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Minor straw return enhances net income in a maize-wheat rotation system

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Straw returning to the field is a common agricultural practice in China. Nevertheless, in the maize-wheat rotation system of the semi-arid region in Northwest China, it is essential to investigate the optimal approach for coupling straw return and fertilization in order to enhance soil quality and crop yield. A field trial conducted in the semi-arid region of northwest China from 2019 to 2021 examined eight different combinations of straw return and fertilization rates. The results indicated that while straw return had minimal impact on soil total nitrogen in the 0–60 cm layer, it did increase soil available phosphorus and potassium in the 0–40 cm layer. Additionally, all straw return treatments notably improved soil organic matter and humus content compared to the untreated control (CK). Specifically, applying N and P fertilizers in combination with returning 1/3 of the straw (NP+1/3S) produced in that season significantly boosted soil organic matter and humus content compared to the CK. Moreover, the NP+1/3S treatment led to a substantial enhancement in the grain yield of wheat and maize, as well as their yield components, including an increase in the number of ears/spikes per square meter, the number of grains per ear/spike, and the 100 or 1000-grain weight. The results may be attributed to a combination of factors, including improved nutrient availability, enhanced soil structure, and increased microbial activity due to the incorporation of straw. Economic analysis showed that NP+1/3S had the highest production to investment ratio (ROI), indicating its potential suitability for the region. This study highlights the significance of carefully selecting combinations of straw return and fertilization to maximize soil fertility, crop yield, and economic benefits in agricultural systems.

KEYWORDS

nitrogen, phosphorus, plant, straw, yield

1 Introduction

As the global population and food demand continue to rise, enhancing grain yield remains a key objective in crop production. Nonetheless, the productivity and sustainability of agriculture face significant challenges (Tilman et al., 2011; Tian et al., 2021). Crop straw, a by-product of agriculture, grows rapidly alongside crop production. China, being a major agricultural nation, reportedly generates approximately 8×10^{11} kg of crop straw annually, with maize and wheat straw being the predominant species (Li et al., 2017). Aside from being repurposed as animal feed, many crop straws are commonly either burned or landfilled, posing a significant environmental threat (Zhang et al., 2018). These crop straws, being rich in nutrients such as carbon (C), nitrogen (N), phosphorus (P), and potassium (K), are often reintroduced to the fields as cost-effective organic fertilizers, a practice widely embraced in Chinese agricultural production. The return of straw to the fields can enhance soil productivity by improving its physiochemical properties, boosting fertility, and regulating microbial activity in the soil (Turmel et al., 2015). Furthermore, this practice is crucial for maintaining or increasing soil organic carbon levels, which aids in carbon sequestration within the soil (Huang et al., 2019). Therefore, the return of straw plays a vital role in regulating the soil ecological processes of farmland, ultimately contributing significantly to the long-term maintenance of soil productivity.

Straw return can enhance soil fertility by increasing soil nutrient content, particularly soil organic matter and total nitrogen in the cultivated layer. For instance, returning maize straw to the field has been shown to significantly boost soil organic matter content in the top 0–10 and 10–20 cm soil layers compared to not returning straw. Long-term field studies indicate that continuous straw return can further elevate soil organic matter and humus content over time (Murphy et al., 2016; Yang et al., 2018). Research also suggests that combining no tillage with straw return in wheat production can enhance the yield and quality of weak-gluten wheat in the middle and lower reaches of the Yangtze River (Ma et al., 2020). However, improper use of straw return technology may negatively impact the sowing and growth of the subsequent crop (Zhou et al., 2021). Straws typically have a high C/N ratio, leading to nitrogen immobilization in soils. Therefore, it is common practice to use supplemental chemical fertilizers when returning straw to the soil. Jat et al. (2020) found that returning straw with chemical fertilizer at a rate of 270 kg N/kg could enhance the yield and nitrogen use efficiency of wheat in the subsequent season. The long-term impact of straw return on soil properties is significant, with the amount, timing, and method of return being key factors affecting soil structure and crop growth. Research by Qie et al. (2022) suggests that crushing and incorporating straw into the soil is more beneficial for increasing soil microbial activity compared to directly returning straws to the field. Moreover, shallow application of straw has shown to have a notable effect on both surface and subsurface soils, including a significant increase in ΔlgK value of humic acid in the topsoil (Zhao and Chen, 2008). Previous studies recommend returning 30%–50% of the straw produced in a given year to the field, as excessive or insufficient application is not conducive to increasing soil organic matter levels (Nash et al., 2018).

