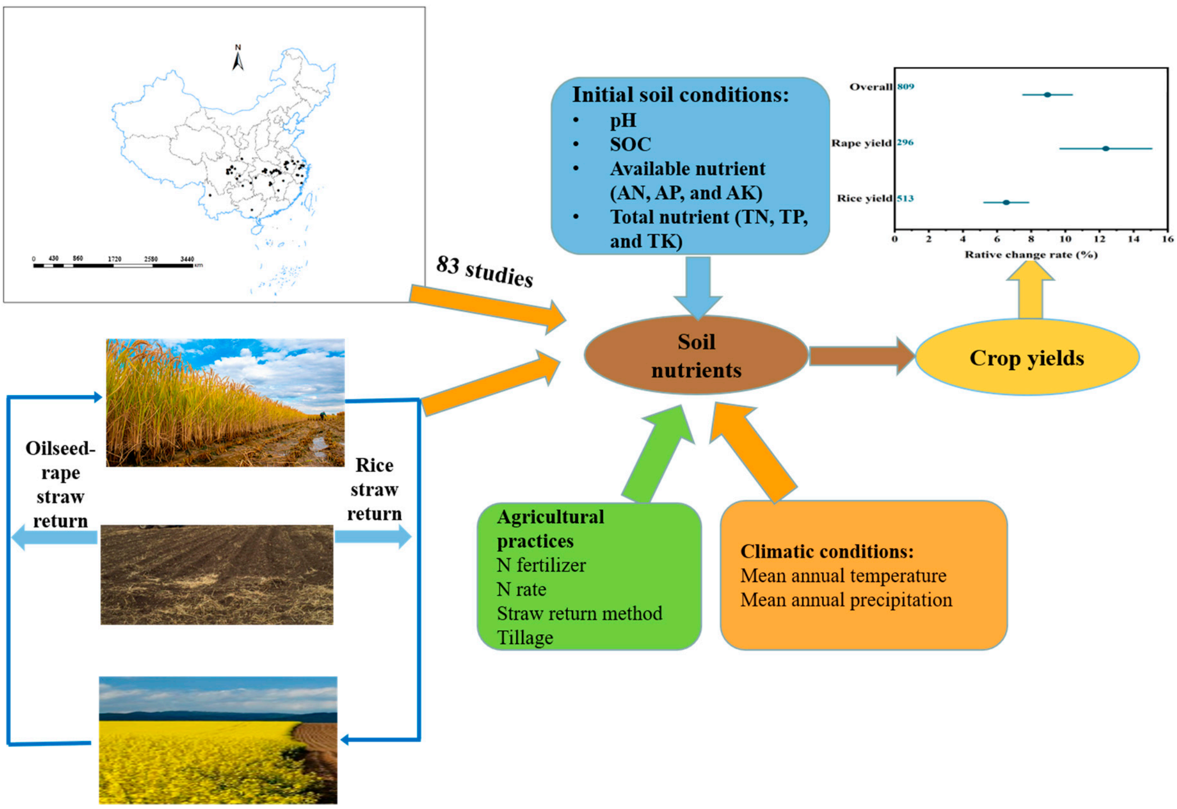

Figure 1. Conceptual figure depicting the relative changes in crop yields in oilseed–rice cropping systems under straw return and geographical distribution of the field experiment sites across China;

includes the meta-analysis. Note: SOC, soil organic carbon; AN, soil available nitrogen, AP, soil available phosphorus, AK, soil available potassium, TN, soil total nitrogen, TP, soil total phosphorus, TK, soil total potassium. The numbers in the left of the pictures represent the sample size. The mean effect and 95% confidence interval (CI) are shown if the CI does not overlap with the 0 line, which means significant effects ($p < 0.05$).

2.2. Data Categorization

The location, test year, initial soil conditions of the experimental site, mean annual temperature (MAT), mean annual precipitation (MAP), rice and oilseed rape yield, and soil indicators were extracted from the selected literature. Soil initial conditions refer to the soil characteristics before straw returned to the field, mainly including soil organic carbon (SOC), soil pH, soil total nitrogen (TN), soil total phosphorus (TP), soil total potassium (TK), soil available nitrogen (AN), soil available phosphorus (AP), and soil available potassium (AK). In addition, for comparison between subgroups, all data were normalized to soil organic matter given in the literature and transformed into SOC according to the following equation: SOC = soil organic matter/1.724. The extracted analysis data needed to be grouped with the same criteria for each attribute to allow comparison across studies. The data grouping is detailed in Table S1. The amount of straw returned to the field in oilseed rape season is generally 1.5–10 t hm^{-2}, and the amount of straw returned to the field in rice season is generally 3.0–12.0 t hm^{-2}. The rice straw's N, P_2O_5, and K_2O of were 0.83%, 0.27%, and 2.06%, respectively. The oilseed rape straw's N, P_2O_5, and K_2O were 0.82%, 0.32%, and 2.24%, respectively [21]. The straw incorporation refers to the return of the straw to the soil after the harvest of the previous crop and the turning of the straw into the soil before the sowing or transplanting of the last crop. Straw mulching refers to covering the soil surface with crop straw. The amount of nitrogen fertilizer applied refers to the total amount applied during the rice or rape season, including the basal fertilizer applied 1–2 days before planting under normal conditions. The amount of nitrogen fertilizer (pure nitrogen) applied to rice and rape was 68–336 kg hm^{-2}. No-till means that the crop is sown directly on the original stubble without plowing the land before sowing. The rotation tillage layer is generally 15–20 cm, and the plowing tillage layer is 20–30 cm. According to United States Department of Agriculture (USDA) soil classification system, soil texture classes were categorized as sandy, loam, and clay soils.

2.3. Data Analysis

Our meta-analysis assessed the effect of SR on crop yield and soil physicochemical properties under rice–oilseed rape cropping systems. Data were analyzed by meta-analysis using the natural logarithm of the response ratio (lnR) [22].

$$\text{LnR} = \ln{(\text{Xt}/\text{Xc})}$$

where Xt is the mean observed variables (crop yield and soil properties) of the SR treatment, Xc is the mean observed variables of no-SR treatment.

Typically, the effect sizes can be weighed by the inverse of the pooled variance or replications. However, in the meta-analysis study, the studies that were most commonly chosen did not provide data on standard deviations. Hence, we utilized the unweighted method for the meta-analysis. To compute the mean effect sizes and the 95% confidence interval (CI), we made use of the R package called "nlme" [23].

$$\text{lnR} = \alpha + \beta \times \text{M} + \text{error}$$

where α is the intercept with the same dimension as lnR, β represents the response due to the SR treatment, and error represents the residual that the SR variable did not explain. The SR treatments (SR and no SR) were considered as fixed effects, while the studies were used as random effects. The mean effects of SR treatment were deemed significant if the confidence intervals did not overlap with 0 (p values = 0.05). To determine significant differences between mean effects in different subgroups, their 95% CI should not overlap. To facilitate interpretation, all results were reported as the percentage change in yields and soil properties for each SR treatment after back-transformation.

A stepwise regression analysis was used to analyze the relationship between lnR and other parameters using SPSS version 19 (SPSS Inc. Chicago, IL, USA). To further quantify the relative importance of climate conditions, agriculture management practices, and initial soil properties, a random forest approach was used using R software's "randomForest" packages [24]. All figures in this study were created with OriginPro 2021 (OriginLab Corporation, Microcal, Northampton, MA, USA).

3. Results

3.1. Overall Effect of SR on Crop Yield

The response ratio (lnR) of crop yield to SR showed significant variability in rice–oilseed rape cropping systems in China, ranging from −0.20 to 0.83 for rice yield and −0.39 to 1.13 for oilseed rape yield (Figure 2). The distribution frequencies of lnR conformed to Gaussian normal distribution in rice yield (R^2 = 0.947, p < 0.001) and in oilseed rape yield (R^2 = 0.975, p < 0.001). The positive effect size of the SR on crop yield accounted for a high percentage, i.e., 83.90% for rice and 80.70% for oilseed rape. The crop yield was increased by 8.95% (95% CI: 7.52–10.40%) under SR. In addition, the positive response of oilseed rape yield to SR was substantially higher than in rice yield, with a significant increase of 12.37% (95% CI: 9.75–12.06%) in oilseed rape and 6.54% (95% CI: 5.25–7.85%) in rice yield.

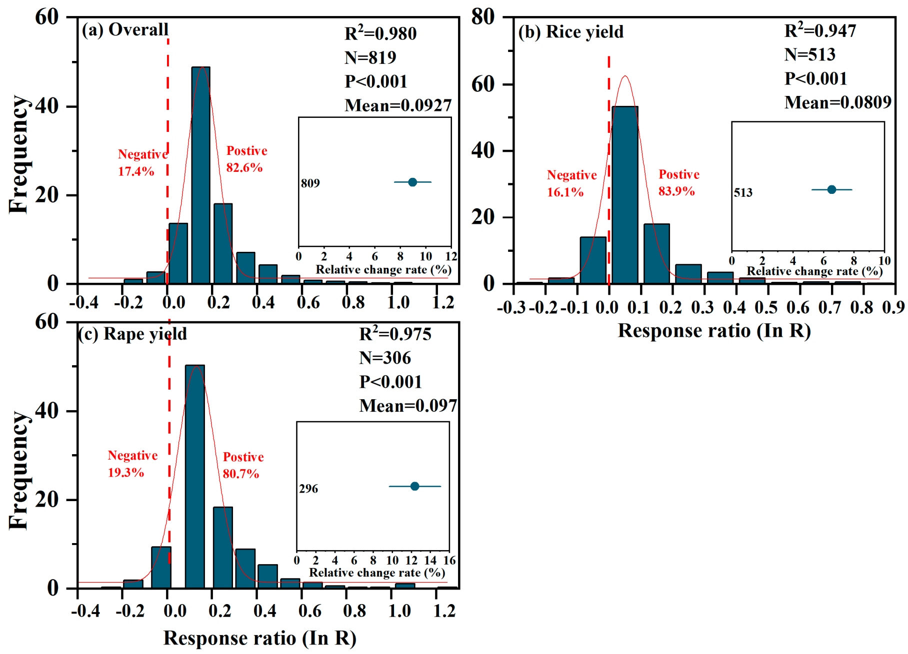

Figure 2. Frequency distributions of response ratio (ln R) and relative change rate (**a**–**c**) and for rice and oilseed rape yield responses to straw return. Note: for the response ratio ln R, <0, =0, and >0 indicate negative, neutral, and positive, respectively. The numbers on the left of the pictures represent the sample size. The mean effect and 95% confidence interval (CI) are shown if the CI does not overlap with the 0 line, which means significant effects (p < 0.05).

