Effects of Straw Incorporation and Nitrogen Application Regulating C/N Ratio on Soil Inorganic Nitrogen, Enzyme Activity, and Crop Yield (Postprint)

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Abstract

The quality of straw, particularly its C/N ratio, is an important factor affecting straw decomposition rate and nutrient release. Under straw return conditions, how to scientifically and rationally apply nitrogen fertilizer is a key issue in straw utilization and optimized fertilization research. Taking the C/N ratio of carbon and nitrogen input from straw return as the entry point, this study investigated the effects of different nitrogen inputs under straw return on soil inorganic nitrogen, soil microbial biomass nitrogen, enzyme activity, and crop yield in a wheat-maize rotation field through field experiments conducted in 2012–2013 (with treatments including: no straw return and no fertilization, straw return without nitrogen application, straw return with inorganic nitrogen fertilizer to adjust C/N ratios to 10:1, 16:1, and 25:1, and straw return with organic nitrogen fertilizer to adjust C/N ratio to 25:1). The results showed that: 1) At a C/N ratio of 25:1, the application of organic and inorganic nitrogen fertilizers had no significant effect on soil inorganic nitrogen content; under inorganic nitrogen fertilizer application, the lower the C/N ratio, the higher the soil inorganic nitrogen content. 2) Straw return with nitrogen application increased soil microbial biomass nitrogen content, but there were no significant differences among the various straw return with nitrogen treatments; different nitrogen application treatments under straw return had no significant effect on urease activity; straw return with nitrogen application increased FDA hydrolase activity, which showed an increasing trend with decreasing C/N ratio, and the effect of inorganic nitrogen fertilizer application was stronger than that of organic nitrogen fertilizer. 3) Straw return with inorganic nitrogen fertilizer application significantly increased the aboveground biomass of wheat and maize; adjusting C/N ratio to 10:1 and 16:1 with inorganic nitrogen fertilizer increased the aboveground biomass of wheat and maize at both seedling and maturity stages compared with a C/N ratio of 25:1; adjusting C/N ratio to 25:1 with organic nitrogen fertilizer had no significant effect on aboveground biomass compared with straw return without nitrogen application. Straw return with inorganic nitrogen fertilizer application increased crop yield, with the highest yield achieved at a C/N ratio of 16:1 adjusted by inorganic nitrogen fertilizer, while adjusting C/N ratio to 25:1 with organic nitrogen fertilizer showed a trend of decreasing crop yield. Based on the comprehensive results, adjusting the C/N ratio to 16:1 with inorganic nitrogen fertilizer application is relatively reasonable.

Full Text

Effects of Straw Retention and Nitrogen Fertilization Regulating C/N Ratio on Soil Inorganic Nitrogen, Enzyme Activities, and Crop Yield

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Abstract

Straw quality, particularly its C/N ratio, is a critical factor affecting decomposition rate and nutrient release. Under straw retention conditions, how to scientifically and rationally apply nitrogen fertilizer represents a key issue in straw utilization and optimized fertilization research. Using the C/N ratio of carbon and nitrogen inputs from straw retention as the entry point, this study investigated the effects of different nitrogen inputs under straw retention on soil inorganic nitrogen, soil microbial biomass nitrogen, enzyme activities, and crop yields in a wheat-maize rotation field through a field experiment conducted from 2012 to 2013. The experiment included six treatments: (1) straw removal without fertilizer, (2) straw retention without nitrogen, (3) straw retention with mineral nitrogen fertilizer adjusting C/N ratio to 10:1, (4) straw retention with mineral nitrogen fertilizer adjusting C/N ratio to 16:1, (5) straw retention with mineral nitrogen fertilizer adjusting C/N ratio to 25:1, and (6) straw retention with organic nitrogen fertilizer adjusting C/N ratio to 25:1. The results showed that: (1) At a C/N ratio of 25:1, there was no significant difference in soil inorganic nitrogen content between organic and mineral nitrogen fertilizer applications; however, under mineral nitrogen fertilizer application, lower C/N ratios resulted in higher soil inorganic nitrogen content. (2) Straw retention with nitrogen fertilization increased soil microbial biomass nitrogen content, though differences among various straw retention with nitrogen treatments were not significant; different nitrogen application treatments under straw retention had no significant effect on urease activity; straw retention with nitrogen fertilization increased FDA hydrolyase activity, which showed an increasing trend with decreasing C/N ratio, with mineral nitrogen fertilizer being more effective than organic nitrogen fertilizer. (3) Straw retention with mineral nitrogen fertilizer significantly increased above-ground biomass of wheat and maize; compared with the C/N ratio of 25:1, adjusting C/N ratio to 10:1 and 16:1 with mineral nitrogen fertilizer increased above-ground biomass at both seedling and maturity stages of wheat and maize; organic nitrogen fertilizer adjusting C/N ratio to 25:1 had no significant effect on above-ground biomass compared with straw retention without nitrogen. Straw retention with mineral nitrogen fertilizer increased crop yields, with the highest yield achieved at C/N ratio of 16:1, while organic nitrogen fertilizer adjusting C/N ratio to 25:1 showed a trend of decreasing crop yields. Based on these comprehensive results, applying mineral nitrogen fertilizer to adjust C/N ratio to 16:1 appears to be the most reasonable practice.

