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Soil nitrogen and carbon storages and carbon pool management index under sustainable conservation tillage strategy

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Agricultural practices are significant to increase the soil nitrogen and organic carbon sequestration to adapt and mitigate the climate change in a recent climate change scenario. With this background, we carried out research in the Longzhong Loess Plateau region of China. This research was conducted under a randomized complete block design, with three replicates. Adopt the method of combining outdoor positioning field test with indoor index measurement to explore the soil bulk density (BD), nitrogen components (*viz.,* nitrate nitrogen (NO_3^--N), ammonia nitrogen (NH_4^+-N), total nitrogen (TN), microbial biomass nitrogen (MBN) and nitrogen storage (NS), and carbon components [*viz.,* soil organic carbon (SOC), easily oxidized organic carbon (EOC), microbial biomass carbon (MBC) and carbon storage (CS), carbon pool index (CPI), carbon pool activity (A) and carbon pool activity index (AI) and carbon pool management index (CPMI)] and C/N, ratio under different tillage practices [*namely.,* conventional tillage (CT), no tillage (NT), straw mulch with conventional tillage (CTS) and straw mulch with no tillage (NTS)]. Our results depicted that different conservation tillage systems significantly increased soil BD over conventional tillage. Compared with CT, the NTS, CTS and NT reduced soil NO_3^--N, increased the soil NH_4^+-N, TN, MBN and NS, among them, NS under NTS, CTS and NT treatment was 25.0, 14.8 and 13.1% higher than that under CT treatment, respectively. Additionally, conservation tillage significantly increased SOC, EOC, MBC, CS, CPI, AI, CPMI and C/N, ratio than CT. Inside, CS under NTS, CTS and NT treatment was 19.4, 12.1 and 13.4% higher than that under CT treatment, respectively. Moreover, during the 3-year study period, the CPMI under NTS treatment was the largest (139.26, 140.97, and 166.17). Consequently, we suggest that NTS treatment was more sustainable strategy over other investigated conservation tillage practices and should be recommended as climate mitigation technique under climate change context.

1. Introduction

In terrestrial ecosystems, soil carbon and nitrogen pools play a significant role in the biochemical cycle. Nitrogen and organic carbon are not only important soil quality indicators for crop production, however increase of their storages can reduce the increase of atmospheric CO_2 and N_2O concentration in the atmosphere resultant to decrease the greenhouse effect (Nath et al., 2017). Currently, ecological environment and climate change, the research on soil carbon and nitrogen pool is more extensive (Eduardo et al., 2019). Soil carbon pool is the largest organic carbon pool in terrestrial ecosystem, which is not only the "sink" but also the "source" of CO_2 (Srivastava et al., 2016, 2020). Due to the huge storage capacity of soil organic carbon (about $1,300 \sim 2000$ pg; Li et al., 2019), which is mainly distributed on the surface of the soil and active exchange with atmosphere, the small change of its storage can lead to the large fluctuation of the concentration of greenhouse gasses such as CO_2 and then affect the global climate change (Huang et al., 2018). In the farmland ecosystem, conventional tillage practice will destroy soil aggregates and decompose soil organic carbon by exposing it to microorganisms (Shi et al., 2017; Raghavendra et al., 2021; Zhang et al., 2022). Additionally, the mechanical disturbance of farming methods will strengthen soil respiration (Zhang et al., 2016). This carbon will be released into the atmosphere through emission, resulting in the greenhouse effect. The carbon pool management index (CPMI) broadly reflects the soil carbon pool changes and carbon pool activity, and is often used to characterize the status of soil carbon pool under different backgrounds (Liu et al., 2017; Jiang et al., 2021). Consequently, the impact of soil carbon pool and its dynamic changes on the stability and sustainable development of agroecosystem has become a scientific hotspot in the international geoscience, ecology and environmental circles. With the international community's attention to the fixation of CO_2 and N_2O in farmland soil, there are more and more reports on the storage of carbon and nitrogen in farmland soil.

Due to the fragile ecological environment, large interannual variation of precipitation, poor stability of agricultural production system, low and unstable output in the Loess Plateau, it has become one of the key research areas in the hot fields of ecology and related sciences (Ma et al., 2020). Conventional tillage and other unreasonable cultivation measures have exacerbated the crop production damage, resulting in different problems such as barren farmland soil, low land carrying capacity and increased greenhouse gas emissions on the Loess Plateau (Hao et al., 2021). Conservation tillage has become a sustainable practice to protect farmland, improve land sustainability and stability because it can reduce soil erosion, improve soil physical and chemical properties, reduce the mineralization and decomposition of organic matter, help soil carbon and nitrogen sequestration and improve soil quality (Su et al., 2006; Yang et al., 2015). According to the statistics of FAO, conservation tillage has been promoted in more than 70 countries, with a cultivated area of more than 1.7×10^8 hm², which has also been widely popularized in China (Chen et al., 2009). Previous studies have shown that conservation tillage such as no tillage and straw mulching can significantly affect the content of organic carbon and nutrients in the surface and deep soil, promote the formation of soil water stable aggregates, improve soil erosion resistance and carbon and nitrogen sequestration, so as to achieve carbon pool stability (Issaka et al., 2019; Zhang et al., 2021). Kushwa et al. (2016) studied the farmland soil in central India, they found that the conservation tillage based on no tillage and less tillage was more conducive to the accumulation of soil organic carbon, total nitrogen (TN) and available phosphorus content than traditional tillage, but it would not have a significant impact on the yield of soybean wheat rotation system, but saved energy and time. Stockfisch et al. (1999) found in Saxony, Germany, that long-term shallow tillage will make organic carbon and microbial biomass nitrogen (MBN) enriched in the soil surface, while long-term less tillage or no tillage will make the stratification and accumulation of soil organic matter disappear completely. Wang et al. (2018) observed that conservation tillage system can improve the soil organic carbon accumulation and encouraging to land restoration. Compared with CT, no tillage and straw mulching can increase soil carbon storage, especially the combination of the straw with no tillage is the most significant; Zhang et al. (2015) noted that conservation tillage increased the content of organic carbon and TN in the upper soil, had no significant effect on the deep soil, and did not increase the storage of carbon and nitrogen in the soil profile during field experiment of the double cropping system of winter wheat and corn in Beijing, China. Peng et al. (2011) recorded in the study of rice cultivation in Sichuan basin that compared with traditional rotation, no tillage ridge cultivation can significantly increase the surface soil organic carbon and active carbon. Under no tillage ridge cultivation, the soil CPMI is improved, nonetheless it is reduced under traditional rotation, and conservation tillage improves the quality of rice soil. In the study of rain fed agricultural areas, some scholars found that no tillage, straw mulching and less tillage were helpful to the accumulation of soil active carbon, and significantly improved the soil water holding capacity and CPMI (Dong et al., 2021). To some extent, these studies have revealed the correlation between farming management and soil carbon and nitrogen content and storage,

inversely there is a lack of long-term monitoring of conservation tillage, especially in the ecologically fragile area of the Loess Plateau. At present, the research on the impact of tillage methods and straw returning on the change of soil carbon and nitrogen pool in this area is insufficient, and the relevant mechanism is still unclear, which seriously hinders the sustainable development of local agriculture. Consequently, it is necessary to explore the impact mechanism of sustainable conservation tillage on farmland soil carbon and nitrogen storage and CPMI in the Loess Plateau, in order to provide theoretical and practical basis for formulating reasonable agricultural farming measures and promoting the sustainable development of agriculture in this area.