This study delves into the relationship between soil nutrients and the economic benefits of maize-wheat rotation over multiple years, considering both short-term and long-term effects. By thoroughly examining various modes of straw return, the research offers more detailed and specific guidelines compared to existing studies. The analysis of different straw return amounts and fertilizer application methods sheds light on the complex interplay between soil nutrients and crop growth. Additionally, the investigation of different soil depths enhances the comprehensiveness of the study, making it a unique and in-depth contribution to the field of straw returning. The primary objective of this study is to explore the effects of various combinations of straw return and fertilization on soil fertility and crop production within a maize-wheat rotation system. Specifically, the research aims to assess how straw return impacts soil nutrient levels, such as total nitrogen, available phosphorus, and potassium, at different soil depths. Furthermore, the study aims to investigate the effects of straw return on soil organic matter and humus content, as well as its implications for crop yield and economic outcomes. Through these objectives, the research aims to offer insights into the most effective strategies for integrating straw return and fertilization practices to improve soil health, crop productivity, and economic sustainability in agricultural settings.

2 Materials and methods

2.1 Experimental site

The long-term experimental site was located in Chuyuan Village, Fuping County, Shaanxi Province (109°11′N, 34°42′E). The site represents a typical agricultural area in the semi-arid region of northwest China, where maize-wheat rotation is a common cropping system. This allows for the study's findings to be applicable to a broader agricultural context in similar agroecological zones. The average annual temperature was 13°C, the annual precipitation was about 550 mm, concentrated in June to September, was a warm temperate semi-humid dry season wind climate, agricultural production was mainly dry agriculture. The evaluated soil belongs to aridisols and was silty loam in texture. The basic properties of 0–20 cm surface soil were shown in Table 1.

2.2 Experimental design and field management

The experiment started in the 2019 corn season (late June). The experimental design consisted of a randomized complete block design with 3 replicates. Each plot had an area of 30 m^2 (5 m × 6 m) and followed a maize-wheat rotation, a commonly used cropping system in the region. There were 8 treatments involving straw return supplemented with mineral fertilizers at varying rates (Table 2). In the straw return treatments, maize and wheat straw were chopped into small pieces post-harvest and then incorporated into the 0–20 cm soil depth using rotary tillage. Any remaining straw was removed from plots that did not receive straw return. For treatments with supplemental mineral fertilizers, nitrogen (as urea), phosphorus (as calcium superphosphate), and potassium (as potassium chloride) were applied as basal fertilizers at specified rates for each crop season.

Straw return equivalent indicates the total amount of straw harvested from the previous season. 2019 maize = 28,000 kg/hm^2, 2020 wheat = 5,250 kg/hm^2, 2020 maize = 30,000 kg/hm^2, 2021 wheat = 5,000 kg/hm^2. CK stands for no fertilization and no straw return to field, S stands for straw return to field, NP stands for only application of nitrogen fertilizer and phosphate fertilizer, NPK stands for application of nitrogen fertilizer, phosphate fertilizer and potassium fertilizer, NPKS stands for

TABLE 1 Characteristics of the top 0–20 cm soil in the experimental site.

Bulk density g/cm^3	Total porosity % (v/v)	pH	Organic matter g/kg	Total N g/kg	Available P mg/kg	Available K mg/kg
1.40	49.6	8.62	7.61	0.60	5.91	87.3

TABLE 2 Straw return and fertilization rates for each treatment.

Treatment	N (kg/hm^2)	P_2O_5 (kg/hm^2)	K_2O (kg/hm^2)	Straw return equivalent
CK	0	0	0	0
S	0	0	0	1
NP	150	120	0	0
NP+1/3S	150	120	0	1/3
NP+2/3S	150	120	0	2/3
NP + S	150	120	0	1
NPK	150	120	90	0
NPKS	150	120	90	1

application of nitrogen fertilizer, phosphate fertilizer, potassium fertilizer and straw return to field.