3.2. Responses of Soil Properties to Straw Return and Their Relationships with Crop Yield

Meta-analysis results showed that the soil nutrients significantly improved by SR treatment, compared to control (no SR) in rice–oilseed rape cropping systems (Figure 3). For example, the SR also significantly improved SOC by 12.14% (95% CI: 9.99–14.34%), TN by 6.65% (95% CI: 5.12–8.21%), TP by 8.78% (95% CI: 4.74–12.98%), TK by 2.59% (95% CI: 0.68–4.53%), AN by 11.07% (95% CI: 8.68–13.51%), AP by 13.35% (95% CI: 8.74–18.16%), AK by 25.36% (95% CI: 19.23–31.80%), MBC by 24.77% (17.27–32.76%), and MBN by 22.46% (9.35–37.13%), but the effect on soil pH was found to be non-significant. In addition, it is worth noting that the increase in soil nutrients from straw return was greater in the oilseed rape season than in the rice season.

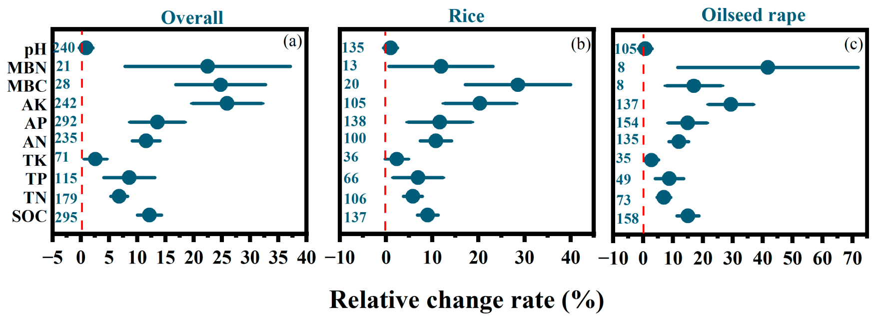

Figure 3. Distribution of relative changes in soil nutrients and soil physical properties in oilseed–rice cropping systems responding to straw return. (**a**) Overall; (**b**) straw return under rice season; (**c**) straw return under oilseed rape season; SOC, soil organic carbon; AN, soil available nitrogen; AP, soil available phosphorus; AK, soil available potassium; TN, soil total nitrogen; TP, soil total phosphorus; TK, soil total potassium; MBC, microbial biomass carbon; MBN, microbial biomass nitrogen. The numbers on the left of the pictures represent the sample size. The mean effect and 95% confidence interval (CI) are shown if the CI does not overlap with the 0 line, which means significant effects ($p < 0.05$).

Linear regression analysis showed that rice yield improvement had a significant negative correlation with initial soil conditions such as SOC, TN, AN, TP, and AP (Figure 4). The oilseed rape yield increase had a significantly positive correlation with SOC and TN, but a negative correlation with AP and AK (Figure 5).

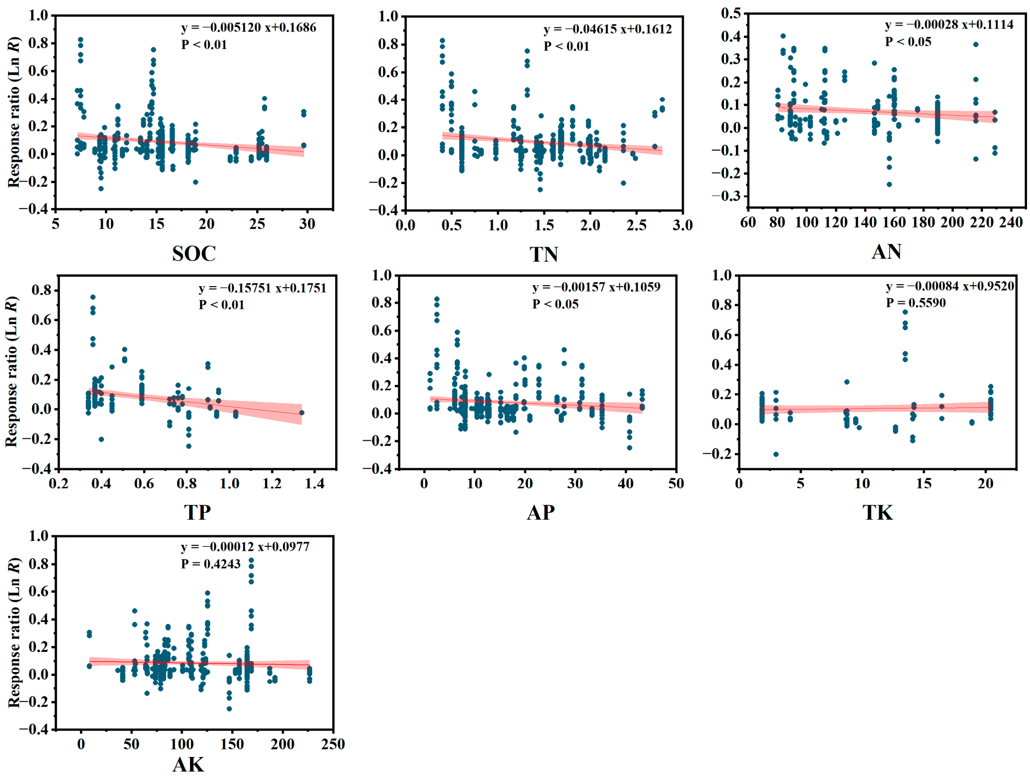

Figure 4. Relationships between rice yield responses to straw return for soil organic carbon (SOC), pH, soil total nitrogen (TN), soil total phosphorus (TP), soil total potassium (TK), soil available nitrogen (AN),

soil available phosphorus (AP), and soil available potassium (AK) in the oilseed rape–rice cropping system. The red line in the figure is the line of the fitted equation for the two covariates, y is the rice yield responses to straw return, x is the dimension of the region where the sample is located, and the red area is the 95% confidence interval of the fitted equation.

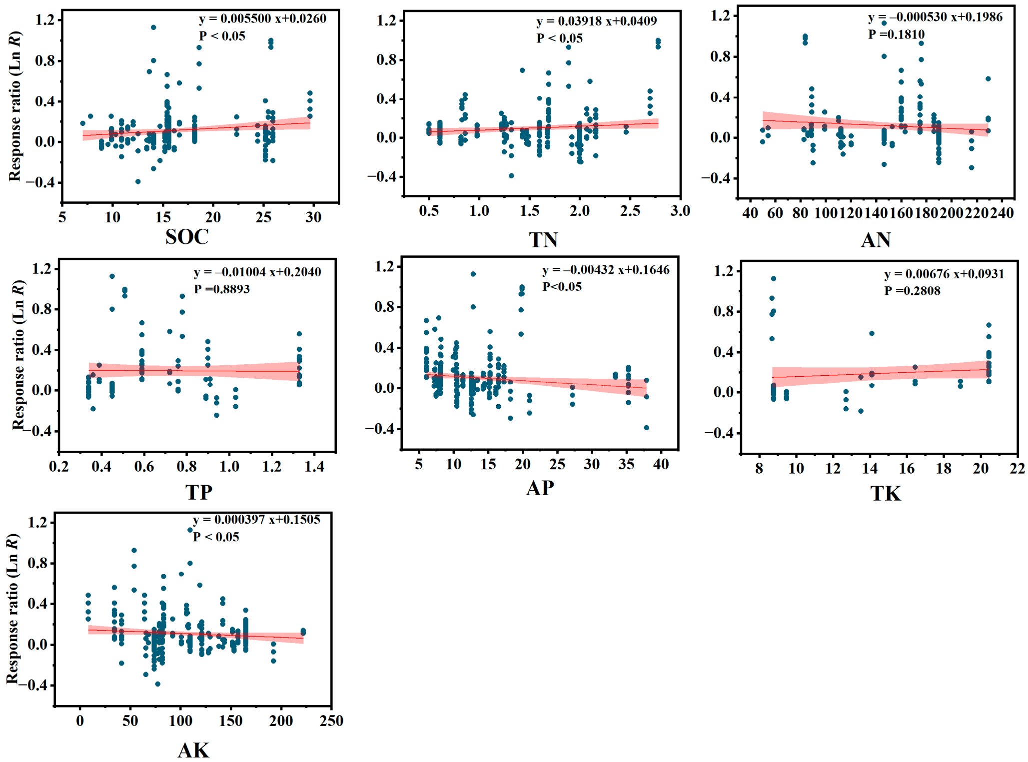

Figure 5. Relationships between oilseed rape yield responses to straw return for soil organic carbon (SOC), pH, soil total nitrogen (TN), soil total phosphorus (TP), soil total potassium (TK), soil available nitrogen (AN), soil available phosphorus (AP), and soil available potassium (AK) in the oilseed rape–rice cropping system. The red line in the figure is the line of the fitted equation for the two covariates, y is the oilseed rape yield responses to straw return, x is the dimension of the region where the sample is located, and the red area is the 95% confidence interval of the fitted equation.