In order to solve these problems, we studied the effects of sustainable conservation tillage on soil carbon and nitrogen storage and CPMI in the wheat field on a Loess Plateau, this study will provide theoretical basis and basic data for understanding the dynamic changes of farmland soil organic carbon and nitrogen storage and the carbon and nitrogen sequestration potential of conservation tillage measures. For this reason, we put forward some assumptions: (1) The implementation of sustainable conservation tillage may positively affect the content of carbon and nitrogen components in the soil by reducing the disturbance to the soil and improving the soil texture (Wang H. Y. et al., 2021) (2) Sustainable conservation tillage may enhance soil compactness, increase soil organic carbon and TN content, and then increase soil carbon and nitrogen storages (Chen et al., 2022); (3) Sustainable conservation tillage may significantly affect soil carbon pool, compared with traditional tillage, it will improve CPMI and has good carbon and nitrogen sequestration potential (Yadav et al., 2021). We believe that this study will contribute to the sustainable development of the regional farmland ecosystem.

2. Materials and methods

2.1. Site description

This experiment was conducted at the dry farming experiment station of Gansu Agricultural University in Dingxi, Gansu Province (35°64′N, 104°64′E; Figure 1), which is a typical semi-arid rainfed farming area with an average altitude of 2000 m, an average annual temperature of 6.4°C, an average annual evaporation of 1,531 mm and a frost-free period of about 140 d. The average annual rainfall was 409.5 mm and the average rainfall during the reproductive period was 302.9 mm (Sadiq et al., 2021).

The eolian soil of research area is a Huangmian sandy loam in texture, low in organic carbon content with slightly alkaline pH and is classified as a Calcaric Cambisol (Alhassan et al., 2021). It is the main cropping soil type in the area and dominant soils on the Loess Plateau belt. Prior to this study, the main soil physical and chemical quality indicators collected from the 0–30 cm soil layer in March 2019 are shown in Table 1. The northern China Loess Plateau particularly Dingxi belt had a long history of wheat

farming under conventional tillage practice which comprises inversion of soil and several operations for soil smoothing. Crop-straw mainly wheat stubble was continually removed earlier to the next crop cycle.

2.2. Experimental design

The research setup was started in 2016 under tillage practices. This paper presents the results from 2019 to 2021. Four tillage treatments were laid out in this study, all using a completely randomized block design. The treatments were conventional tillage (CT), no-tillage (NT), conventional tillage with straw mulch (CTS) and no-tillage with straw mulch (NTS). Each treatment was designed with three replicated plots, making a total of 12 plots with a plot size of 4 m × 6 m. The description of each treatment is shown in Table 2. Spring wheat "Dingxi 42" often planted by local farmers was selected as the test variety. We used 150 kg·ha^{-2} diammonium phosphate (N + P$_2$O$_5$) and 62.5 kg·ha^{-2} urea (46%) as a base fertilizer applied at sowing. To avoid edge effects between plots, each plot was separated by a 0.5 m wide barrier strip. Crop was sowing by 25 March and harvested by 1 August each year.

2.3. Sample collection and measurements

During the harvest of spring wheat every year from 2019 to 2021, the soil samples are collected. Five randomly selected sampling points in an 's' shape in each trial plot. The soil samples of 0–30 cm soil layer are collected with a soil drill with a diameter of 5 cm. The soil samples of the same soil layer form a mixed soil sample, remove sundries, put them in plastic bags, place them in the sample box with ice bags, and transport them to the laboratory at low temperature for determination and analysis (Wu et al., 2020).

2.3.1. Determination of soil bulk density

Briefly, using the ring-knife method, in each test plot, a sample of the soil was cut with the ring-knife in the 0–30 cm layer in its original state, weighed immediately but without disturbing the soil sample, then dried (105–110°C, 24 h) and weighed again to obtain the dry soil weight, and finally the bulk density was obtained according to the standard calculation formula (BD) (Lu et al., 2019).

2.3.2. Determination of soil nitrogen pool

The contents of nitrate nitrogen (NO$_3^-$-N) and ammoniacal nitrogen (NH$_4^+$-N) in soil was determined according to the method described by Yang B. J. et al. (2014) using a 2 mol/l KCL solution with a 5:1 water to soil ratio for extraction followed by flow analyzer determination. The content of soil TN was determined by semi-micro Kjeldahl method (Huang et al., 2021). The content of microbial biomass nitrogen in soil was determined by fumigation leaching–TN assay according to Chen et al., (2021).
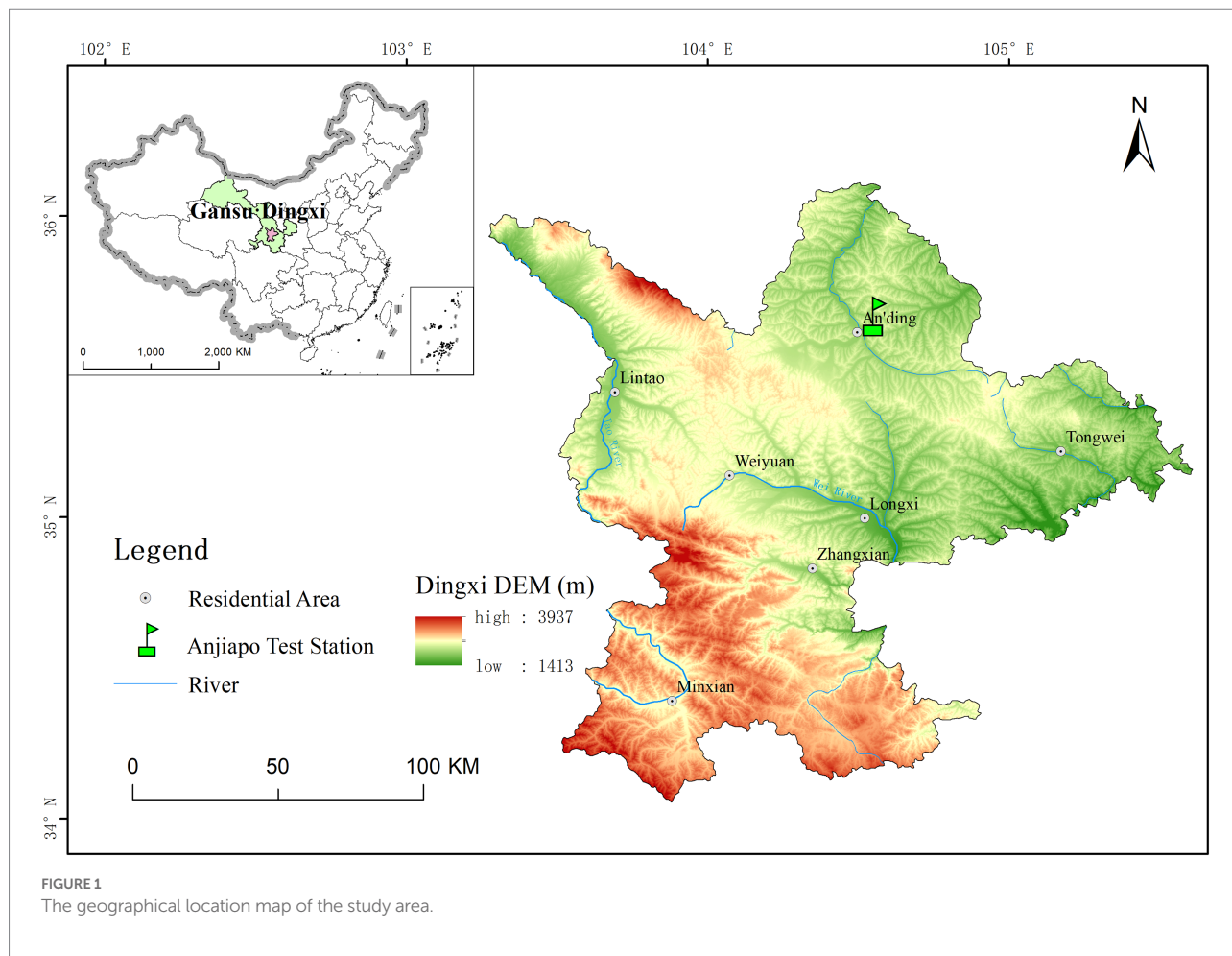
FIGURE 1
The geographical location map of the study area.