Keywords: straw retention; organic nitrogen fertilizer; inorganic nitrogen fertilizer; C/N ratio; soil enzyme; soil microbial biomass nitrogen; crop yield

1. Materials and Methods

1.1 Experimental Site Description

The field experiment was conducted at the Yucheng Comprehensive Experimental Station of the Chinese Academy of Sciences (Yucheng City, Shandong Province). The soil is primarily fluvo-aquic soil with an average annual temperature of 13.1 °C. Precipitation is low and concentrated, with an average annual rainfall of 593.2 mm, showing significant seasonal variation concentrated in summer (June–August). Before the experiment, the basic physicochemical properties of the 0–20 cm soil layer were: organic matter 16.77 g · kg^{1}, total nitrogen 0.95 g · kg^{1}, total phosphorus 0.97 g · kg^{1}, total potassium 20.92 g · kg^{1}, and pH 8.60. The cropping system was winter wheat–summer maize rotation with double cropping annually.

1.2 Experimental Design

The experiment was conducted during the 2012 maize season and the 2012–2013 wheat season. Six treatments were established: (1) CK: straw removal without fertilizer; (2) S: straw retention without nitrogen; (3) SF: straw retention with conventional nitrogen application (C/N ratio 10:1); (4) SCN: straw retention with mineral nitrogen fertilizer adjusting C/N ratio to 25:1; (5) SCTN: straw retention with mineral nitrogen fertilizer adjusting C/N ratio to 16:1; and (6) SM: straw retention with organic nitrogen fertilizer (cattle manure) adjusting C/N ratio to 25:1. Each treatment had three replications, totaling 18 plots, with each plot measuring 10.3 m × 7.7 m (79.3 m^{2}).

Maize season fertilization: The SF treatment received 270 kg · hm^{2} nitrogen, with a basal to topdressing ratio of 1:2, applied at the maize trumpet stage. The

SCN treatment received 90 kg · hm ^{2} nitrogen as basal fertilizer. The SCTN treatment received 180 kg · hm ^{2} nitrogen, with 90 kg as basal fertilizer and 90 kg as topdressing at the trumpet stage. Cattle manure was composted before application at 12,360 kg · hm ^{2} as basal fertilizer. All nitrogen fertilizers were urea.

Wheat season fertilization: The SF treatment received 270 kg · hm ^{2} nitrogen, with a basal to topdressing ratio of 4:6, applied at the wheat jointing stage. The SCN treatment received 56 kg · hm ^{2} nitrogen as basal fertilizer. The SCTN treatment received 112 kg · hm ^{2} nitrogen, with 56 kg as basal fertilizer and 56 kg as topdressing at the jointing stage. Cattle manure was applied at 8,000 kg · hm ^{2} as basal fertilizer. All nitrogen fertilizers were urea.

Except for the no-fertilizer treatment, phosphorus and potassium application rates were the same as the SF treatment: 180 kg · hm ^{2} P O and 90 kg · hm ^{2} K O as basal fertilizers, using calcium superphosphate and potassium magnesium sulfate, respectively. After harvest, straw was completely crushed and returned to the field using a straw returning machine, with approximately 7,000 kg · hm ^{2} in the maize season and 7,500 kg · hm ^{2} in the wheat season.