2.3 Sample collection and analysis

Soil samples were collected in June 2021 at depths of 0–20 cm, 20–40 cm, and 40–60 cm using a ring knife with an inner diameter of 10 cm, following the harvest of wheat. Three samples were obtained from each plot and combined to create a composite sample. The collected soil samples were subsequently air dried and ground to pass through a 2-mm sieve.

Soil nutrient analysis methods included determining soil total N using the Kjeldahl method (Gusarov, 2020), extracting available P with 0.5 mol/L $NaHCO_3$ solution and determining it through molybdenum blue colorimetry (Lu, 2000), extracting available K with 1 mol/L ammonium acetate solution and determining it with a flame photometer (M425, Sherwood Scientific, Cambridge, United Kingdom). Soil organic matter was determined using the potassium dichromate and heat capacity method, while soil humus was determined through sodium pyrophosphate leaching with the $K_2Cr_2O_7$ volumetric method (Cusack et al., 2010).

Maize and wheat yields from the 2021 growing season were analyzed for yield. In the case of maize, 20 ears were collected from each plot and measurements such as ear length, ear diameter, cob tip length, and fresh weight were taken. Following air drying, the ears were threshed and parameters like moisture content, dry weight, and 100-grain weight were determined. As for wheat, all plants within a 1.5 m^2 square in each plot were harvested and fresh weights were recorded. After air drying and threshing, measurements for moisture content, air-dried weight, and 1000-grain weight were obtained. The calculation of maize and wheat yield per hectare was based on plant density and plot area.

2.4 Economic return

$$AI = TO - TI$$
$$ROI = TO / TI$$

Where, AI represents annual net income (yuan/hm^2), TO represents total output (yuan/hm^2), and TI represents total input (yuan/hm^2), ROI represents the ratio of production to investment.

The total input includes fertilizer and field management. The N, P, and K fertilizer was calculated as 8.5 yuan/kg, 5.7 yuan/kg, and 6.5 yuan/kg. Field management included field preparation, straw cutting and incorporation, seed cost, sowing, irrigation, weeding, harvesting, and labor cost. Annual cost of field management was estimated to be 18,827–18840 yuan/hm^2. Prices of maize and wheat was both calculated as 4.6 yuan/kg, respectively. The ROI was then calculated.

2.5 Statistical analysis

Mixed model methodology was employed for data analysis, with treatment as the fixed effect and block as the random effect. Differences among treatments were assessed using SPSS (PASW Statistics 20) software, applying Fisher's protected LSD method at a significance level of α = 0.05.

3 Results

3.1 Soil nitrogen, phosphorus and potassium

The total nitrogen content of soil ranged from 0.6 g/kg to 0.8 g/kg, with all treatments showing generally low levels of total nitrogen. There was no significant difference in total nitrogen

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TABLE 3 Total N and available P and K in the top 0–20, 20–40, and 40–60 cm soils.

Treatments	Total N (g/kg)			Available P (mg/kg)			Available K (mg/kg)		
	0–20 cm	20–40 cm cm	40–60 cm cm	0–20 cm cm	20–40 cm cm	40–60 cm cm	0–20 cm cm	20–40 cm cm	40–60 cm cm
CK	0.6a	0.7ab	0.7bc	5.9a	10.8a	6.3a	87.3a	104.2a	119.0a
S	0.6a	0.6cd	0.6cd	10.6a	7.3a	4.1a	88.8a	105.0a	97.0a
NP	0.6a	0.6d	0.6d	7.6a	13.2a	11.8a	117.2a	93.0a	102.0a
NP+1/3S	0.7a	0.7bc	0.7ab	10.0a	11.0a	5.3a	106.6a	122.9a	102.7a
NP+2/3S	0.7a	0.7bc	0.7b	8.8a	8.1a	5.0a	107.0a	123.1a	110.7a
NP + S	0.7a	0.7 bc	0.7ab	7.6 a	10.6a	15.8a	111.4a	103.2a	128.9a
NPK	0.7a	0.8a	0.8a	5.5a	7.2a	7.0a	97.0a	144.6a	123.0a
NPKS	0.7a	0.7bc	0.7b	13.3a	12.0a	14.6a	143.0a	114.6a	141.9a

Different letters in the same column indicate significant differences ($p < 0.05$), the same below.