TABLE 1 Determination of basic soil indicators in the 0−30cm soil layer of spring wheat prior to planting in 2019.

Soil property	Values	Measurement method
NO_3^--N ($mg\,kg^{-1}$)	25.72 ± 0.3	Colorimetric method
NH_4^+-N ($mg\,kg^{-1}$)	11.38 ± 0.5	Colorimetric method
TN ($g\,kg^{-1}$)	0.58 ± 0.04	Semimicro-Kjeldahl method
TP ($mg\,kg^1$)	0.43 ± 0.03	Colorimetric method
TK ($g\,kg^{-1}$)	18.50 ± 0.05	Colorimetric method
SOC ($g\,kg^{-1}$)	5.75 ± 0.6	Walkley-Black dichromate oxidation
SWC (%)	14.75 ± 0.5	Oven-dry method
B.D ($g\,cm^{-3}$)	1.35 ± 0.04	Core sampler method
Soil texture	Sandy-loam	Hydrometer method

NO_3^--N, nitrate nitrogen; NH_4^+-N, ammonium nitrogen; TN, total nitrogen; TP, total phosphorous; TK, total potassium; SOC, organic carbon; SWC, gravimetric soil water content; B.D, soil bulk density.

2.3.3. Determination of soil carbon pool and C/N

The soil organic carbon (SOC) was determined using the potassium dichromate oxidation external heating method following the method of Wang et al. (2020). The easily oxidized

TABLE 2 Specific instructions for the implementation of each tillage method.

Treatment	Operation
CT	Pre-planting "three tillage and two purfling" treatment in line with local farming experience
NT	No tillage all year round, sowing is done in one go with a no-till planter
CTS	Tillage is the same as for CT, with the straw from the previous crop guillotined to 10–15 cm after sowing and evenly mulched over the original plot at a rate of 4,000 kg·hm^{-2}
NTS	Direct planting as in NT with no crop planter. With the straw from the previous crop guillotined to 10–15 cm after sowing and evenly mulched over the original plot at a rate of 4,000 kg·hm^{-2}.

organic carbon (EOC) in soil is determined according to the method described by Zhao et al. (2021). The microbial biomass carbon (MBC) was determined by chloroform fumigation extraction method according to the method of Liu et al., (2018). Finally, soil C/N ratio was calculated according to the contents of soil organic carbon and TN.

2.3.4. Calculation of soil carbon and nitrogen storages

The calculation method of soil organic carbon storage (R_{SOC}) and total nitrogen storage (R_{TN}) is as follows:

$$R_{SOC} = SOC_n \times BD_n \times D_n \times 0.1$$

$$R_{TN} = TN_n \times BD_n \times D_n \times 0.1$$

In the formula: R_{SOC} and R_{TN} are soil organic carbon storage ($t \bullet hm^{-2}$) and TN storage ($t \bullet hm^{-2}$) of layer N, SOC_n and TN_n are soil organic carbon and TN of layer N ($g \bullet kg^{-1}$), BD_n is soil bulk density of layer N ($g \bullet kg^{-1}$), D_n is soil thickness of layer N (cm), and 0.1 is unit conversion coefficient (Wu et al., 2021).

2.3.5. Calculation of soil carbon pool management index

The calculation method of soil CPMI is as follows (Zhu et al., 2015; Yadav et al., 2021):

$$\text{Carbon pool management index} (\text{CPMI},\%) = \text{Carbon pool index} (\text{CPI}) \times \text{Carbon pool activity index} (\text{AI}) \times 100\%$$

$$\text{Carbon pool index} (\text{CPI},\%) = \text{sample organic carbon content} (\text{SOC}) \div \text{reference soil organic carbon content} (\text{SOC}) \times 100\%$$

$$\text{Carbon pool activity index} (\text{AI},\%) = \text{sample carbon pool activity} (\text{A}) \div \text{reference soil carbon pool activity} (\text{A}) \times 100\%$$

$$\text{Carbon pool activity} (\text{A}) = \text{sample active organic carbon content} (\text{AOC}) \div \text{inactive organic carbon content} (\text{AOC})$$

In the formula: Taking traditional tillage (CT) as the reference soil, soil active organic carbon is EOC, the content of no-active organic carbon is equal to the difference between the content of organic carbon and active organic carbon (Yang et al., 2018).

2.4. Statistical analysis

We used SPSS 20.0 to perform analysis of variance (ANOVA) on the data in the paper, using the (Duncan's test, $p < 0.05$) method for mean separation and plotted graphs using Origin 2022. To analyze and compare the effects of different years and different tillage practices and their mutual coupling effects on soil carbon and nitrogen pools, a two-way analysis of variance (two-way ANOVA) was used. Additionally, principal component analysis (PCA) was performed on the indicators to assess the multivariate variability

introduced by the different treatments on soil carbon and nitrogen pools as well as on carbon and nitrogen stocks and carbon pool management indices. Pearson correlation analysis was used to describe the correlation among the factors in the experiment.

3. Results

3.1. Effect of different tillage methods on soil bulk density

The soil bulk density under treatments in spring wheat field is shown in the Figure 2. From different treatments in the same year, the soil bulk density of 0–30 cm of spring wheat showed the same changing trend. NTS and NT treatments were significantly higher than CTS and CT treatments ($p < 0.05$). From different years of the same treatment, the soil bulk density decreased with the passage of time duration of CT treatment implementation, increased with the increase of year under NT and NTS treatment, inversely there was no significant change under CTS treatment.
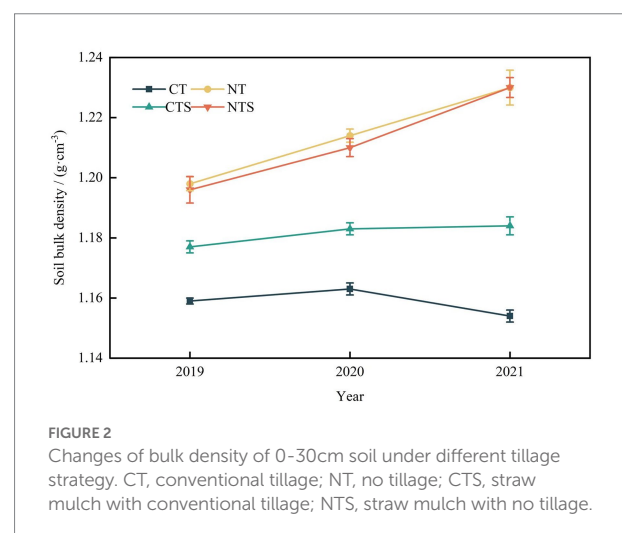

FIGURE 2
Changes of bulk density of 0–30cm soil under different tillage strategy. CT, conventional tillage; NT, no tillage; CTS, straw mulch with conventional tillage; NTS, straw mulch with no tillage.