3.3. Effect of SR in Different Climatic Conditions on Yield and Soil Properties

The magnitude of crop yield improvement by SR varied under different temperature and precipitation conditions (Figure 6). For example, rice and oilseed rape yield was 5.87% and 9.27%, and 9.27% and 18.54% at MAT < 16 °C and MAT ≥ 16 °C, compared to the control, respectively. The impact of SR on crop yield was more significant in regions with MAP of 1200 mm, resulting in an increase of 8.98% and 16.17% in rice and oilseed rape yield, respectively. In comparison, regions with MAP between 1000 and 1200 mm demonstrated smaller increases in yield of 5.07% and 8.04% for rice and oilseed rape, respectively, while regions with MAP of 1000 mm experienced a notable increase of 11.11% in rice yield but a meager increase of 5.22% in oilseed rape yield. The meta-analysis demonstrated that under the conditions of MAP ≤ 1000 mm and MAT ≥ 16 °C, the SOC significantly increased by 23.90% and 9.29%, TN by 10.55% and 8.04%, AN by 24.59% and 7.21%, TP by 13.24% and 12.51%, AP by 25.03% and 6.37%, and was more outstanding than MAP > 1000 mm and MAT < 16 °C, respectively. In addition, the highest increases i.e., 41.02% and 40.08% in AK was observed in regions with MAT ≥ 16 °C and MAP ≥ 1200 mm, respectively. Moreover, the effect of different climatic conditions on soil pH was insignificant. Both mean annual temperature and precipitation had a positive correlation with yield increase under straw-return conditions ($p < 0.01$) (Figure 7).

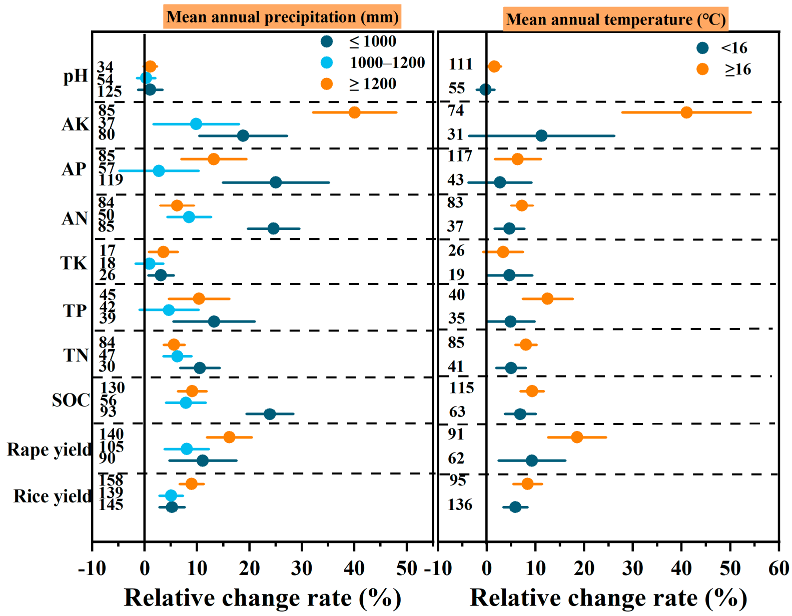

Figure 6. The effect of straw return on crop yield and soil properties under different climatic conditions during the rice–oilseed cropping systems by mean annual temperature and mean annual precipitation. Note: SOC, soil organic carbon, AN, soil available nitrogen, AP, soil available phosphorus, AK, soil available potassium, TN, soil total nitrogen, TP, soil total phosphorus, TK, soil total potassium. The numbers on the left of the pictures represent the sample size. The mean effect and 95% confidence interval (CI) are shown if the CI does not overlap with the 0 line, which means significant effects ($p < 0.05$).

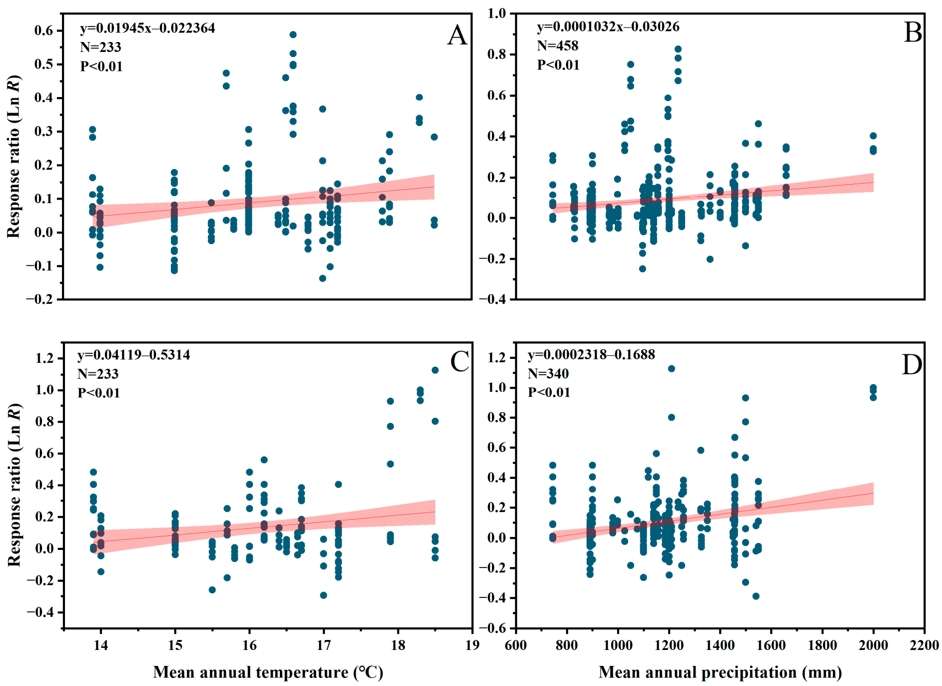

Figure 7. Relationships between rice yield (**A**,**B**) and oilseed rape yield (**C**,**D**) responses to straw return for mean annual temperature and mean annual precipitation in the oilseed rape–rice cropping system. The red line in the figure is the line of the fitted equation for the two covariates, y is the rice yield (**A**,**B**) and rape yield (**C**,**D**) responses to straw return, x is the dimension of the region where the sample is located, and the red area is the 95% confidence interval of the fitted equation.

3.4. Effect of SR in Initial Soil Conditions on Yield and Soil Properties

3.4.1. Initial Soil Conditions with Different Soil pH, Texture, and SOC

At soil pH ≤ 6, the effect of SR on crop yield (rice and oilseed rape yields were increased by 7.13% and 16.14%, respectively), and the SOC, AP, TK, and AK contents were more effective, with increases of 13.85%, 13.34%, 4.93%, and 38.12%, respectively, higher than at soil pH > 6 (Figure 8). Additionally, the lifting effect on TP (8.56%) was more substantial at soil pH > 6. With an increase in SOC content in the soil, the rice yield decreased gradually. The main results were as follows: SOC ≤ 12 g kg^{-1} (8.23% and 12.04% for rice and oilseed yields, respectively), 12–18 g kg^{-1} (6.80% and 12.75% for rice and oilseed yields, respectively), and ≥18 g kg^{-1} (4.40%, 16.11% for rice and oilseed yields, respectively), respectively. The effect of SR on soil conditions with SOC ≤ 12 g kg^{-1} (11.14%, 12.13% and 12.72% for TN, AN, and AP, respectively) was greater than that on soil conditions with SOC of 12–18 g kg^{-1} or ≥ 18 g kg^{-1}. In soil conditions with SOC ≥ 18 g kg^{-1}, the TK and AK were increased by 6.95% and 43.67% under SR treatment, respectively, higher than SOC of 12–18 g kg^{-1} or ≤ 12 g kg^{-1}. Under SR, the rice and oilseed rape yield-increasing effect in soil texture with loam (6.85%) and clay (14.85%) was the highest. The more pronounced effect of SR on soil nutrients concerned loam- and clay-textured soil than sandy soils in the rice–oilseed cropping system.