1.3 Sampling and Analysis Methods

At the seedling, jointing, filling, and maturity stages of both maize and wheat, soil samples from the 0–20 cm layer were collected using the five-point method. Fresh soil samples were extracted with 2 mol · L ^{1} KCl solution at a soil to water ratio of 10:1, shaken for 30 min, and filtered. Ammonium and nitrate nitrogen in the filtrate were determined according to Lu Rukun' s method [24]. Soil microbial biomass nitrogen (MBN) was measured using the chloroform fumigation-extraction method [25]. Soil urease activity was determined using Kandeler and Gerber's method [26], expressed as g(NH -N) · g ^{1}(soil) · (2h) ^{1}. FDA hydrolyase activity was measured according to Sánchez-Monedero et al. [27], expressed as g(fluorescen) · g ^{1}(soil) · h ^{1}.

Above-ground biomass was sampled at the seedling, jointing, filling, and maturity stages of maize and wheat. For wheat, three 20-cm row segments were randomly collected from each plot; for maize, three plants were randomly collected from each plot. Samples were oven-dried at 75 °C to constant weight and weighed.

At wheat maturity, 4 m^2 of wheat plants were harvested from each plot and air-dried to determine grain yield. At maize maturity, 20 maize plants were randomly collected from each plot and air-dried to determine grain yield.

1.4 Data Processing and Analysis

Duncan' s test was used to compare the effects of different treatments on soil inorganic nitrogen, microbial biomass nitrogen, enzyme activities, above-ground biomass, and yield. Repeated measures ANOVA was used to analyze treatment effects on these indicators. Pearson correlation analysis was used to examine relationships between soil inorganic nitrogen content and microbial biomass nitrogen, enzyme activities, and above-ground biomass. All analyses were performed using SPSS software (SPSS 14.0, Chicago, USA) with significance level at $P<0.05$. Data were organized using Microsoft Excel and plotted using Sigmaplot software (Sigmaplot 12.5, California, USA).

2. Results

2.1 Effects of Straw Retention and Nitrogen Application Regulating C/N Ratio on Soil Inorganic Nitrogen Content

The effects of straw retention with nitrogen application regulating C/N ratio on soil inorganic nitrogen content (sum of ammonium and nitrate nitrogen) are shown in Table 1 . Different nitrogen application treatments under straw retention significantly affected soil inorganic nitrogen content ($P<0.05$). In the maize season, the SF treatment had the highest soil inorganic nitrogen content at all sampling stages, significantly higher than the S treatment. At the seedling and jointing stages, SCTN and SCN treatments showed no significant difference in inorganic nitrogen content, but at the filling and maturity stages, SCTN was significantly higher than SCN. Except at the jointing stage, SCN and SM treatments showed no significant difference in inorganic nitrogen content. The dynamic changes in inorganic nitrogen content varied among treatments: from seedling to jointing stage, S, SCN, and SM treatments showed increased inorganic nitrogen content, which reached minimum values at the filling stage; while SF and SCTN treatments showed continuous increase from seedling to filling stage.

In the wheat season, SF treatment had significantly higher inorganic nitrogen content than other treatments at the seedling and jointing stages, but no significant differences were observed among treatments at the filling and maturity stages. Inorganic nitrogen content across all treatments showed a pattern of decreasing first then increasing, reaching minimum values at the jointing stage except for SF treatment. Overall, both treatment and sampling time significantly affected soil inorganic nitrogen content ($P<0.05$), with treatment ranking as SF>SCTN>SCN>SM S CK. Among the three mineral nitrogen treatments, soil inorganic nitrogen content differed significantly, with lower C/N ratios resulting in higher inorganic nitrogen content, while no significant difference was observed between mineral and organic nitrogen applications.