TABLE 3 Nitrogen contents under sustainable conservation tillage.

Year	Treatment	NO$_3^-$-N (mg/kg)	NH$_4^+$-N (mg/kg)	TN (g/kg)	MBN (mg/kg)
2019	CT	33.85 ± 0.40 Ab	11.93 ± 0.05 Db	0.60 ± 0.01 Dc	23.87 ± 0.04 Dc
	NT	31.47 ± 0.69 Ba	13.26 ± 0.01 Cb	0.64 ± 0.02 Cc	25.73 ± 0.08 Cc
	CTS	33.78 ± 0.36 Ab	14.24 ± 0.33 Bb	0.67 ± 0.01 Bc	26.92 ± 0.05 Bc
	NTS	30.83 ± 0.36 Bab	15.52 ± 0.04 Ab	0.72 ± 0.02 Ac	28.69 ± 0.12 Ac
2020	CT	36.11 ± 0.93 Aa	12.88 ± 0.02 Cb	0.64 ± 0.01 Db	25.55 ± 0.04 Db
	NT	32.44 ± 0.29 Ba	15.31 ± 0.94 Ba	0.68 ± 0.02 Cb	27.33 ± 0.08 Cb
	CTS	35.17 ± 0.89 Aab	17.14 ± 0.88 ABa	0.71 ± 0.01 Bb	28.52 ± 0.05 Bb
	NTS	29.82 ± 0.43 Cb	19.07 ± 0.74 Aa	0.76 ± 0.03 Ab	30.28 ± 0.12 Ab
2021	CT	37.76 ± 0.44 Aa	14.99 ± 0.48 Ca	0.66 ± 0.01 Da	26.61 ± 0.04 Da
	NT	32.31 ± 0.09 Ba	15.77 ± 0.40 Ca	0.72 ± 0.02 Ca	28.94 ± 0.08 Ca
	CTS	36.41 ± 0.38 Aa	18.22 ± 0.52 Ba	0.75 ± 0.01 Ba	30.14 ± 0.05 Ba
	NTS	31.75 ± 0.59 Ba	21.13 ± 0.85 Aa	0.80 ± 0.03 Aa	31.90 ± 0.12 Aa

Different capital letters indicate that there are significant differences between different treatments in the same year; Different lowercase letters indicate that there are significant differences between different years of the same treatment. NO$_3^-$-N, nitrate nitrogen; NH$_4^+$-N, ammoniacal nitrogen; TN, total nitrogen; MBN, microbial biomass nitrogen.

3.2. Soil nitrogen contents and storage under tillage methods

As shown in Table 3. The content of soil NO$_3^-$-N showed a trend that CT was significantly higher than no tillage and straw mulched treated plots ($p < 0.05$), which was trended as CT > CTS > NT > NTS, the content of soil NH$_4^+$-N in conservation tillage was significantly higher than that in CT ($p < 0.05$), and NTS treatment was significantly higher than CTS and NT treatment ($p < 0.05$). The content of TN in soil was the largest under NTS treatment and the smallest under CT treatment, there was significant difference among treatments ($p < 0.05$). The contents of soil MBN was significantly correlated with TN content, and the change trend was consistent with TN content. NTS, CTS and NT treatment were significantly higher than CT treatment ($p < 0.05$). From different years of the same treatment, the content of soil NO$_3^-$-N increased with years under CT, NT and CTS treatments, decreased first and then increased with years under NTS treatment, and the content of soil NH$_4^+$-N increased with years under each treatment. The contents of TN and MBN in soil showed the same change trend, and increased with the increase of years under each treatment, which was significantly higher in 2021 than in 2020 and 2019.

The soil nitrogen storage under conservation tillage was significantly higher than traditional tillage, and being significantly ($p < 0.05$) highest under NTS treatment than other treatments including all tested years. Regarding different years, soil nitrogen storage increased with the passage of time duration of tillage systems implementation, which was significantly higher in 2021 than in 2020 and 2019 ($p < 0.05$). Additionally, during the three-year study period, the average nitrogen storage of 0–30 cm soil ranged from 2.20 to 2.75 t•hm^{-2}. Compared with CT treatment, the average nitrogen storage of NTS, CTS and NT increased by 25.01, 14.79 and 13.06%, respectively (Figure 3).
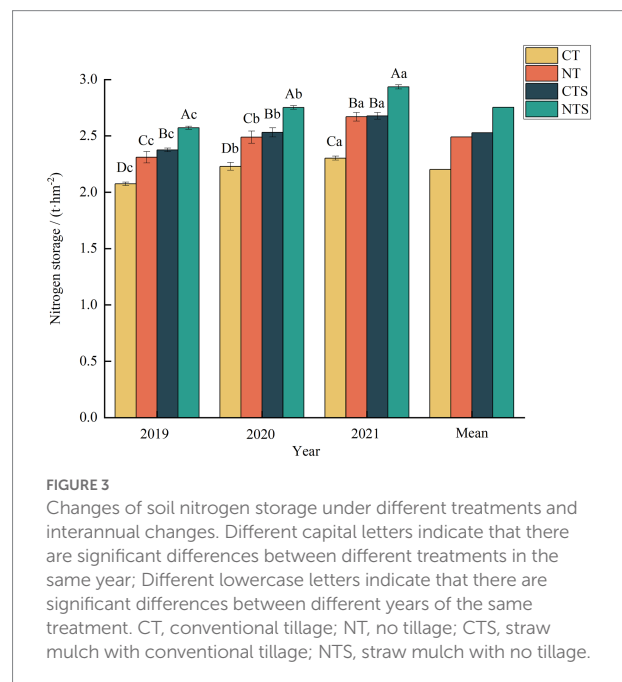

FIGURE 3
Changes of soil nitrogen storage under different treatments and interannual changes. Different capital letters indicate that there are significant differences between different treatments in the same year; Different lowercase letters indicate that there are significant differences between different years of the same treatment. CT, conventional tillage; NT, no tillage; CTS, straw mulch with conventional tillage; NTS, straw mulch with no tillage.

The two-way ANOVA showed (Table 4) that the interannual change and different tillage treatments had an extremely significant impact on the content of soil NO$_3^-$-N ($p < 0.01$), and the mutual coupling between them had a significant impact on the content of soil NO$_3^-$-N ($p < 0.05$). Similarly, the interannual change and different tillage treatments also have extremely significant effects on the content of soil NH$_4^+$-N ($p < 0.01$), inversely the interaction between them has no significant effect on the content of soil NH$_4^+$-N. Simultaneously, the interannual change and different tillage treatments have extremely significant effects on soil TN ($p < 0.01$), and the interaction between them has a significant impact on soil TN ($p < 0.05$). Additionally, the interannual change, different tillage treatments and their mutual

TABLE 4 Two way ANOVA of year and treatments (NO_3^--N, NH_4^+-N, TN, MBN, nitrogen storage, SOC, EOC, MBC, C/N and Carbon storage).