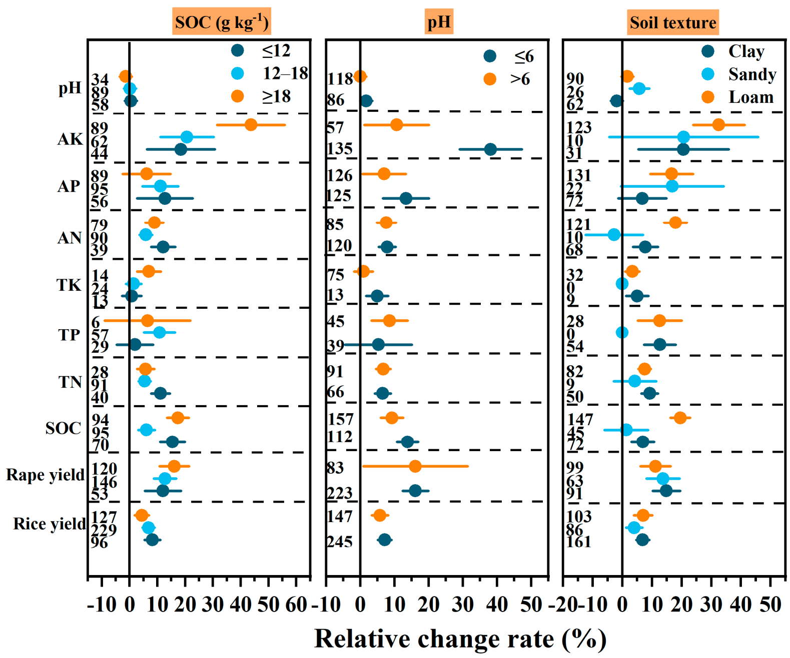

Figure 8. Effects of different soil conditions, i.e., soil organic carbon (SOC), soil pH, and soil texture of straw return on crop yield and soil nutrients in a rice–oilseed rape cropping system. Note: AN, soil available nitrogen, AP, soil available phosphorus, AK, soil available potassium, TN, soil total nitrogen, TP, soil total phosphorus, TK, soil total potassium. The numbers on the left of the pictures represent the sample size. The mean effect and 95% confidence interval (CI) are shown if the CI does not overlap with the 0 line, which means significant effects ($p < 0.05$).

3.4.2. Initial Soil Conditions with Different TN, TP, and TK

The rice and oilseed rape yield were increased by 6.01% and 12.40% for TN ≤ 1.5 g kg^{-1}, 10.17% and 18.59% for TN 1.5–2 g kg^{-1}, 4.52% and 12.24% for TN ≥ 2 g kg^{-1}, respectively, compared to control (Figure S1). In soil conditions with TN ≥ 2 g kg^{-1}, the SOC increased by 20.02% under SR treatment, which was significantly higher than under TN ≤ 2 g kg^{-1}. Oilseed rape yield was increased by 26.24% and 27.34%, as well as AP by 13.21% and 12.10% under soil conditions with TP > 0.5 g kg^{-1} and TK > 10 g kg^{-1}, respectively, which were higher than those with TP ≤ 0.5 g kg^{-1} and TK ≤ 10 g kg^{-1} under SR. The effect of the SR was more pronounced on soils with TP ≤ 0.5 g kg^{-1}, where rice yield increased by 8.01%, SOC by 9.30%, TN by 8.23%, and TP by 11.30%, which were higher than those of TP > 0.5 g kg^{-1}. Rice yield, SOC, TN, and TP were increased by 8.35%, 7.62%, 6.02%, and 12.97%, respectively, by the soil condition, with TK ≤ 10 g kg^{-1}.

3.4.3. Initial Soil Conditions with Different AN, AP, and AK

The effects of SR on crop yield and soil properties were inconsistent under different soil conditions of available N, P, and K (Figure S2). For example, under the soil condition with AN ≤ 100 mg kg^{-1} for SR, the increase in rice yield (8.38%), oilseed rape yield (19.76%), and TN (6.44%), AN (8.33%), and AP (12.46%) was better than the soil condition of AN > 100 mg kg^{-1}. In contrast, in soil conditions with AN > 100 mg kg^{-1}, the SR was more effective in enhancing SOC, TP, and AK contents than AN ≤ 100 mg kg^{-1}. In terms of AP, the increase in oilseed rape yield (15.75%), AN (8.98%), and AP (12.77%) was higher under AP ≤ 12 mg kg^{-1} than AP > 12 mg kg^{-1}. The increment in rice yield (6.38%), SOC (9.61%), TN (6.85%), TP (11.46%), and AK (32.99%) were observed in soil conditions with AP > 12 mg kg^{-1}, which was higher than that AP ≤ 12 mg kg^{-1}. Interestingly, the more pronounced effect of SR on crop yield and soil properties (except soil pH and AN) was concerning AK > 120 mg kg^{-1} than AK ≤ 120 mg kg^{-1}.

3.5. Effects of SR under Different Cultivation Practices on Crop Yield and Soil Nutrients

The crop yield and soil properties during the SR in rice–oilseed rape cropping systems were significantly affected by fertilizer application (Figure 9). No significant enhancement in crop yield and soil nutrients was noted (except SOC) by SR without fertilizer application. However, the increases in crop yield (6.72–12.72%) and soil properties (2.80–26.96%) were significantly affected by fertilizer application under SR. With the increase in fertilizer application, the rice and oilseed rape yields increased gradually, as follows: 5.56% and 4.20% when the N rate ≤ 150 kg hm^{-2}, 6.89% and 12.31% when the N rate was 150–180 kg hm^{-2}, and 7.28% and 17.31% when the N rate ≥ 180 kg hm^{-2}. The soil conditions of SOC, TN, AN, and TP under SR conditions gradually increased when the N rate increased from ≤150 kg hm^{-2} to 150–180 kg hm^{-2} and then decreased when the N rate was higher than 180 kg hm^{-2}. The promotive effect of AK gradually reduced from 35.76% to 15.07% with the increase in fertilizer application.

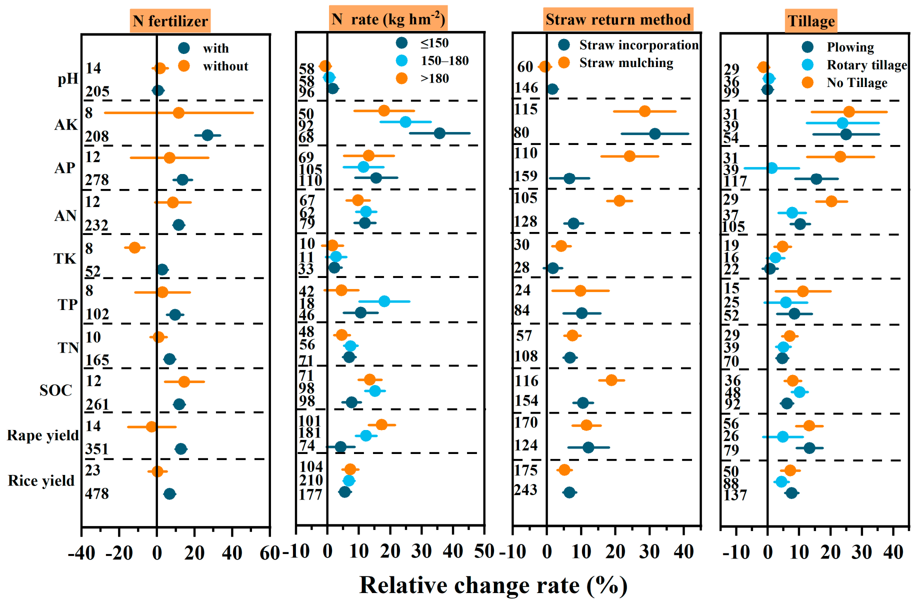

Figure 9. Effects of different agricultural practices i.e., fertilizer, N application rate, tillage, straw return method on crop yield and soil nutrients in a rice–oilseed rape cropping system. Note: SOC,

soil organic carbon, AN, soil available nitrogen, AP, soil available phosphorus, AK, soil available potassium, TN, soil total nitrogen, TP, soil total phosphorus, TK, soil total potassium. The numbers on the left of the pictures represent the sample size. The mean effect and 95% confidence interval (CI) are shown if the CI does not overlap with the 0 line, which means significant effects ($p < 0.05$).

For the different tillage practices, the rice and oilseed rape yields were increased by 7.62% and 13.33% for plowing, respectively, which was more significant than rotary tillage, e.g., 4.38%, 4.82%, or no tillage e.g., 7.20% and 13.24%. Moreover, under no tillage, the soil nutrients with TN, AN, TP, AP, and AK were increased by 6.98%, 20.38%, 11.26%, 23.19%, and 25.94%, respectively, higher than rotary tillage and plowing in rice–oilseed rape cropping systems. Furthermore, straw utilization strategies had a similar impact on rice yield and oilseed rape yield, with straw incorporation increasing them by 6.63% and 12.18%, respectively, and straw mulching by 5.16% and 11.62%, respectively. Additionally, straw mulching had a more obvious impact on soil properties (18.88%, 21.24%, and 24.18 for SOC, AN, and AP, respectively) than straw incorporation (6.10%, 10.38%, 6.60% for SOC, AN, and AP, respectively).

3.6. Relationships between Crop Yield Responses to Straw Return for Soil Nutrients

The linear regression analysis showed that enhancement of rice and oilseed rape yield had a significantly ($p < 0.01$) positive correlation with SOC, TN, AP, and AK (Figures 10 and 11). The relationship between crop yield and TK was significant ($p < 0.05$) in the rice–oilseed rape cropping system. We found that yield increase is linked with the improved soil fertility by the SR.