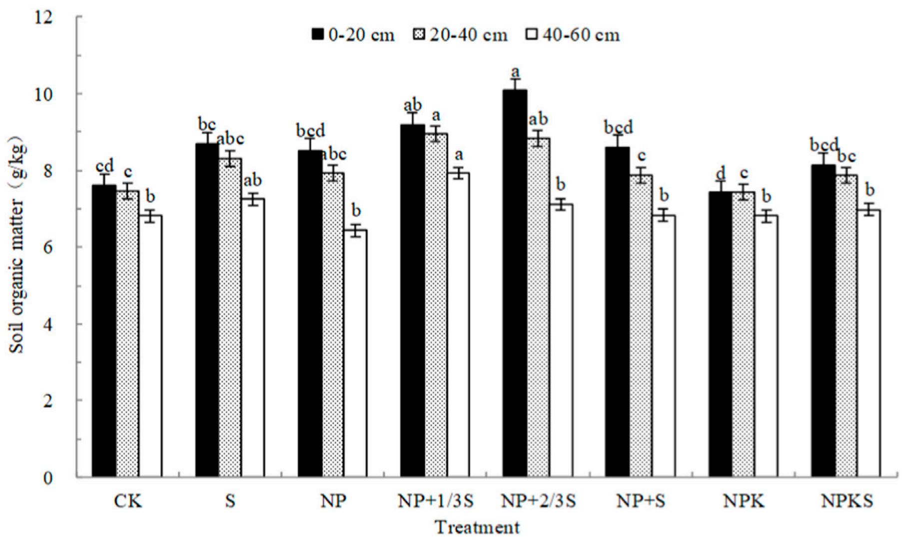

FIGURE 1
Soil organic matter content in the top 0–20, 20–40, and 40–60 cm soils.

content in the top 0–20 cm soil among treatments. In subsoils (20–40 and 40–60 cm), the NP treatment led to significantly lower soil total nitrogen compared to the untreated control, while a combination of NP and straw return at varying rates maintained soil levels similar to CK. Total nitrogen following the NPK treatment was significantly higher than the NP treatment in the top 20–40 cm soil and higher than both CK and NP treatments in the top 40–60 cm soil. However, the NPKS treatment notably reduced total nitrogen in both the top 20–40 cm and 40–60 cm soils (Table 3). Available phosphorus and potassium in the evaluated soils were not significantly affected by the treatments.

3.2 Soil organic matter

The soil organic matter content ranged from 6.4 g/kg to 10.1 g/kg, gradually decreasing with soil depth. In the 0–20 cm soil layer, organic matter content was lowest in the NPK treatment, 2.5% lower than CK, but not significantly different. NP+1/3S and NP+2/3S treatments showed significantly higher organic matter content, increasing by 20.8% and 32.6% respectively. In the 20–40 cm soil layer, organic matter content ranged from 7.4 g/kg to 8.9 g/kg, with NPK treatment being the lowest, 0.4% lower than CK. NP+1/3S and NP+2/3S treatments increased organic matter content by 19.7% and 18.2% compared to CK. In the 40–60 cm soil layer, only NP+1/3S treatment significantly increased organic matter by 16.4% compared to CK, while other treatments showed no significant differences (Figure 1).

3.3 Total carbon content in soil humus

The NP+2/3S, NP+1/3S, and NP + S treatments resulted in a significant increase in soil humus in the top 0–20 cm soil by 52.6%, 46.2%, and 34.1%, respectively, compared to CK (Figure 2). Furthermore, the NP+1/3S and NP+2/3S treatments showed a significant increase in soil humus content in the top 0–20 cm soil by 38.0% and 44.0% compared to the NP treatment, while no significant difference was observed between the NP + S and NP treatments. The total carbon content of humus in 20–40 cm soil layer showed a decreasing trend compared with that in 0–20 cm soil layer, and the contents of CK, NP, and NPK were lower, while the humus content of straw returning treatment was significantly increased. Compared with CK, the increase of straw returning treatment was 26.1%–37.9%, among which the increase of NP+1/3S, NP+2/3S and NP + S treatment was 36.7%, 37.9%, and 29.4%, respectively. Compared with NP treatment, NP+1/3S, NP+2/3S, and NP + S treatments increased by 28.4%, 29.5%, and 21.6%, respectively, and the difference was significant, while NPKS increased by 12.4% compared with NPK treatment, but the difference was not significant. The total carbon content of humus in the 40–60 cm soil layer was lower than that in the 0–40 cm soil layer, ranging from 1.92 g/kg to 2.59 g/kg. The straw returning measures had little effect on the total carbon content of humus in the deep soil layer.