Analysis of variance (ANOVA)										
	NO_3^--N	NH_4^+-N	TN	MBN	Nitrogen storage	SOC	EOC	MBC	C/N	Carbon storage
Source of variation										
Year	13.636**	44.294**	1918.037**	1592.065**	1140.854**	2829.239**	72.738**	2829.239**	25.275**	2206.400**
Treatment	55.961**	47.306**	2591.018**	2150.673**	1784.381**	1725.500**	288.286**	1725.500**	132.742**	1901.704**
(Y × T)	2.605*	1.882^{ns}	4.617*	3.832**	13.201**	75.056**	17.152**	75.056**	22.099**	89.550**

**indicates that the effect is extremely significant (p value < 0.01), *indicates that the effect is significant (p value < 0.05) and ns indicates non-significant. NO_3^--N, nitrate nitrogen; NH_4^+-N, ammoniacal nitrogen; TN, total nitrogen; MBN, microbial biomass nitrogen; SOC, soil organic carbon; EOC, easily oxidized organic carbon; MBC, microbial biomass carbon; C/N, total nitrogen/organic carbon.

TABLE 5 Carbon contents under sustainable conservation tillage.

Year	Treatment	SOC (g/kg)	EOC (mg/kg)	MBC (mg/kg)	C/N
2019	CT	6.39 ± 0.01 Dc	1.30 ± 0.026 Cab	191.59 ± 0.36 Dc	10.70 ± 0.02 Aa
	NT	6.69 ± 0.02 Cc	1.47 ± 0.002 Bc	200.79 ± 0.74 Cc	10.41 ± 0.07 Bab
	CTS	6.81 ± 0.03 Bc	1.51 ± 0.007 Bc	204.40 ± 0.75 Bc	10.12 ± 0.02 Cb
	NTS	7.09 ± 0.02 Ac	1.72 ± 0.023 Ac	212.69 ± 0.68 Ac	9.89 ± 0.06 Db
2020	CT	6.63 ± 0.01 Db	1.39 ± 0.025 Da	198.83 ± 0.36 Db	10.37 ± 0.02 Ab
	NT	7.09 ± 0.02 Cb	1.55 ± 0.002 Cb	212.55 ± 0.74 Cb	10.37 ± 0.07 Ab
	CTS	7.21 ± 0.03 Bb	1.61 ± 0.007 Bb	216.16 ± 0.75 Bb	10.10 ± 0.02 Bb
	NTS	7.48 ± 0.02 Ab	1.86 ± 0.023 Ab	224.46 ± 0.68 Ab	9.88 ± 0.06 Cb
2021	CT	6.84 ± 0.01 Da	1.29 ± 0.026 Cb	205.23 ± 0.36 Da	10.28 ± 0.02 BCc
	NT	7.70 ± 0.02 Ca	1.69 ± 0.002 Ba	230.92 ± 0.74 Ca	10.64 ± 0.06 Aa
	CTS	7.82 ± 0.03 Ba	1.74 ± 0.004 Ba	234.53 ± 0.75 Ba	10.37 ± 0.02 Ba
	NTS	8.09 ± 0.02 Aa	1.99 ± 0.023 Aa	242.83 ± 0.68 Aa	10.15 ± 0.06 Ca

Different capital letters indicate that there are significant differences between different treatments in the same year; Different lowercase letters indicate that there are significant differences between different years of the same treatment. SOC, soil organic carbon; EOC, easily oxidized organic carbon; MBC, microbial biomass carbon; C/N, total nitrogen/organic carbon.

coupling effects have extremely significant effects on soil MBN and nitrogen storage ($p < 0.01$).

3.3. Soil carbon contents, carbon storage and C/N under tillage technique

The changes of soil carbon content and C/N are shown in Table 5. From different treatments in the same year, The SOC content of NTS, CTS and NT treatments was significantly higher than that of CT treatment, and NTS treatment was the highest. The specific performance was NTS > CTS > NT > CT. The change trends of soil EOC and MBC were consistent with SOC, which were the largest under NTS treatment and the smallest under CT treatment, and there were significant differences among treatments ($p < 0.05$). Soil C/N was the largest under CT treatment and the smallest under NTS treatment, and there was significant difference among treatments ($p < 0.05$). From different years of the same treatment, the content of soil SOC and MBC showed an increasing trend with the increase of years, and it was significantly higher in 2021 than in 2020 and 2019 ($p < 0.05$).

Soil EOC increased first and then decreased with the increase of year under CT treatment, and increased with the increase of year under NT, CTS and NTS treatment ($p < 0.05$); Soil C/N decreased with the increase of year under CT treatment, and basically increased with the increase of year under NT, CTS and NTS treatment.

The effects of different tillage measures on carbon storage in 0–30 cm soil are shown in the Figure 4. From different treatments in the same year, soil carbon storage was the largest under NTS treatment and the smallest under CT treatment, and NTS treatment was significantly higher than other treatments ($p < 0.05$), inversely there was no significant difference between NT and CTS treatment ($p > 0.05$). From different years of the same treatment, the soil carbon storage showed an increasing trend with the increase of years under different treatments. The soil carbon storage under each treatment in 2021 was significantly higher than that in 2020 and 2019 ($p < 0.05$). Additionally, during the three-year study period, the average soil carbon storage in 0–30 cm layer ranged from 23.01 to 27.47 t•hm^{-2}. Compared with CT treatment, the average soil carbon storage under NTS, CTS and NT treatment increased by 19.41, 12.15 and 13.40%, respectively (Figure 4).

The two-way ANOVA showed (Table 4) that the interannual changes, different tillage treatments and their coupling effects had extremely significant effects on soil SOC, EOC, MBC, C/N and carbon storage ($p < 0.01$).

3.4. Soil carbon pool management index as influenced by tillage under wheat agroecosystems

The management index of 0–30 cm soil carbon pool under sustainable conservation tillage is shown in the Table 6. In this
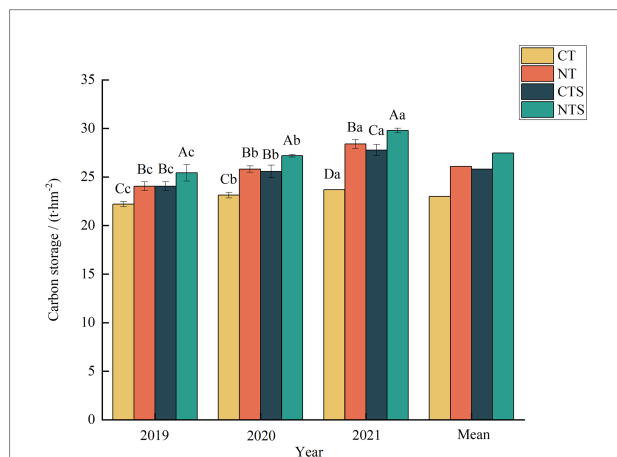
FIGURE 4
Effects of different tillage measures on soil carbon storage. Different capital letters indicate that there are significant differences between different treatments in the same year; Different lowercase letters indicate that there are significant differences between different years of the same treatment. CT, conventional tillage; NT, no tillage; CTS, straw mulch with conventional tillage; NTS, straw mulch with no tillage.