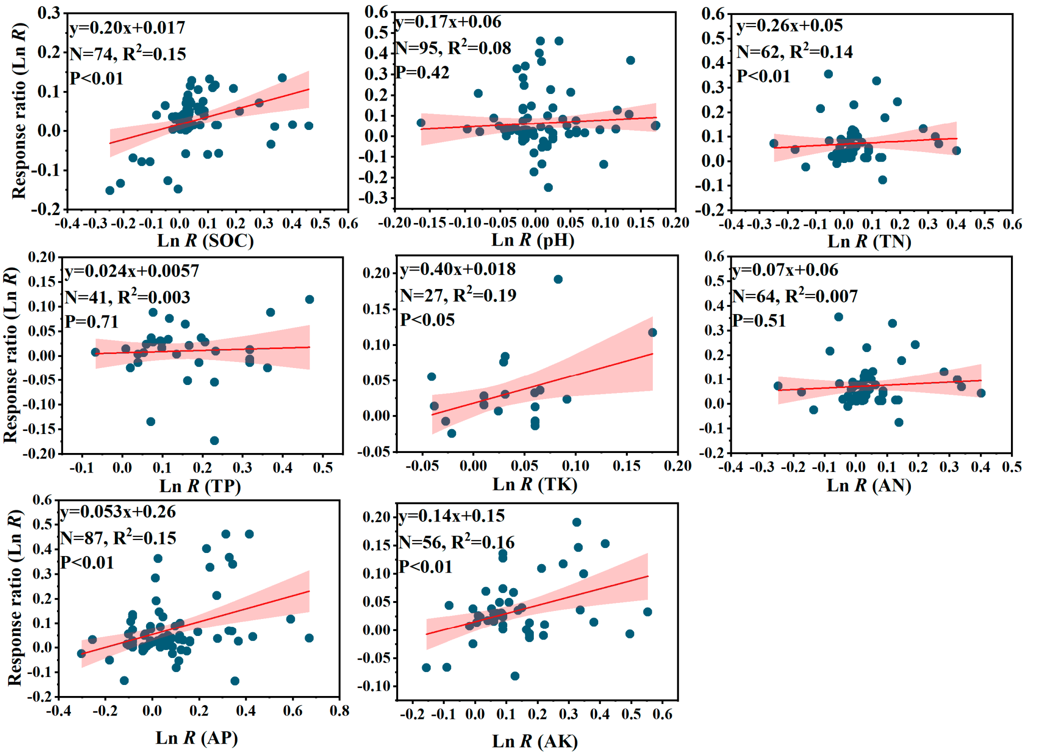

Figure 10. Relationships between rice yield responses to straw return for soil organic carbon (SOC), pH, soil total nitrogen (TN), soil total phosphorus (TP), soil total potassium (TK), soil available nitrogen (AN), soil available phosphorus (AP), soil available potassium (AK), and pH in the oilseed rape–rice cropping system. The red line in the figure is the line of the fitted equation for the two covariates, y is the rice yield responses to straw return, x is the dimension of the soil nutrients responses to straw return, and the dark green area is the 95% confidence interval of the fitted equation.

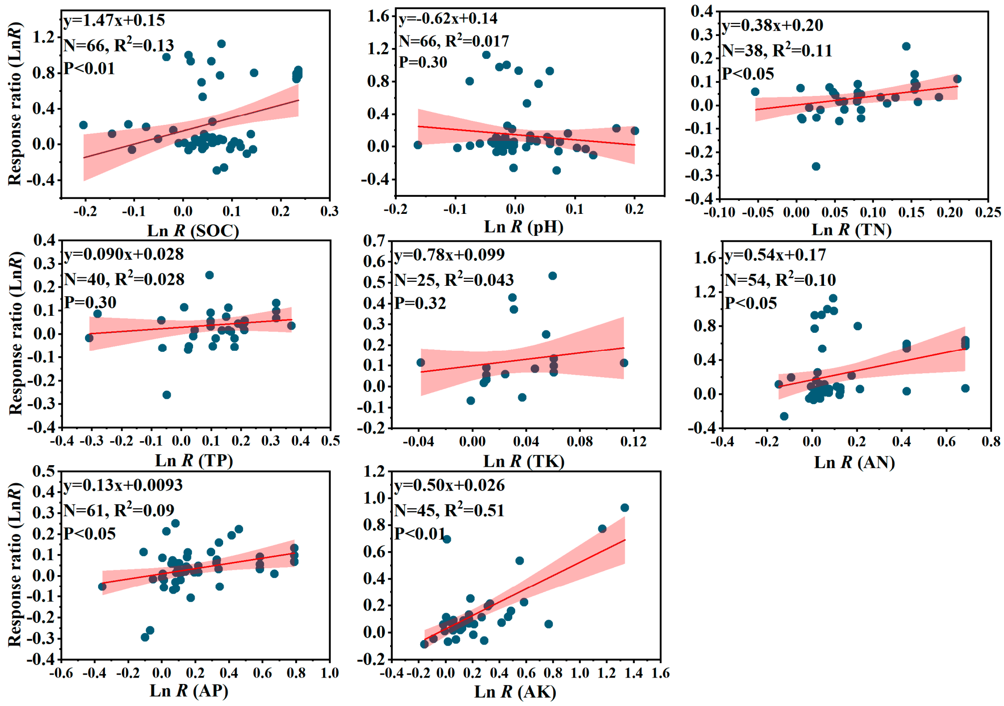

Figure 11. Relationships between rape yield responses to straw return for soil organic carbon (SOC), pH, soil total nitrogen (TN), soil total phosphorus (TP), soil total potassium (TK), soil available nitrogen (AN), soil available phosphorus (AP), soil available potassium (AK), and pH in the oilseed rape–rice cropping system. The red line in the figure is the line of the fitted equation for the two covariates, y is the rape yield responses to straw return, x is the dimension of the soil nutrient responses to straw return, and the dark green area is the 95% confidence interval of the fitted equation.

3.7. Relative Importance of All Variables on Crop Yield under SR

Overall, the effects of climatic conditions on soil quality with SR to rice and oilseed rape crops were 16.01% and 16.89%, respectively (Figure 12). We found that initial soil properties had the substantial effect on rice and oilseed rape yields, with 67.30% and 62.87%, respectively. Moreover, management practices had a higher effect on oilseed rape yield (20.24%) than rice yield (16.69%).

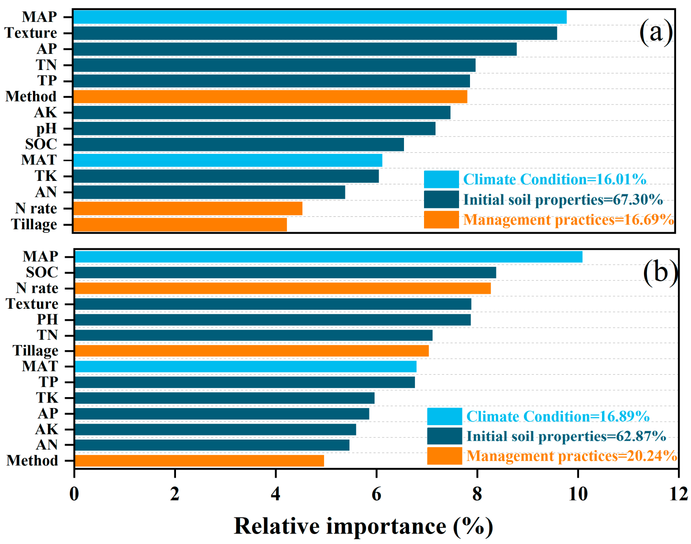

Figure 12. The relative importance (%) of variables for rice yield (**a**) and rape yield (**b**) response to straw return based on random forest regression model. Note: Continuous variables included mean

annual precipitation (MAP), mean annual temperature (MAT), N rate, initial soil conditions (soil total nitrogen (TN), soil total phosphorus (TP), soil total potassium (TK), soil available nitrogen (AN), soil available phosphorus (AP), soil available potassium (AK), soil organic carbon (SOC), pH; categorical variables included texture, tillage, and method in this meta-analysis.

4. Discussion

4.1. Overall Effect of SR on Rice and Oilseed Rape Yield

This study investigated the impacts of SR on crop yields, i.e., rice and oilseed rape yield and soil nutrients using a meta-analysis of Chinese studies. The effects of different climatic conditions, initial soil properties, and agriculture management in the rice–oilseed rape cropping system were mainly considered. The results showed that the rice and oilseed rape yields increased by 6.54% (95% CI: 5.25–7.85%) and 12.37% (95% CI: 9.75–12.06%) under SR, respectively, compared to straw removal in a rice–oilseed rape rotation cropping system. Previous studies found that rice and wheat yields were increased by 4.2–4.5% [20] and 3.53–7.21% [15] for SR in the rice–wheat cropping system. Moreover, the wheat and maize yields were enhanced by 4.83–6.17% [10] and 6.0–11.9% [25] for SR under the wheat–maize cropping system. Primarily, the rice–oilseed rape cropping system is a paddy–dryland crop rotation, which is helpful to maintain soil fertility and enhance arable land-use efficiency [26]. Next, oilseed rape is an excellent oil seed that can be used in cereal crop rotation systems as it disrupts the cycle of soil-borne pathogens [27]. Crop rotation also facilitated the full utilization of various nutrients in the soil [28]. According to our results, the main reason for the increase in yield is that SR can effectively increase the nutrient content. The results agreed with Islam et al. [10], who reported that SR increased crop yields by reducing soil bulk density and increasing TN in wheat–maize cropping systems. Straw decomposition in the soil is accompanied by the release of nitrogen, phosphorus, and potassium nutrients, which provide nutrients for crop growth and improve the physicochemical properties of the soil [27–29]. In addition, SR also promoted soil nutrient cycling in agroecosystems, providing the necessary conditions for increased crop yields [30]. Under SR conditions, microorganisms promoted the metabolism of soil nitrogen in the crop by regulating the rate of fertilizer nutrient release from soil and fertilizer [31]. Therefore, SR is an essential measure for crop yield increase under rice–oilseed rape rotation cropping system.