3.4 Maize yield and yield components

The NP+1/3S, NP+2/3S, S, and NP treatments significantly increased the number of grains per ear by 22.5%, 21.4%, 18.0%, and 15.3%, respectively, compared to CK (Table 4). While other treatments also showed a tendency to increase the number of grains per ear, these increases were not statistically significant. Ear length, on the other hand, exhibited minimal responses to straw return and/or fertilization treatments. All treatments led to notable improvements in both 100-grain weight and grain yield when compared to the CK treatment. Particularly, the NP+1/3S and NP+2/3S treatments resulted in significantly greater 100-grain weight compared to the other treatments (Table 4). The highest grain yield was observed with the NP+1/3S treatment, followed by the NP+2/3S and NP + S treatments, which also showed

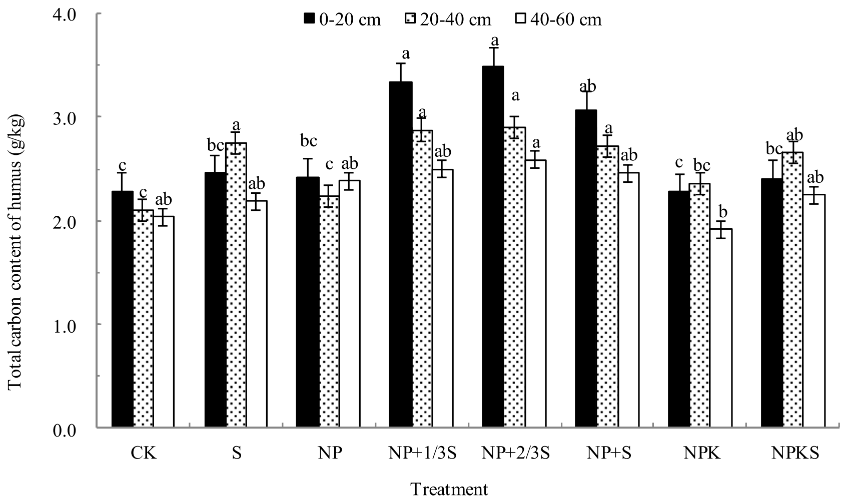

FIGURE 2
Soil humus content in the top 0–20, 20–40, and 40–60 cm soils.

TABLE 4 Maize yield and yield components harvested in October 2021.

Treatments	Number of grains per ear	Ear length (cm)	100-Grain weight (g)	Grain Yield (kg/hm^2)
CK	37.3b	23.8ab	28.9c	6,619.0f
S	44.0a	23.0b	35.6b	8,459.0e
NP	43.0a	23.5ab	34.4b	8,288.0e
NP+1/3S	45.7a	25.6a	40.5a	10,888.3a
NP+2/3S	45.3a	25.4ab	40.0a	10,533.5 ab
NP + S	42.0ab	23.8ab	34.5b	10,069.7bc
NPK	42.0ab	24.2ab	36.8b	9,346.7cd
NPKS	40.7ab	23.2ab	36.5b	8,996.1de

substantially higher grain yields compared to the S and NP treatments. Interestingly, the NPKS treatment did not show a significant increase in grain yield compared to the NPK treatment (Table 4).

3.5 Wheat yield and yield component

Only the NP+1/3S treatment significantly increased the number of spikes per m^2 compared to CK. However, there were no significant differences among NP+1/3S and other straw return/fertilization treatments. All treatments showed a significant improvement in the number of grains per spike compared to CK. The highest number of grains per spike was observed with NP+1/3S, followed by NP+2/3S and NPS, although the differences among these three treatments were not significant. Additionally, the NP+1/3S treatment notably increased the number of grains per spike in comparison to NP, as opposed to the NP+2/3S and NPS treatments. All treatments, except for NP, led to a significant increase in the 1000-grain weight compared to CK. The NP+1/3S treatment resulted in the highest 1000-grain weight, with no significant difference observed between NP+1/3S and NP+2/3S. Consequently, all treatments significantly increased wheat grain yield compared to CK. The NP+1/3S, NP+2/3S, and NP + S treatments resulted in the highest grain yield and were significantly greater than the NP and S treatments. In contrast, there was no significant difference in grain yield and yield components between the NPK and NPKS treatments (Table 5).