study, the soil under traditional tillage (CT) treatment is set as the reference soil. From different treatments in the same year, the soil carbon pool index of 0–30 cm of spring wheat showed the same change trend, which was the largest under NTS treatment and the smallest under CT treatment ($p < 0.05$). The change trend of soil carbon pool activity was consistent with that of soil carbon pool, which was the largest under NTS treatment and the smallest under CT treatment, and there was significant difference among treatments ($p < 0.05$). Soil carbon pool activity index and CPMI also showed the same change trend. Conservation tillage treatment (NT, CTS and NTS) was significantly higher than traditional tillage (CT), and NTS treatment was significantly higher than other treatments ($p < 0.05$). From different years of the same treatment, the soil carbon pool under the three-conservation tillage showed an increasing trend with the increase of years, and there was a significant difference between years ($p < 0.05$). Soil carbon pool activity increased first and then decreased with the increase of years under CT treatment, and increased slightly under NT, CTS and NTS treatment, inversely the difference between years was not significant ($p > 0.05$). Soil carbon pool activity index and CPMI showed the same trend with the interannual change. Under NT and CTS treatment, they decreased first and then increased with the increase of years, while under NTS treatment, they increased gradually with the increase of years, and there were significant differences between years ($p < 0.05$).
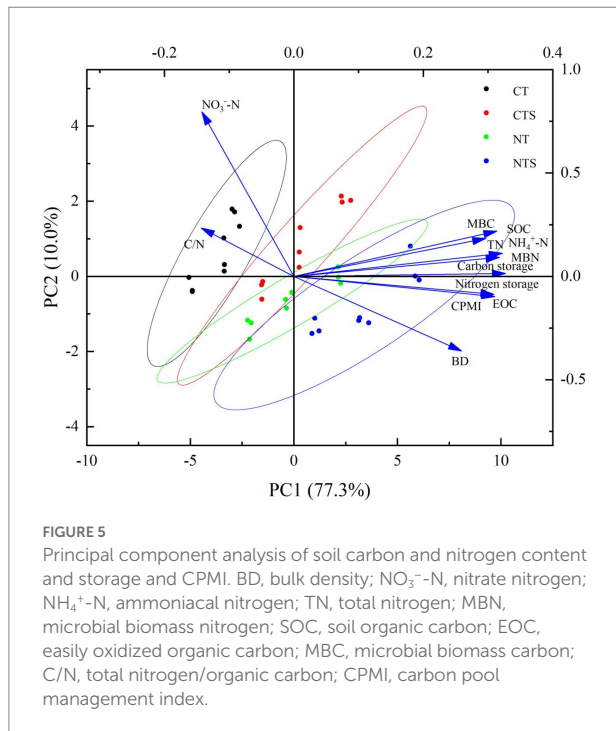
3.5. Correlation between soil nitrogen and carbon contents, storage and carbon pool management index

The correlation among soil carbon and nitrogen pool, carbon and nitrogen storage and CPMI under sustainable conservation

TABLE 6 Soil carbon pool management index of 0–30cm under conservation tillage.

Year	Treatment	Carbon pool index	Carbon pool activity	Carbon pool activity index	Carbon pool management index
2019	CT	1.00 ± 0.000 D	0.26 ± 0.007 Ca	1.00 ± 0.000\u00B0C	100.00 ± 0.00\u00B0C
	NT	1.05 ± 0.006 Cc	0.28 ± 0.001 Ba	1.10 ± 0.054 Bb	115.28 ± 2.78 Bb
	CTS	1.07 ± 0.006 Bc	0.28 ± 0.003 Ba	1.11 ± 0.067 Bab	118.77 ± 3.68 Bb
	NTS	1.11 ± 0.006 Ac	0.32 ± 0.005 Aa	1.25 ± 0.026 Ab	139.26 ± 1.17 Ab
2020	CT	1.00 ± 0.000 D	0.26 ± 0.007 Ca	1.00 ± 0.000\u00B0C	100.00 ± 0.00\u00B0C
	NT	1.07 ± 0.006 Cb	0.28 ± 0.001 Bb	1.05 ± 0.028 BCb	112.66 ± 2.50 Bb
	CTS	1.09 ± 0.006 Bb	0.29 ± 0.003 Ba	1.08 ± 0.036 Bb	117.81 ± 3.41 Bb
	NTS	1.13 ± 0.005 Ab	0.33 ± 0.004 Aa	1.25 ± 0.014 Ab	140.97 ± 1.07 Ab
2021	CT	1.00 ± 0.000 D	0.23 ± 0.006 Cb	1.00 ± 0.000\u00B0C	100.00 ± 0.00\u00B0C
	NT	1.13 ± 0.006 Ca	0.28 ± 0.001 Bab	1.21 ± 0.033 Ba	135.87 ± 3.23 Ba
	CTS	1.14 ± 0.006 Ba	0.29 ± 0.001 Ba	1.23 ± 0.038 Ba	140.67 ± 3.85 Ba
	NTS	1.18 ± 0.005 Aa	0.33 ± 0.004 Aa	1.40 ± 0.019 Aa	166.17 ± 1.68 Aa

Different capital letters indicate that there are significant differences between different treatments in the same year; Different lowercase letters indicate that there are significant differences between different years of the same treatment.

FIGURE 5
Principal component analysis of soil carbon and nitrogen content and storage and CPMI. BD, bulk density; NO$_3^-$-N, nitrate nitrogen; NH$_4^+$-N, ammoniacal nitrogen; TN, total nitrogen; MBN, microbial biomass nitrogen; SOC, soil organic carbon; EOC, easily oxidized organic carbon; MBC, microbial biomass carbon; C/N, total nitrogen/organic carbon; CPMI, carbon pool management index.

FIGURE 6
Correlation between soil carbon and nitrogen content and storage and CPMI. *Indicates signifcant at 0.05 level, **indicates signifcant at 0.01 level, ***indicates signifcant at 0.001 level. BD, bulk density; NO$_3^-$-N, nitrate nitrogen; NH$_4^+$-N, ammoniacal nitrogen; TN, total nitrogen; MBN, microbial biomass nitrogen; SOC, soil organic carbon; EOC, easily oxidized organic carbon; MBC, microbial biomass carbon; C/N, total nitrogen/organic carbon; CPMI, carbon pool management index.

tillage is shown in Figures 5, 6. Figure 5 is a principal component analysis chart. The horizontal axis interpretation rate is 77.3% and the vertical axis interpretation rate is 10.0%. It can be seen that the correlation is mainly determined by the horizontal axis. Meanwhile, Figure 6 shows that there is a very significant positive correlation between soil BD and CPMI, the correlation coefficient is 0.73, NO$_3^-$-N and CPMI have a significant negative correlation, the correlation coefficient is −0.49, NH$_4^+$-N, TN, and MBN, CPMI have a very significant positive correlation, and the correlation coefficients are 0.80, 0.91 and 0.91, respectively. SOC, EOC, MBC and CPMI showed very significant positive correlation, and the correlation coefficients were 0.87, 0.92 and 0.87, respectively. Whereas, there was a significant negative correlation between soil C/N and CPMI, and the correlation coefficient was −0.43. At the same time, soil carbon and nitrogen storages had a very significant positive correlation with CPMI, and the correlation coefficients were 0.89 and 0.92, respectively.