In the present study, the yield increase of oilseed rape was higher than that of rice under SR conditions. The main reason may be that the cumulative effect of rice straw on nutrient uptake was better than oilseed rape straw. Rice straw has a high nitrogen content and rapid decomposition, which significantly impacted soil nutrient content in the oilseed rape season [9]. Moreover, oilseed rape is a dryland crop, and the oxygen-rich soil environment is favorable for straw decay [17]. However, rice reproduction takes place in a flooded, anaerobic environment that inhibits the activity of aerobic microorganisms in the soil [32], resulting in lower straw nutrient release rates. The present study also found that straw return significantly increased the contents of several soil nutrients. It is worth noting that the increase in soil nutrients from straw return was greater in the oilseed rape season than in the rice season. The results agreed with Dai et al. [33], who also observed that dryland was more favorable for straw decomposition and nutrient accumulation than the paddy environment.

The variability in crop yield and soil nutrients could be related to the cumulative effect of several factors after SR, such as climate, soil conditions, and different cultivation practices. The relative impact analysis showed that the variable response to rice and oilseed rape yield was 16.01% and 16.89%, respectively, for climatic conditions, 16.69% and 20.24%, respectively, for management practices, 67.30% and 62.87%, respectively, for initial soil properties. The results indicated that these variables profoundly affected crop yield and should be well understood before considering effective strategies to maximize rice and oilseed rape yields.

4.2. Crop Yield and Soil Properties Were Affected by Climate Conditions under SR

The results of the meta-analysis indicated that crop yield and soil nutrients were significantly increased by MAT $\geq$ 16 °C than MAT < 16 °C under the SR condition. In general, the decomposition of straw was facilitated due to the high activity of soil microorganisms and enzymes under high-temperature conditions (MAT $\geq$ 16 °C), which had a significant positive impact on the improvement of the soil [34]. In the rice–oilseed rotation system, the most excellent effect on crop yield was observed at MAP $\geq$ 1200 mm. In addition, the highest soil nutrient content enhancement was found at MAP $\leq$ 1000 mm. Precipitation-rich areas directly accelerate straw decomposition through soil enzyme activity, structure, and organic carbon content [14]. Sui et al. [35] also found a significant correlation between straw decomposition and crop yield. However, low precipitation promoted alternating wet and dry conditions, which enhanced the soil microbial diversity [36]. Additionally, the significance of the influential factors indicated that rice and oilseed rape yields were notably affected by climate conditions, particularly mean annual precipitation. As a result, maintaining adequate levels of soil moisture and temperature was vital for enhancing crop yields during the growing season. Also, using SR at low precipitation in the rice and oil cropping system plays a crucial role in soil health improvement and has a high potential for a significant increase in future crop yields.

4.3. Crop Yield and Soil Properties Were Affected by Agricultural Management Practices under SR

The spatial distribution of crop residues in soil was significantly affected by different tillage practices [37]. Suitable tillage practices can accelerate the decomposition rate of straw, improve soil microbial activity, and facilitate the yield-increasing effect [38]. The meta-analysis results showed that the yield-increase effect of plowing was significantly higher than rotation tillage under SR conditions. Plowing turned the crop straw into 20–30 cm of soil layer, which contributed to the decomposition of crop straw [39]. In addition, plowing was effective in improving soil fertility degradation in shallow tillage and low-nutrient agricultural production [15]. No tillage is a type of conservation tillage. In this study, no tillage was observed to have the most pronounced effect in improving the soil nutrient profile. The results were in agreement with Chen et al. [40], who observed that no tillage was the most robust practice concerning crop yields and soil carbon sequestration. Furthermore, there are advantages such as preventing soil erosion, increasing precipitation storage, and retaining soil moisture [41,42]. The organic matter and microbial carbon and nitrogen contents increased significantly under the no-tillage condition, which provided sufficient nutrients for the growth of microbial communities [31]. Enrichment of capillary water in the soil provided more suitable living conditions for microorganisms under a combination of no-till and SR conditions [43]. Therefore, no tillage combined with SR can enhance soil fertility more effectively.

The fertilizer applied is the most critical factor affecting crop yield. In the present study, the crop yield and soil nutrients were increased by SR combined with fertilizer application in the rice–oilseed cropping system, compared to straw removal. In contrast, no significant effect on crop yield and soil properties in addition to SOC was found under SR without fertilizer application. These results are consistent with a previous study [10]. Moreover, soil microbes require a certain amount of N uptake when decomposing straw and, therefore, compete with crops for nitrogen under nutrient-deficient conditions [11]. The application of nitrogen fertilizer has been found to enhance microbial activity, accelerate straw decomposition, and supply ample nutrients to boost grain production, according to Guan et al. [34]. However, excessive utilization of fertilizers can have a detrimental effect on soil structure, as noted by Shi et al. [43]. Thus, adhering to the 4Rs approach, which entails precise N fertilizer dosing, timing, application method, and source, is crucial for sustaining crop yields, particularly under SR circumstances. In pursuit of high yields, farmers have commonly applied fertilizer at rates higher than 180 kg hm^{-2}; however, an adequate N supply can alleviate competitive pressure and stimulate root growth, contributing to a higher seed yield [44]. In this study, the SR in the range of 150–180 kg hm^{-2} applied N resulted in a relatively high yield response while maximizing the nutrient content of the soil. The findings agreed with Li et al. [45], who found that a moderate reduction in N fertilizer application did not significantly affect the chemical properties and microbial community structure of the soil. On the contrary, high N application resulted in increased production costs and a high potential risk of environmental pollution [1]. Therefore, proper fertilization is essential for SR.

Furthermore, the SR methods, i.e., straw mulching and incorporation, significantly increased crop yield; furthermore, the effect of straw incorporation had a better yield increase than straw mulching. Straw incorporation and mixing it well into the soil facilitate the decomposition of straw in situ [46]. However, straw mulching negatively affected seedling germination and pre-growth, leading to limited root development [10]. Moreover, the abundance of straw present on the soil's surface heightened the likelihood of disease. Interestingly, the straw mulching enhanced various nutrients in the soil to a greater extent than straw incorporation. The results are consistent with Lu [14], who found that straw mulching caused a relatively low rate of straw decomposition, leading to slow nutrient release. Large nutrients were not taken up by plants and remained in the soil. Straw mulching also contributed to the sequestration of soil organic carbon throughout the tillage layer by significantly increasing the surface microbial residual carbon [46]. Studies indicated that plowing and straw mulching improved soil aeration and permeability, and provided better conditions for nutrient uptake in crops [47,48]. The combination of no tillage and straw mulching improved crop yields, mainly due to reduced soil disturbance under no-tillage conditions, and promoted soil moisture retention and organic matter accumulation [49]. Therefore, more research is required in future with a focus on tillage practices and straw mulching to maximize crop yields and soil health improvement.

4.4. Crop Yield and Soil Fertility Were Affected by Initial Soil Properties under SR

The response of crop yield and soil nutrients to SR is also influenced by the initial soil properties [50,51]. The SOC is an essential indicator of comprehensive soil fertility [52]. Initial soil conditions such as high SOC were more suitable for increased oilseed rape yield under SR, while the opposite was true for increased rice yield. Higher SOC facilitated the improvement of soil structure, water retention properties, and micronutrient contents [53]. Additionally, Lu [14] discovered that SR in soils with low SOC did not help crop growth and even led to yield reduction. The crop yield and soil nutrients were significantly improved under SR in soils with a pH $\leq$ 6 in a rice–oilseed cropping system, which implied that acidic soils were more favorable for straw return. Under the SR condition, we noticed that loam and clay soils had a greater impact on crop yields and nutrient content compared to sandy soils. Sandy soils had larger particles and fewer fixed sites for nutrients, resulting in the applied nutrients being easily lost with water leaching [54]. Additionally, the nutrient contents in sandy soils were lower, and the water and fertilizer retention capacity were poor. Nutrient deficiency in the process of straw decomposition may affect the pre-growth of plants [55]. In contrast, loam and clay soils may have high water-holding capacity and soil fertility, facilitating the decomposition of straw. Additionally, the observations on soil nutrient content under sandy soil conditions are relatively small, and more research is needed in the future.

As the TN increased, the SR treatment showed an increasing trend towards oilseed rape yield improvement. The positive effect on the N supply stimulated microbial activity and favored straw decomposition [56]. Sufficient N from soil prevented microorganisms from competing with plants for N, affecting early plant growth [57]. There was a notable impact of SR on the productivity of crops and the quality of soil when applied to soils containing low levels of AK ($\leq$120 mg kg^{-1}) as compared to soils that had high AK concentrations (>120 mg kg^{-1}). In soils with low AK, straw decay maintained the soil potassium balance for crop growth by releasing potassium. However, in soils with high AK, potassium release by straw decay can further lead to high soil potassium content, inhibiting the uptake and utilization of other nutrients. The differences in the yield-increasing effect of SR in other soil conditions needs further investigation. Therefore, proper consideration of soil fertility for crop yield improvement is of great interest for the researchers and the farming community.

4.5. Limitations

In this study, we determined the effect of straw return on rice and oilseed rape yields and soil nutrient content under a rice–oilseed rotation system. There were factors that were not considered in this study due to limited data availability. These factors include the time between plowing the straw and sowing (planting) the crop and the ratios of C:N, C:P, and C:S in the straw, from microbiological activity in the soil. Therefore, future research is necessary to fill this gap.