3.6 Economic benefits

Grain yield has a direct impact on total revenue. For instance, the combination of NP with varying rates of straw return notably increased the grain yield of wheat and maize (Tables 4, 5), leading to a significantly higher total revenue in comparison to CK (Table 6). With an increase in the rate of straw return from 1/3S to S, the total revenue showed a gradual decrease. The NP+1/3S treatment resulted in the highest total revenue, which was 64.1% greater than that of the CK (Table 6). While the total investment for the NPKS treatment was the highest among all treatments, the net income associated with this treatment only surpassed that of CK and NP. Return on

TABLE 5 Wheat yield and yield components harvested in June 2021.

Treatments	Number of spikes per (m^2)	Number of grains per spike	1000-Grain weight (g)	Grain yield (kg/hm^2)
CK	384.7b	35.7c	40.8d	6,045.7e
S	419.0ab	44.3ab	45.9c	7,444.0d
NP	455.3ab	42.3b	42.6d	7,081.3d
NP+1/3S	497.7a	48.3a	49.0a	9,903.5a
NP+2/3S	462.3ab	47.0ab	48.4ab	9,361.6b
NPS	459.0ab	46.0ab	46.4bc	9,058.7bc
NPK	455.7ab	45.0ab	45.5c	8,777.8cd
NPKS	457.3ab	46.0ab	45.2c	8,377.1d

TABLE 6 Interannual economic benefits for different straw return/fertilization treatments.

Treatments	To Yuan/hm^2	TI Yuan/hm^2	Net income Yuan/hm^2	ROI
CK	27,284.4	18,227.0	9,057.4	1.50
S	34,191.5	18,227.0	15,964.5	1.88
NP	32,991.0	20,753.0	12,238.0	1.59
NP+1/3S	44,782.8	20,766.0	24,016.8	2.16
NP+2/3S	42,797.5	20,961.0	21,836.5	2.04
NP + S	41,175.4	21,366.0	19,809.4	1.93
NPK	39,105.9	21,923.0	17,182.9	1.78
NPKS	37,467.5	22,536.0	14,931.5	1.66

Investment (ROI) serves as a static indicator of the profit and loss status. In this study, the NP+1/3S treatment exhibited the highest ROI. Interestingly, when compared to NPK, the addition of extra straw return (NPKS treatment) actually decreased the ROI (Table 6).

4 Discussion

4.1 Impact of different straw return and fertilization combinations on soil fertility

The impact of various straw return and fertilization combinations on soil fertility has noteworthy implications for sustainable agricultural practices. In this study, soil total N levels were found to be low, ranging from 0.6 to 0.8 g/kg. It was observed that nutrient release from inorganic fertilizers occurred at a faster rate compared to the decomposition of crop straw, which was influenced by factors such as soil temperature, humidity, and soil texture. (Caires et al., 2017; Song et al., 2018). In the present study, soil total N levels exceeded those from straw return treatments following NPK treatment. Conversely, Liu et al. (2021) observed a 15.57% increase in soil total N content and a 17.11% increase in organic C after 3 years of cultivation with straw return compared to NPK treatment. Discrepancies in experimental design, soil type, fertilizer application, crop types, and other variables between the two studies may account for the varying outcomes. Crop straws generally have low levels of nitrogen and phosphorus, but are high in potassium. As a result, the NPKS treatment led to a notable increase in soil available potassium, while nitrogen and phosphorus levels remained unaffected. Previous research has shown that returning straw to the field can enhance microbial activity, with no significant impact on nitrogen and phosphorus levels (Li et al., 2017). However, unlike the present study, these previous findings did not specifically highlight the increase in available potassium due to straw returning. A meta-analysis conducted by Zhang et al. (2019) found that straw return can significantly increase soil organic carbon content in the short term (less than 2 years), while soil total N, mineral N, available P, and available K showed no increase until 2–5 years later. Our study suggests that the impact of straw return on soil organic matter content is less pronounced in deeper soils, consistent with the findings of Zhang et al. This could be attributed to the fact that crop straws returned to the soil surface may not have direct contact with deeper soils, resulting in a slower decomposition rate, limited downward movement, and lower soil fertility in subsoils (Bai et al., 2013; Luan et al., 2019). Both the NP+1/3S and NP+2/3S treatments significantly increased soil organic matter and soil humus in multiple soil layers, while the NP + S treatment did not. The study by Luan et al. (2019) suggests that the limited effectiveness of full equivalent straw return (NP + S) in improving soil organic matter may be due to heavy crop straw coverage hindering nutrient exchange between the soil and the atmosphere, thus impeding decomposition processes. These findings highlight the importance of optimizing straw return rates to enhance soil organic matter content and promote soil health in agricultural systems.