4. Discussion

4.1. Effects of sustainable conservation tillage on soil nitrogen composition and nitrogen storage

Different tillage treatments have an important impact on soil nitrogen contents and pools (Andrea et al., 2020; Wang W. Y. et al., 2021). The results show that conservation tillage can change the contents of NH$_4^+$-N, TN, MBN and NS. Other studies have shown that conservation tillage can improve soil nitrogen contents and nitrogen storage and reduce soil nitrogen loss in the dry farming
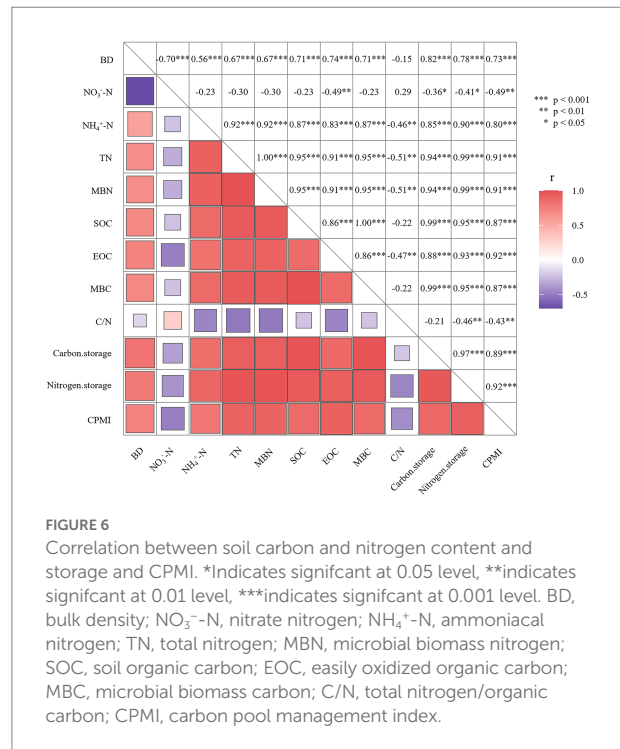
area of the Loess Plateau (Hao et al., 2021). This study found that compared with traditional tillage, conservation tillage significantly reduced the content of soil NO$_3^-$-N, which was the smallest under NTS treatment. With the increase of conservation tillage years, the content of soil NO$_3^-$-N continued to decrease, inversely the content of soil NO$_3^-$-N under traditional tillage treatment continued to increase with the increase of years. This may be because sustainable traditional farming has seriously damaged the structure of the soil arable layer. The soil nutrients in the plow layer are lost, the water content is reduced, the soil aeration is enhanced (Han et al., 2018), and then the nitrification of the soil is enhanced (Zhang et al., 2018). NH$_4^+$-N is more easily converted to NO3-N in this case, which leads to an increase in the residual NO$_3^-$-N content in the soil. Additionally, under conventional tillage, spring wheat has weak growth, poor rhizosphere development and weak ability to absorb nutrients from the soil, which also leads to the residue of NO$_3^-$-N in the soil (Yang et al., 2015). Nevertheless, the soil under conservation tillage treatment is compact, the wheat grows vigorously, and the root system is developed. The NO$_3^-$-N in the soil is not easy to be leached to the lower layer, instead, it is widely absorbed and utilized by crop roots. Additionally, conservation tillage plays a good role in water and fertilizer conservation, accordingly inhibiting the role of soil nitrification and reducing the content of NO$_3^-$-N in the soil (Wang et al., 2020). This study also found that compared with traditional tillage, conservation tillage significantly increased the contents of soil TN, NH$_4^+$-N and MBN showed an increasing trend with the increase of conservation tillage years. This is because the reduction of tillage intensity reduces the disturbance to the soil and promotes the activity of soil microorganisms, so as to transfer more nitrogen

from crop straw to the soil. Additionally, sustainable conservation tillage increases the compactness of the soil and contributes to the retention of soil nitrogen. On the other hand, the covered straw will continuously decompose and transport nitrogen to the soil. Consequently, conservation tillage increases soil TN Content of MBN. For NH_4^+-N, on the one hand, it is because soil NH_4^+-N mainly comes from TN mineralization, and straw mulching will significantly increase soil TN content. On the other hand, no tillage increases soil mineralization and reduces soil nitrification (Melero et al., 2011). Consequently, under no tillage treatment, N element exists in the form of NH_4^+-N for a long time. As a result, it is concluded that conservation tillage can prevent nitrogen leaching and then increase soil NH_4^+-N content (Issaka et al., 2019).

It is generally believed that conservation tillage such as no tillage and straw mulching is beneficial to improve soil nitrogen storage, which is mainly reflected in the upper soil (Rahmat et al., 2012). This may be due to the different disturbance of different tillage measures to the soil, resulting in different soil structure and ventilation, affecting the micro biological activity in the soil, then affecting the mineralization rate of soil nitrogen, and finally affecting the soil nitrogen storage (Du et al., 2010). This study found that different tillage measures had different effects on 0–30 cm soil nitrogen storage. The soil nitrogen storage under sustainable conservation tillage was significantly higher over conventional tillage. The soil nitrogen storage under NTS, CTS and NT systems was significantly highest in the second and third years of the study compared with first year of study period. This is because no tillage and straw returning can improve soil structure, improve soil physical and chemical properties, promote soil microbial activity, and effectively add soil nitrogen sources, so as to increase soil nitrogen storage in long term application. Analogously, sustainable conservation tillage will increase soil compactness and further increase soil nitrogen fixation capacity, The stable growth of soil nitrogen content in straw returning treatment is more conducive to the improvement of soil long-term nitrogen fixation capacity and the sustainable development of agricultural ecosystem (Carter, 2004). The small increase of soil nitrogen storage under traditional tillage may be due to the application of base fertilizer.

4.2. Effects of sustainable conservation tillage on soil carbon composition and carbon storage

Soil carbon component is an extremely important part of soil and an important factor to measure soil fertility, and soil carbon storage is an important index to evaluate soil carbon pool. The research shows that conservation tillage, mainly with straw mulching and no tillage and less tillage, can increase soil carbon and nitrogen storages, reduce soil carbon and nitrogen nutrient loss, and accordingly improve crop productivity (Lu et al., 2018).