2.2 Effects of Straw Retention and Nitrogen Application Regulating C/N Ratio on Soil Microbial Biomass Nitrogen

The effects of straw retention with nitrogen application regulating C/N ratio on soil MBN content are shown in Figure 1 [Figure 1: see original paper]. In the maize season, the dynamic trend of microbial biomass nitrogen under straw retention treatments was generally consistent, showing a pattern of decreasing, then increasing, then decreasing again, with maximum values at the filling stage. Compared with straw retention without nitrogen, straw retention with mineral or organic nitrogen increased microbial biomass nitrogen at all growth stages, with the C/N ratio of 25:1 showing the highest values, though differences were not significant. In the wheat season, microbial biomass nitrogen under straw retention treatments showed a pattern of decreasing, then increasing, then decreasing. Nitrogen application also increased microbial biomass nitrogen. Unlike the maize season, among straw retention with mineral nitrogen treatments, the C/N ratio of 10:1 showed higher values than the other two nitrogen treatments except at the seedling stage, possibly because as time progressed, more recalcitrant components in straw accumulated, and nitrogen application provided more nitrogen source for microorganisms, promoting microbial nitrogen assimilation. Overall, SCN treatment had the highest MBN content, significantly higher than S treatment, followed by SM treatment, with treatment ranking as SCN SM SCTN SF CK S (Figure 1B), though differences among treatments were not significant.

2.3 Effects of Straw Retention and Nitrogen Application Regulating C/N Ratio on Soil Enzyme Activities

The effects of straw retention with nitrogen application regulating C/N ratio on soil urease activity showed different patterns between maize and wheat seasons (Figure 2 [Figure 2: see original paper]). In the maize season, urease activity showed a trend of decreasing then gradually increasing. Compared with the control, straw retention decreased urease activity, particularly at the seedling stage. At seedling, jointing, and filling stages, nitrogen application under straw retention had no significant effect on soil urease activity. At maturity, mineral nitrogen application significantly increased urease activity compared with straw retention without nitrogen, while organic nitrogen had no significant effect. In the wheat season, urease activity showed a gradually increasing trend. Except at the seedling stage, straw retention decreased urease activity compared with straw removal. The effect of nitrogen application under straw retention was mainly observed at seedling and jointing stages: at seedling stage, SCTN and SM significantly increased urease activity; at jointing stage, SF and SCTN significantly increased urease activity. ANOVA indicated that CK had higher urease activity than other treatments, but differences among treatments were not significant, with treatment ranking as CK SF SCTN SCN S SM. Sampling time and the interaction between sampling time and treatment significantly affected soil urease activity.

The effects of different treatments on FDA hydrolyase activity are shown in Figure 3 [Figure 3: see original paper]. In the maize season, no significant differences in FDA hydrolyase activity were observed among treatments at the seedling stage. At jointing stage, straw retention with nitrogen increased FDA hydrolyase activity: SF, SCTN, and SM increased by 1.12%, 26.19%, and 3.27% respectively compared with S treatment, while SCN significantly decreased activity by 7.74%. At filling stage, except for SCN, straw retention with nitrogen decreased FDA hydrolyase activity: SF, SCTN, and SM decreased by 13.56%, 17.26%, and 9.45% respectively compared with S treatment, while SCN significantly decreased activity by 39.56%. At maturity, SF and SM significantly increased FDA hydrolyase activity by 81.09% and 43.33% respectively compared with S treatment, SCTN increased by 11.38%, while SCN significantly decreased activity by 35.49%. In the wheat season, no significant differences were observed at seedling stage. At jointing stage, straw retention with nitrogen increased FDA hydrolyase activity: SF, SCTN, SCN, and SM increased by 16.80%, 43.42%, 14.50%, and 32.19% respectively compared with S treatment. At filling stage, straw retention with nitrogen significantly decreased FDA hydrolyase activity compared with straw retention without nitrogen. At maturity, straw retention with nitrogen significantly increased FDA hydrolyase activity: SCN, SCTN, and SM significantly increased by 62.40%, 68.36%, and 76.02% respectively, while SF significantly increased by 47.32% compared with S treatment. ANOVA indicated that, except for SCN treatment, straw retention with nitrogen increased FDA hydrolyase activity compared with straw retention without nitrogen, with mineral nitrogen being more effective than organic nitrogen, showing treatment ranking as SF SCTN SM S SCN CK.