5. Conclusions

This meta-analysis quantified the effect of SR on crop yield and soil properties under different conditions. Straw return significantly improved crop yields, while the yield increase in oilseed rape was more significant than in rice. Moreover, SR significantly increased the contents of several soil nutrients (soil organic carbon, total nutrients, available nutrients). Interestingly, the increase in crop yields was attributed to the increase in soil organic carbon, total nitrogen, and available potassium. However, it is worth noting that the increase in soil nutrients from straw return was greater in the oilseed rape season than in the rice season. Additionally, the increase in yield was mainly affected by climate factors, initial soil properties, and agronomic practices. For example, the increase in crop yields was significant in regions with warm and wet climates (≥16 °C annual temperature and ≥1200 mm annual precipitation). Moreover, both mean annual temperature and precipitation had a positive correlation with yield increase under straw-return conditions. Initial soil conditions such as low soil organic carbon and total nitrogen content were more suitable for increased rice yield under SR, while the opposite was true for increased oilseed rape yield. Without fertilizer application, the SR did not lead to substantial improvements in crop yield and soil nutrients, while its effect was more pronounced with nitrogen fertilizer application at 150–180 kg hm^{-2}. The positive effect of SR on crop yield was more obvious under the tillage practices with plowing. For the straw-return method, straw incorporation had a more pronounced effect on crop yields than straw mulching. Overall, SR can be a good practice for soil fertility improvement and agricultural sustainability, if well managed in integration with fertilizer application methods and tillage practices in the rice–oilseed rape cropping system in China.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture14030414/s1, Table S1. A list of variables in the meta-analysis for rice-oilseed cropping systems. Figure S1. Effect of different soil conditions i.e., soil total nitrogen (TN), soil total phosphorus (TP), soil total potassium (TK) of straw return on crop yield and soil nutrients in a rice-oilseed rape cropping system. Figure S2. Effect of different soil conditions i.e., soil available nitrogen (AN), soil available phosphorus (AP), soil available potassium (AK) of straw return on crop yield and soil nutrients in a rice-oilseed rape cropping system.

Author Contributions: L.L., J.S. and U.A. designed the study; L.L., Q.S., X.H. and Q.L. collected and analyzed the data; L.L., J.S. and Q.S. wrote the manuscript. All authors have read and agreed to the published version of the manuscript.

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References

1. Yousaf, M.; Li, X.; Zhang, Z.; Ren, T.; Cong, R.; Ata-Ul-Karim, S.T.; Fahad, S.; Shah, A.N.; Lu, J. Nitrogen fertilizer management for enhancing crop productivity and nitrogen use efficiency in a rice-oilseed rape rotation system in China. *Front. Plant Sci.* **2016**, *7*, 1496. [CrossRef] [PubMed]
2. Zheng, H.; Huang, H.; Zhang, C.; Li, J. National-scale paddy-upland rotation in Northern China promotes sustainable development of cultivated land. *Agric. Water Manag.* **2016**, *170*, 20–25. [CrossRef]
3. Timsina, J.; Connor, D.J. Productivity and management of rice-wheat cropping systems: Issues and challenges. *Field Crops Res.* **2001**, *69*, 93–132. [CrossRef]
4. Food and Agriculture Organization (FAO). *FAOSTAT Database-Crops Production*; FAO: Rome, Italy, 2020. Available online: http://www.fao.org/faostat/zh/#data/QC (accessed on 30 January 2024).
5. Kim, I.S.; Binfield, J.; Patton, M.; Zhang, L.; Moss, J. Impact of increasing liquid biofuel usage on EU and UK agriculture. *Food Policy* **2013**, *38*, 59–69. [CrossRef]
6. Wozniak, E.; Waszkowska, E.; Zimny, T.; Sowa, S.; Twardowski, T. The rapeseed potential in Poland and Germany in the context of production, legislation, and intellectual property rights. *Front. Plant Sci.* **2019**, *10*, 1423. [CrossRef]
7. FAOSTAT. *FAO Cereal Supply and Demand Brief*; FAOSTAT: Rome, Italy, 2019.
8. Bai, Y.; Wang, L.; Lu, Y.; Yang, L.; Zhou, L.; Ni, L.; Cheng, M. Effects of long-term full straw return on yield and potassium response in wheat-maize rotation. *J. Integr. Agric.* **2015**, *14*, 2467–2476. [CrossRef]
9. Xu, J.; Han, H.; Ning, T.; Li, Z.; Lal, R. Long-term effects of tillage and straw management on soil organic carbon, crop yield, and yield stability in a wheat-maize system. *Field Crops Res.* **2019**, *233*, 33–40. [CrossRef]
10. Islam, M.U.; Guo, Z.; Jiang, F.; Peng, X. Does straw return increase crop yield in the wheat-maize cropping system in China? A meta-analysis. *Field Crops Res.* **2022**, *279*, 108447. [CrossRef]
11. Li, L.; He, L.; Li, Y.; Wang, Y.; Ashraf, U.; Hamoud, Y.A.; Hu, X.; Wu, T.; Tang, X.; Pan, S. Deep fertilization combined with straw incorporation improved rice lodging resistance and soil properties of paddy fields. *Eur. J. Agron.* **2023**, *142*, 126659. [CrossRef]
12. Li, H.; Dai, M.W.; Dai, S.L.; Dong, X.J. Current status and environment impact of direct straw return in China's cropland—A review. *Ecotoxicol. Environ. Saf.* **2018**, *159*, 293–300. [CrossRef] [PubMed]
13. Wang, X.J.; Jia, Z.K.; Liang, L.Y.; Zhao, Y.F.; Yang, B.P.; Ding, R.X. Changes in soil characteristics and maize yield under straw returning system in dryland farming. *Field Crops Res.* **2018**, *218*, 11–17. [CrossRef]
14. Lu, X. A meta-analysis of the effects of crop residue return on crop yields and water use efficiency. *PLoS ONE* **2020**, *15*, e0231740. [CrossRef] [PubMed]
15. Zhu, L.Q.; Hu, N.J.; Yang, M.F.; Zhan, X.H.; Zhang, Z.W. Effects of Different Tillage and Straw Return on Soil Organic Carbon in a Rice-Wheat Rotation System. *PLoS ONE* **2014**, *9*, e88900. [CrossRef] [PubMed]
16. Yang, H.; Xu, M.; Koide, R.T.; Liu, Q.; Dai, Y.; Liu, L.; Bian, X. Effects of ditch-buried straw return on water percolation, nitrogen leaching and crop yields in a rice-wheat rotation system. *J. Sci. Food Agric.* **2015**, *96*, 1141–1149. [CrossRef] [PubMed]
17. Li, J.F.; Gan, G.Y.; Chen, X.; Zou, J.L. Effects of long-term straw management and potassium fertilization on crop yield, soil properties, and microbial community in a rice-oilseed rape rotation. *Agriculture* **2021**, *11*, 1233. [CrossRef]
18. Peng, X.L.; Dong, Q.; Zhang, C.; Li, P.F.; Li, F.L.; Liu, Z.L.; Yu, C.L. Effects of Straw Return Rate on Soil Reducing Substances and Rice Growth under Different Soil Conditions. *Chin. J. Rice Sci.* **2023**, 1–17.
19. Htun, Y.M.; Tong, Y.; Gao, P.C.; Ju, X.T. Coupled effects of straw and nitrogen management on N_2O and CH_4 emissions of rainfed agriculture in Northwest China. *Atmos. Environ.* **2017**, *157*, 156–166. [CrossRef]
20. Li, Y.B.; Li, P.; Wang, S.H.; Xu, L.Y.; Deng, J.J.; Jiao, J.G. Effects of organic fertilizer application on crop yield and soil properties in rice-wheat rotation system: A meta-analysis. *Chin. J. Appl. Ecol.* **2021**, *32*, 3231–3239.
21. Song, D.L.; Hou, S.P.; Wang, X.B.; Liang, G.Q.; Zhou, W. Nutrient resource quantity of crop straw and its potential of substituting. *J. Plant Nutr. Fertil.* **2018**, *24*, 1–21.
22. Gurevitch, J.; Hedges, L.V. Statistical issues in ecological meta-analyses. *Ecology* **1999**, *80*, 1142–1149. [CrossRef]
23. Pinheiro, J.; Bates, D.; Debroy, S.; Sarkar, D. R The R Core Team Nlme: Linear and Nonlinear Mixed Effects Models. R Package Nlme Version 3: 1–83. Available online: https://svn.r-project.org/R-packages/trunk/nlme/ (accessed on 30 January 2024).
24. Terrer, C.; Phillips, R.P.; Hungate, B.A.; Rosende, J.; Pett-Ridge, J.; Craig, M.E.; van Groenigen, K.J.; Keenan, T.F.; Sulman, B.N.; Stocker, B.D.; et al. A trade-off between plant and soil carbon storage under elevated CO_2. *Nature* **2021**, *591*, 599–603. [CrossRef]
25. Zhao, H.; Sun, B.H.; Lu, F.; Zhang, G.; Wang, X.K.; Ouyang, Z.Y. Straw incorporation strategy on cereal crop yield in China. *Crop Sci.* **2015**, *55*, 1773–1781. [CrossRef]
26. Eickhorst, T.; Tippkötter, R. Management-induced structural dynamics in paddy soils of south east China simulated in microcosms. *Soil Tillage Res.* **2009**, *102*, 168–178. [CrossRef]