Wang et al. (2019) showed in their research on dryland corn that conservation tillage based on less tillage plus stubble and no tillage plus stubble increased the carbon content in the soil and was conducive to the retention of soil aggregates and SOC in dryland. Peeyush et al. (2016) reviewed the impact of conservation tillage on soil physical and chemical properties and organic carbon pool. He said that in the long-term experiment, farmland can increase soil organic carbon through conservation tillage, and greatly improve the physical and chemical properties of the soil tilth. Intensive tillage brings crop residues into the soil, destroys soil aggregates, increases soil aeration, and is not conducive to soil nutrient sequestration and crop growth. Our findings from this study found that compared with traditional tillage, sustainable conservation tillage increased the content of SOC, EOC and MBC in 0–30 cm soil and decreased C/N. with the continuous progress of conservation tillage, the content of SOC, EOC, MBC and C/N in soil showed an increasing trend, which was consistent with the research results of Shu et al. (2015) and Asma et al. (2015). This is because SOC is the dominant factor controlling the cycle of soil energy and nutrients, the source of stable energy and nutrients of microbial community, and has an important impact on the formation of soil microbial biomass. Consequently, the higher the content of SOC, the greater the soil MBC. Conservation tillage with no tillage and straw returning as the main measures avoids the disturbance to the soil, accordingly enhancing the aggregation of soil particles, effectively reducing nutrient loss and increasing soil carbon and nitrogen sequestration. Additionally, in the wheat growth stage, the straw covered on the surface will decompose under the action of microbial decomposition, and part of the organic matter will enter the soil surface, so as to increase the soil SOC content (Kushwa et al., 2016). Simultaneously, conservation tillage, mainly with no tillage and straw mulch, reduced the evaporation of water in the soil, increase the soil water storage and enhance the soil microbial activity, so as to enhance the decomposition of decomposers, and then increase the soil MBC content. Soil EOC is easily oxidized and decomposed, and directly participates in the process of soil biochemical transformation. The higher its content, the greater the activity of soil carbon. This study shows that the EOC content of NTS and CTS treatment is significantly higher than that of NT and CT treatment. This is because a large amount of straw on the surface is very easy to decompose and form an obvious litter layer on the surface. The high input of exogenous carbon is conducive to the growth of roots, which changes the quantity and chemical composition of root exudates, affects the functional groups and quantity of soil organisms, and significantly increases the content of soil EOC (Sun et al., 2013). Under sustainable conservation tillage, Due to the continuous decomposition of straw mulching and the input of carbon into the soil, the content of soil carbon components increased continuously (Wang et al., 2022).

Soil carbon storage is the carbon retention in ecosystem and an important index to measure the scale and quantity of primary productivity of ecosystem. Studies have shown that no tillage and

straw returning can significantly increase the content of soil organic carbon in the crop plow layer, so as to improve the soil carbon storage (Chen et al., 2015). Another study shows that soil carbon storage does not always increase after sustainable conservation tillage. This study found that compared with traditional tillage, conservation tillage was more helpful to improve the soil carbon storage of 0–30 cm, and the soil carbon storage showed an increasing trend with the increase of conservation tillage years. This may be because no tillage reduces the disturbance to the soil and slows down the mineralization and decomposition of soil organic matter. Additionally, since 2018, straw has been returned to the field to cover the surface, increasing the input of soil organic matter. With time, organic matter eventually enters the soil and accumulates. Nevertheless, traditional tillage is easy to lead to the fragmentation of soil aggregates and the loss of oxidized organic carbon mineralization (Lenka et al., 2015), at the same time, after the crops are harvested, the straw residues are basically removed, and the soil cannot obtain organic matter in time, resulting in the decline of soil quality. The study also found that single no tillage and single straw returning can significantly improve the soil carbon storage and carbon sequestration potential, nonetheless the combination of tillage method and straw returning can achieve better carbon sequestration effect (Liu et al., 2022).

4.3. Carbon pool management index and its correlation under sustainable conservation tillage

Carbon pool management index can indicate the dynamic changes of soil organic carbon and its active components. Affected by soil carbon pool and carbon pool activity, CPMI can reflect the differences of soil quality under different soil environmental conditions and the changes of soil quality under different tillage measures from the perspective of organic carbon pool (Yang et al., 2018), the increase of this index indicates the increase of soil fertility, otherwise it indicates the decrease of soil fertility (Liu et al., 2017). This study found that taking the soil under traditional tillage treatment as the reference soil sample, conservation tillage increased the A, AI, CPI and CPMI of 0–30 cm soil, and the CPMI increased continuously under sustainable conservation tillage. This is mainly because compared with sustainable traditional tillage, sustainable no tillage and straw mulching are conducive to the improvement of soil quality. The increase of CPMI of sustainable no tillage is mainly achieved by increasing the content of soil organic carbon and increasing the activity of soil organic carbon. Nevertheless, straw mulching in successive years increases the amount of straw input into the soil and the rate of soil carbon sequestration is large (Zhu et al., 2015). On the other hand, there is a steady stream of straw decomposed through decomposition, consequently, more organic carbon remains in the soil, which increases the soil CPMI. Consequently, no tillage straw mulching

(NTS) treatment has the best effect on soil carbon and nitrogen fixation, which is helpful to improve soil CPMI (Li et al., 2015).

A large number of studies have shown that soil carbon and nitrogen are important factors affecting CPMI, and their content and existing form directly affect the stability of CPMI. Some studies have also shown that soil bulk density, water and other factors are also important indicators affecting CPMI. The increase of CPMI indicates that the management mode has the effect of fertilizing the soil and the soil is developing healthily. In this study, there is a very significant positive correlation between soil bulk density and CPMI (0.73), because the increase of bulk density means the increase of soil compactness, which promotes the formation of soil aggregates, is conducive to the fixation of organic carbon, and then increases the CPMI. Soil TN, NH_4^+-N, MBN and nitrogen storage have a very significant positive correlation with CPMI. This is because the growth and decline trend of carbon and nitrogen in soil is basically the same. Conservation tillage based on no tillage and straw mulching increases the content of carbon and nitrogen in soil, accordingly increasing the content of soil nitrogen components and CPMI. Nevertheless, soil NO_3^--N content has a significant negative correlation with CPMI (-0.49), which is because conservation tillage increases the diffusion rate of soil water, resulting in soil NO_3^--N leaching. On the other hand, under conservation tillage, crops grow vigorously, their roots are developed, and they have a strong ability to absorb nutrients into the soil. NO_3^--N in the form of inorganic nitrogen will be absorbed and utilized by crops. Additionally, soil SOC, EOC, MBC and carbon storage have a very significant positive correlation with CPMI, indicating that EOC and MBC have a close relationship with total organic carbon (Yang J. M. et al., 2014). They largely depend on the content of total organic carbon, and the content of these carbon components determines the soil carbon storage, indicates the change of soil quality, and then reflects the CPI and stability. This result is consistent with the research conclusions of Jiang et al. (2021) and Liu et al. (2017).

5. Conclusion

Through the study on the carbon and nitrogen components, storages and CPMI of 0–30 cm soil in wheat field under different tillage measures for many years, this study provides a basis for the response mechanism of soil carbon and nitrogen storages and carbon pool of spring wheat on the Loess Plateau to different tillage measures. The results showed that compared with conventional tillage, sustainable conservation tillage significantly increased soil bulk density. Additionally, sustainable conservation tillage decreased the content of soil NO_3^--N, inversely significantly increased the contents of soil NH_4^+-N, TN and MBN. Simultaneously, sustainable conservation tillage also significantly increased the contents of

soil SOC, EOC and MBC. Our results also showed that compared with conventional tillage, sustainable conservation tillage increased soil carbon and nitrogen storages, soil carbon pool index, carbon pool activity and carbon pool activity index, and then improved soil CPMI, especially NTS treatment. The correlation shows that there is a significant correlation between soil bulk density, carbon, nitrogen components and storages and CPMI, indicating that soil physical and chemical properties and carbon and nitrogen content determine the stability of carbon pool. In summary, we conclude that conservation tillage can improve soil physical and chemical properties, fertilize soil and significantly improve soil carbon and nitrogen storages. NTS treatment is more conducive to soil carbon and nitrogen accumulation, soil carbon pool activity and CPMI, which can be used as an agricultural tillage measure worthy of popularization in the study area.

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 authors.

Author contributions

JY: data processing, methodology, visualization, and writing – original draft. YL and MZ: data processing. MS: English revision. LL and JW: investigation. GX and SL: sample collection and experimental operation. GL and LY: design test, supervision, and funding acquisition. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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