2.4 Effects of Straw Retention and Nitrogen Application Regulating C/N Ratio on Above-ground Biomass and Yield of Maize and Wheat

The effects of different treatments on crop above-ground biomass are shown in Table 2 . In the maize season, at seedling stage, SF, SCTN, and SCN significantly increased above-ground biomass compared with S treatment, while SM had no significant effect. S treatment significantly decreased above-ground biomass compared with CK. Among the three mineral nitrogen treatments, SF and SCTN had significantly higher biomass than SCN. At jointing stage, straw retention with nitrogen significantly increased above-ground biomass compared with S treatment, with no significant differences among nitrogen treatments. At filling stage, SF, SCTN, and SCN significantly increased above-ground biomass compared with S treatment, while SM showed no significant difference. At maturity, SF, SCTN, and SCN significantly increased above-ground biomass compared with S treatment, while SM significantly decreased biomass, with SF and SCTN being significantly higher than SCN.

In the wheat season, at seedling stage, SF and SCTN significantly increased above-ground biomass compared with S treatment, while SCN and SM had no significant effect. No significant differences were observed among treatments at jointing and filling stages. At maturity, S treatment showed the lowest above-ground biomass, while SCTN showed the highest. Between the two C/N 25:1 treatments, SCN had lower biomass, but differences among nitrogen treatments were not significant. Overall, straw retention with nitrogen regulating C/N ratio mainly affected above-ground biomass at seedling and maturity stages, with no significant differences between SCTN (C/N 16:1) and SF (C/N 10:1) treatments.

The effects of different treatments on crop yields are shown in Table 3 . In the maize season, SCTN produced the highest yield, while CK had the lowest. Among the five straw retention treatments, SM produced the lowest yield, significantly lower than SF and SCTN. No significant differences were observed among the three mineral nitrogen treatments. No significant difference was found between mineral and organic nitrogen applications at C/N 25:1 for wheat yield. In the wheat season, SCN produced the highest yield, while CK had the lowest. Among the five straw retention treatments, SM was significantly lower than other treatments. The three mineral nitrogen treatments showed no significant differences in wheat yield but were all significantly higher than straw retention without nitrogen. Based on input-output analysis of maize and wheat yields, SCTN treatment was most economical.

3. Discussion

3.1 Effects of Straw Retention and Nitrogen Application Regulating C/N Ratio on Soil Inorganic Nitrogen Content

Straw retention with nitrogen application regulating C/N ratio significantly affected soil inorganic nitrogen content ($P<0.05$). After straw incorporation, decomposition rate is influenced by straw chemical composition. A C/N ratio of 25:1 is generally considered the critical threshold determining whether straw incorporation leads to soil nitrogen immobilization [12]. Since both maize and wheat straw have C/N ratios higher than 25:1, their incorporation inevitably causes soil microbial nitrogen immobilization, requiring supplemental nitrogen to alleviate immobilization and meet nitrogen demands for straw decomposition and crop growth. Across both wheat and maize seasons, soil inorganic nitrogen content differed significantly among mineral nitrogen treatments, with lower C/N ratios resulting in higher inorganic nitrogen content, indicating that low C/N ratios favor soil nitrogen supply under straw retention [14]. Additionally, since different C/N ratios were achieved by varying external nitrogen application rates, different nitrogen rates may also have contributed to differences in inorganic nitrogen content, subsequently affecting microbial biomass nitrogen, enzyme activities, and crop yield. Organic nitrogen is generally considered more favorable for soil nitrogen mineralization than mineral nitrogen [28]. However, this study found no significant difference in soil inorganic nitrogen content between mineral and organic nitrogen applications at the same C/N ratio, possibly because the composting process of cattle manure consumed readily decomposable nitrogen, leaving mostly recalcitrant components. Regarding dynamic changes, inorganic nitrogen content patterns differed among treatments in the maize season: S, SCN, and SM treatments reached minimum values at filling stage, while SF and SCTN treatments showed continuous increases, likely due to the second topdressing application providing readily available nitrogen. In this study, the three mineral nitrogen treatments showed significantly different soil inorganic nitrogen content, with lower C/N ratios yielding higher content, which benefits crop nitrogen utilization but may also increase nitrogen loss.