4.2 Response of crop yield and economic efficiency to conservation tillage patterns

The study revealed that higher crop yield was achieved when 33%–66% of crop straw was added to the NP treatment (i.e., NP+1/3S and NP+2/3S treatments). In contrast, previous research suggests that optimal crop yield is linked to a 50%–100% return of crop straw, with a turning point observed at 150% crop straw return (Liu et al., 2015; Li et al., 2018). Straw-returning tests showed that 100% straw-returning sustained increases in crop yield and carbon content over 18 years (the average trial period of the studies considered) (Wang et al., 2015). The discrepancies observed between the current study and previous research may be attributed to variations in soil texture, climatic conditions, cropping systems, straw return rates, cultivars, and methods of straw incorporation (Liu et al., 2022). Shen et al. (2012) proposed that straw mulching may enhance soil water status and subsequently increase grain yield in compact-type maize. Nonetheless, various studies have shown that a 100% straw return may not be beneficial for enhancing crop yield, possibly due to hindered root growth caused by reduced soil porosity and higher soil bulk density resulting from straw mulching (Mu et al., 2020; Yang et al., 2020; Wang et al., 2022). The excessive straw return may negatively impact soil fertility, emergence rates, and crop yields, emphasizing the importance of optimizing tillage practices to maximize productivity while minimizing environmental risks (Zhou et al., 2021). Caires et al. found that straw return at 50%–100% could improve maize and wheat yield by 16.29%–26.06% and 7.57%–13.16%, comparing to a 52.1%–64.5% increase in maize yield and a 49.8%–63.6% in wheat yield in the present study (Caires et al., 2017; Cai et al., 2022). The combined application of wheat and corn straw resulted in a notable increase in grain yield for double cropping crops, with the interannual variation in yield showing a strong correlation with soil properties (Cui et al., 2022). Bai et al. (2022) demonstrated that returning straw to the field can enhance soil fertility, protect the ecological environment, and increase maize yield. This practice serves as an efficient agricultural technology that balances economic and environmental advantages. By enhancing the utilization of straw resources, reducing fertilization costs, and promoting farmland fertility maintenance, straw return supports sustainable high grain yields (Xu et al., 2018; Huang et al., 2022).

The economic viability and practical implications of implementing different conservation tillage practices are crucial considerations for farmers and policymakers. While NPK fertilizer application combined with full straw return was not economically beneficial due to increased input costs and limited yield improvements, treatments with partial straw return (NP+1/3S and NP+2/3S) showed promising economic returns. The NP+1/3S treatment, in particular, demonstrated the highest return on investment, highlighting its potential as a sustainable and economically viable tillage practice.

5 Conclusion

The study emphasizes the importance of optimizing conservation tillage practices for sustainable agricultural production systems. By combining straw return with customized fertilization strategies based on local soil and climatic conditions, farmers can improve soil fertility, boost crop yields, and enhance economic returns while minimizing environmental impacts. Our findings suggest that the short-term impact of straw return on soil total N, available P, and available K was not significant, but it notably increased soil organic matter and humus content. The NP+1/3 S treatment yielded the highest maize and wheat yields, leading to the greatest return on investment (ROI). Thus, we recommend the NP+1/3S treatment for producers in the region. Future research should focus on long-term monitoring of soil health and crop productivity to confirm the sustainability of conservation tillage practices in various agroecosystems.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JL: Conceptualization, Formal Analysis, Software, Validation, Writing–original draft. ZG: Conceptualization, Data curation, Validation, Writing–original draft. SY: Conceptualization, Funding acquisition, Project administration, Supervision, Writing–review and editing.

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Conflict of interest

Authors JL, ZG, and SY were employed by the Shaanxi Provincial Land Engineering Construction Group Co., Ltd.

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