27. Huang, M.; Zhou, X.; Xie, X.; Chen, J.; Cao, F.; Zou, Y. Increased soil fertility in a long-term rice-oilseed rape cropping system and its potential roles in reducing nitrogen inputs and environmental impacts. In *Cropping Systems: Applications, Management and Impact*; Nova Science Publishers, Inc.: Hauppauge, NY, USA, 2017; pp. 103–113.
28. Xuan, D.T.; Guong, V.T.; Rosling, A. Different crop rotation systems as drivers of change in soil bacterial community structure and yield of rice, *Oryza sativa*. *Biol. Fertil. Soils* **2012**, *48*, 217–225. [CrossRef]
29. Wang, Z.; Wang, Z.; Ma, L.; Lv, X.; Meng, Y.; Zhou, Z. Straw returning coupled with nitrogen fertilization increases canopy photosynthetic capacity, yield and nitrogen use efficiency in cotton. *Eur. J. Agron.* **2021**, *126*, 126267. [CrossRef]
30. Chen, S.; Liu, S.W.; Zheng, X.; Yin, M.; Chu, G.; Xu, C.M.; Yan, J.X.; Chen, L.P.; Wang, D.Y.; Zhang, X.F. Effect of various crop rotations on rice yield and nitrogen use efficiency in paddy-upland systems in southeastern China. *Crop J.* **2018**, *6*, 576–588. [CrossRef]
31. Yang, H.S.; Zhou, J.J.; Weih, M.; Li, Y.F.; Zhai, S.L.; Zhang, Q.; Chen, W.P.; Liu, J.; Liu, L.; Hu, S.J. Mycorrhizal nitrogen uptake of wheat is increased by earthworm activity only under no-till and straw removal conditions. *Appl. Soil Ecol.* **2020**, *155*, 103672. [CrossRef]
32. Luo, X.S.; Han, S.; Lai, S.S.; Huang, Q.Y.; Chen, W.L. Long-term straw returning affects Nitrospira-like nitrite oxidizing bacterial community in a rapeseed-rice rotation soil. *J. Basic Microb.* **2017**, *57*, 309–315. [CrossRef]
33. Dai, W.C.; Gao, M.; Lan, M.L.; Huang, R.; Wang, J.Z.; Wang, Z.F.; Han, X.F. Nutrient release patterns and decomposition characteristics of different crop straws in drylands and paddy fields. *Chin. J. Eco-Agric.* **2017**, *25*, 188–199.
34. Guan, X.K.; Wei, L.; Turner, N.C.; Ma, S.C.; Yang, M.D.; Wang, T.C. Improved straw management practices promote in situ straw decomposition and nutrient release, and increase crop production. *J. Clean. Prod.* **2020**, *250*, 119514. [CrossRef]
35. Sui, P.X.; Tian, P.; Lian, H.L.; Wang, Z.Y.; Ma, Z.Q.; Qi, H.; Mei, N.; Sun, Y.; Wang, Y.Y.; Su, Y.H.; et al. Straw incorporation management affects maize grain yield through regulating nitrogen uptake, water use efficiency, and root distribution. *Agronomy* **2020**, *10*, 324. [CrossRef]
36. Fierer, N.; Schimel, J.P. Effects of drying-rewetting frequency on soil carbon and nitrogen transformations. *Soil Biol. Biochem.* **2002**, *34*, 777–787. [CrossRef]
37. Zhou, H.; Zhang, C.L.; Zhang, W.L.; Yang, Q.J.; Li, D.; Liu, Z.Y.; Xia, J.F. Evaluation of straw spatial distribution after straw incorporation into soil for different tillage tools. *Soil Tillage Res.* **2020**, *196*, 104440. [CrossRef]
38. Sun, B.J.; Jia, S.X.; Zhang, S.X.; Mclaughlin, N.B.; Zhang, X.P.; Liang, A.Z.; Chen, X.W.; Wei, S.C.; Liu, S.Y. Tillage, seasonal and depths effects on soil microbial properties in black soil of Northeast China. *Soil Tillage Res.* **2016**, *155*, 421–428. [CrossRef]
39. Zhang, S.L.; Sadras, V.; Chen, X.P.; Zhang, F.S. Water use efficiency of dryland wheat in the Loess Plateau in response to soil and crop management. *Field Crops Res.* **2013**, *151*, 9–18. [CrossRef]
40. Chen, S.Y.; Yang, P.P.; Zhang, Y.M.; Dong, W.X.; Hu, C.S.; Oenema, O. Responses of cereal yields and soil carbon sequestration to four long-term tillage practices in the north china plain. *Agronomy* **2022**, *12*, 176. [CrossRef]
41. Abdullah, A.S. Minimum tillage and residue management increase soil water content, soil organic matter and canola seed yield and seed oil content in the semiarid areas of Northern Iraq. *Soil Tillage Res.* **2014**, *144*, 150–155. [CrossRef]
42. Dong, W.Y.; Liu, E.K.; Wang, J.B.; Yan, C.G.; Li, J.; Zhang, Y.Q. Impact of tillage management on the short- and long-term soil carbon dioxide emissions in the dryland of Loess Plateau in China. *Geoderma* **2017**, *307*, 38–45. [CrossRef]
43. Shi, J.L.; Wang, S.J.; Li, S.; Tian, X.H. Increasing soil organic carbon sequestration and yield stability by no-tillage and straw-returning in wheat-maize rotation. *Agron. J.* **2022**, *114*, 1534–1545. [CrossRef]
44. Xu, X.; Pang, D.; Chen, J.; Luo, Y.; Zheng, M.; Yin, Y.; Li, Y.; Li, Y.; Wang, Z. Straw return accompanies with low nitrogen moderately promoted deep root. *Field Crops Res.* **2018**, *221*, 71–80. [CrossRef]
45. Li, H.; Zhang, Y.Y.; Yang, S.; Wang, Z.R.; Feng, X.; Liu, H.Y.; Jiang, Y. Variations in soil bacterial taxonomic profiles and putative functions in response to straw incorporation combined with N fertilization during the maize growing season. *Agric. Ecosyst. Environ.* **2019**, *283*, 106578. [CrossRef]
46. Liu, Z.H.; Huang, F.Y.; Wang, B.F.; Li, Z.Y.; Zhang, P.; Jia, Z.K. Impacts of mulching measures on crop production and soil organic carbon storage in a rainfed farmland area under future climate. *Field Crops Res.* **2021**, *273*, 108303. [CrossRef]
47. Wang, H.M.; Zheng, J.; Fan, J.L.; Zhang, F.C.; Huang, C.H. Grain yield and greenhouse gas emissions from maize and wheat fields under plastic film and straw mulching: A meta-analysis. *Field Crops Res.* **2021**, *270*, 108210. [CrossRef]
48. Cui, H.; Luo, Y.; Chen, J.; Jin, M.; Li, Y.; Wang, Z. Straw return strategies to improve soil properties and crop productivity in a winter wheat-summer maize cropping system. *Eur. J. Agron.* **2022**, *133*, 126436. [CrossRef]
49. Xu, X.; Wang, X.Y.; Bao, X.L.; Wang, Y.; Liu, Y.J.; Huo, H.N.; He, H.B.; Xie, H.T. Effect of long-time no-tillage and stover mulching on maize yield and its stability. *Chin. J. Appl. Ecol.* **2022**, *33*, 671–676.
50. Liu, W.; Liu, W.; Kan, Z.; Chen, J.; Zhao, X.; Zhang, H. Effects of tillage and straw management on grain yield and SOC storage in a wheat-maize cropping system. *Eur. J. Agron.* **2022**, *137*, 126530. [CrossRef]
51. Liu, X.; Zhou, F.; Hu, G.Q.; Shao, S.; He, H.B.; Zhang, W.; Zhang, X.D.; Li, L.J. Dynamic contribution of microbial residues to soil organic matter accumulation influenced by maize straw mulching. *Geoderma* **2019**, *333*, 35–42. [CrossRef]
52. Meyer, M.; Diehl, D.; Schaumann, G.E.; Munoz, K. Multiannual soil mulching in agriculture: Analysis of biogeochemical soil processes under plastic and straw mulches in a 3-year field study in strawberry cultivation. *J. Soil. Sediment.* **2021**, *21*, 3733–3752. [CrossRef]

53. Powlson, D.S.; Glendining, M.J.; Coleman, K.; Whitmore, A.P. Implications for soil properties of removing cereal straw: Results from long-term studies. *Agron. J.* **2011**, *103*, 279–287. [CrossRef]
54. Lin, Y.R.; Watts, D.B.; Santen, E.V.; Cao, G.Q. Influence of poultry litter on crop productivity under different field conditions: A meta-analysis. *Agron. J.* **2018**, *110*, 807–818. [CrossRef]
55. Han, T.F.; Ma, C.B.; Huang, J.; Liu, K.L.; Xue, Y.D.; Li, D.C.; Liu, L.S.; Zhang, L.; Liu, S.J.; Zhang, H.M. Variation in rice yield response to fertilization in China: Meta-analysis. *J. Integr. Agric.* **2019**, *52*, 1918–1929.
56. Murphy, C.J.; Baggs, E.M.; Morley, N. Rhizosphere priming can promote mobilization of N-rich compounds from soil organic matter. *Biol. Fertil. Soils* **2015**, *81*, 236–243. [CrossRef]
57. Li, L.; Zhang, Z.; Tian, H.; Ashraf, U.; Hamoud, Y.A.; Alaa, A.A.; Tang, X.; Duan, M.; Wang, Z.; Pan, S. Nitrogen Deep Placement Combined with Straw Mulch Cultivation Enhances Physiological Traits, Grain Yield and Nitrogen Use Efficiency in Mechanical Pot-Seedling Transplanting Rice. *Rice Sci.* **2022**, *29*, 89–100.