3.2 Effects of Straw Retention and Nitrogen Application Regulating C/N Ratio on Soil Microbial Biomass Nitrogen and Enzyme Activities

Nitrogen availability after straw retention determines soil microbial biomass [14]. This experiment showed that straw retention with supplemental nitrogen increased soil inorganic nitrogen content, with higher nitrogen rates resulting in higher inorganic nitrogen content. However, increased inorganic nitrogen from higher nitrogen rates did not lead to increased microbial biomass nitrogen. Shaukat et al. [15] also found in laboratory incubation studies that microbial biomass nitrogen increase after straw retention with nitrogen did not increase linearly with mineral nitrogen rate, with maximum microbial biomass nitrogen at C/N 18:1 and significantly lower values at C/N 9:1. In this study, the non-linear increase in microbial biomass nitrogen with nitrogen rate may be related to the experimental site having reached a relatively balanced, saturated state of soil microbial biomass after years of continuous straw retention [29]. Therefore, soil microbial biomass nitrogen did not differ significantly among straw retention with nitrogen treatments. Microbial biomass nitrogen increased at seedling stage due to stimulation from wheat and maize straw incorporation, decreased at jointing stage as readily decomposable components were consumed, increased again at filling stage due to root exudates from accelerated crop growth, and decreased at maturity as crop nitrogen demand increased and microbial nitrogen assimilation decreased [30]. Overall, straw retention with nitrogen increased soil microbial biomass nitrogen, with SCN treatment showing the highest values, followed by SM treatment, though differences among straw retention with nitrogen treatments were not significant. This indicates that increased nitrogen rate after straw retention did not enhance microbial biomass nitrogen, and adjusting input C/N ratio to 25:1 was most beneficial for microbial biomass nitrogen increase. At the same C/N ratio (25:1), mineral nitrogen treatment showed higher microbial biomass nitrogen than organic nitrogen, indicating mineral nitrogen contributed more to microbial biomass nitrogen increase [30].

Soil microbial nitrogen mineralization-immobilization processes after straw retention significantly affect soil nitrogen supply and reduce nitrogen loss [31-32]. In this study, dynamic changes in microbial biomass nitrogen and soil inorganic nitrogen content during the maize season showed that microbial biomass nitrogen decreased while soil inorganic nitrogen increased from seedling to jointing stage and from filling to maturity stage, while microbial biomass nitrogen increased but soil inorganic nitrogen decreased from jointing to filling stage (except for SF and SCTN treatments due to topdressing). Correlation analysis showed a highly significant negative relationship between soil inorganic nitrogen content and microbial biomass nitrogen content (Table 4), indicating a constraining relationship between them, with nitrogen immobilized in soil microbes being available for remineralization and crop uptake [33].

Soil enzymes play important roles in soil nutrient cycling, and their activities can serve as indicators of soil microbial activity and fertility [34]. Soil enzymes are mainly secreted by soil microorganisms and are closely related to microbial activity, thus showing positive correlation with soil microbial biomass [35-36]. Straw retention provides carbon, nitrogen, and energy sources for soil microorganisms, stimulating microbial growth and increasing soil enzyme activities [37]. Soil urease is a specific hydrolase that hydrolyzes urea to ammonium nitrogen for plant uptake. This study showed that different nitrogen applications under straw retention did not increase soil urease activity, with a trend of decreased activity compared with straw removal. Wu et al. [38] also found decreased soil urease activity after straw retention in laboratory incubation studies, attributing this to low soil inorganic nitrogen content at the beginning of incubation. Other studies have shown that nitrogen application decreases soil urease activity because high ammonium nitrogen content inhibits urease activity [39-40]. This study also showed a negative correlation between soil inorganic nitrogen content and urease activity (Table 4), suggesting that increased inorganic nitrogen from straw retention with nitrogen may have decreased urease activity. FDA hydrolysis is catalyzed by soil lipase, protease, and esterase, and FDA hydrolyase activity can represent soil microbial activity and significantly correlates with soil microbial biomass [24]. This study showed that straw retention increased FDA hydrolyase activity, which increased with decreasing C/N ratio, possibly because low C/N ratio increased soil inorganic nitrogen content and microbial activity, thereby increasing FDA hydrolyase activity. The study also showed a highly significant positive correlation between soil inorganic nitrogen content and FDA hydrolyase activity (Table 4), though straw retention with mineral nitrogen adjusting C/N to 25:1 decreased FDA hydrolyase activity, particularly in the maize season, with reasons requiring further investigation.

3.3 Effects of Straw Retention and Nitrogen Application Regulating C/N Ratio on Crop Above-ground Biomass and Yield

This study showed that straw retention with nitrogen increased crop above-ground biomass. SF treatment produced the highest biomass, followed by SCTN treatment. Straw retention with mineral nitrogen significantly increased above-ground biomass, though no significant differences existed among the three treatments. Straw retention with organic nitrogen showed no significant effect on above-ground biomass compared with straw retention without nitrogen. Correlation analysis showed a highly significant positive relationship between soil inorganic nitrogen content and above-ground biomass (Table 4), indicating that increased inorganic nitrogen content can increase crop above-ground biomass. Cai et al. [41] also found that increased nitrogen rate raised inorganic nitrogen content, above-ground biomass, and crop nitrogen uptake, with increased above-ground biomass closely related to increased nitrogen uptake [33]. In this study, the three mineral nitrogen treatments showed no significant differences in above-ground biomass effects, but effects differed at seedling and maturity stages, with SF and SCTN producing higher biomass than SCN, while showing no differences between themselves, possibly because excessive nitrogen does not increase crop nitrogen uptake and reduces nitrogen use efficiency [42].

For crop yield, straw retention with mineral nitrogen increased crop yields, particularly in the wheat season, while straw retention with organic nitrogen at C/N 25:1 showed a trend of decreasing crop yields. Due to high C/N ratios of maize and wheat straw, retention often causes soil nitrogen immobilization, reducing soil inorganic nitrogen content and affecting crop growth, leading to yield reduction [43-44]. In this study, all three mineral nitrogen treatments increased crop yields, but no significant correlation existed between soil inorganic nitrogen content and crop yield (r=0.043, P=0.759). Although SCN and SM treatments had the same input C/N ratio and showed no significant difference in inorganic nitrogen content, SCN produced higher yields than SM, particularly significantly increasing wheat yield, possibly due to differences in crop nitrogen uptake intensity among treatments. Miao et al. [45] found that straw retention tended to increase wheat yield, possibly related to above-ground nitrogen uptake. However, this study did not measure crop nitrogen content, so we cannot determine whether organic nitrogen reduced crop nitrogen uptake and affected yield. Additionally, above-ground biomass was not consistent with crop yield, possibly because straw retention with nitrogen regulating C/N ratio affected crop nitrogen uptake and the distribution ratio of absorbed nitrogen between grain and straw [46], resulting in inconsistent patterns between yield and above-ground biomass.

Conclusions

1) Under straw retention with mineral nitrogen fertilizer, soil inorganic nitrogen content differed significantly among treatments, with lower C/N ratios resulting in higher inorganic nitrogen content. No significant difference existed between mineral and organic nitrogen applications.

2) Straw retention with nitrogen increased soil microbial biomass nitrogen content, but differences among straw retention with nitrogen treatments were not significant. Straw retention with nitrogen regulating C/N ratio had no significant effect on soil urease activity, showing a trend of decreased activity compared with straw removal without fertilization. Except for SCN treatment, straw retention with nitrogen increased FDA hydrolyase activity, which tended to increase with decreasing C/N ratio.

3) Straw retention with nitrogen regulating C/N ratio mainly affected crop above-ground biomass at seedling and maturity stages, with no significant differences between SCTN (C/N 16:1) and SF (C/N 10:1) treatments. Straw retention with mineral nitrogen significantly increased above-ground biomass, with higher nitrogen rates producing greater biomass. Organic nitrogen adjusting C/N to 25:1 showed no significant effect on above-ground biomass compared with straw retention without nitrogen. Straw retention with mineral nitrogen increased crop yields, with no significant differences among mineral nitrogen rates. Overall, applying mineral nitrogen fertilizer to adjust C/N ratio to 16:1 appears most reasonable. However, as these results are based on only one year of

experimentation, further multi-year studies are needed to confirm these findings.

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