Effects of organic fertilizers on organic carbon accumulation in alkalized saline soil and silage maize yield

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Abstract: To understand the combined effect of organic and chemical fertilizers on soil carbon emissions and carbon balance of a farmland ecosystem, this study investigated the organic fertilizer nitrogen replacing different proportions of chemical fertilizer nitrogen. The results showed that, compared to F_{100}, the $O_{15}F_{85}$ treatment increased the yield and net ecosystem productivity carbon sequestration of silage maize under mild, moderate, and severe salinization levels, as well as the contents of soil organic carbon, microbial carbon, and humin carbon, while reducing plant carbon emissions. The $O_{15}F_{85}$ treatment did not significantly increase soil carbon emissions (CEC), but $O_{30}F_{70}$, $O_{45}F_{55}$ and O_{100} treatments significantly increased CEC. The soil carbon balance analysis showed that the farmland ecosystem was a "sink" for atmospheric CO_2 under each treatment. The $O_{15}F_{85}$ treatment produced an "excitation effect" to enhance the carbon sink effect of silage maize farmland under mild, moderate and severe salinization levels while maintaining stable production and emissions. Although the O_{100} treatment increased the carbon sink of farmland under different salinization levels, the yield was significantly reduced and did not represent practical production levels. Correlation analysis showed that soil organic carbon components and ecosystem carbon balance were closely related to soil total salt, pH and bulk density, while soil dissolved organic carbon, humus carbon components and carbon emissions were closely related to soil moisture and temperature. Therefore, the purpose of improving the carbon sink of saline-alkali land can be achieved through soil salt inhibition, soil structure remodeling and water supplement and warming regulation, which provides technical and theoretical support for reducing carbon emissions, achieving carbon neutrality and alleviating global warming.

Keywords: carbon balance, carbon component, organic carbon, organic substitution, saline-alkali land
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1 Introduction

With the transformation of the main contradictions of socialism with Chinese characteristics, people pursue a higher quality of life, which has led to a rapid development of the dairy industry. In Ningxia, in northwest inland China, the scale of dairy farming has gradually increased in recent years, but represents only a small area, with the total cultivated area only accounting for 24.84% of the total area of Ningxia. The cultivated land available for forage planting is limited, and the mismatch between the rapid development of dairy farming and the supply of forage grass is prominent[1]. At the same time, the area of salinized farmland accounts for 66.46% of the Yellow River irrigation area of Ningxia, among which the area of moderately saline-alkali land is 4.9×10^4 hm^2 and severely saline-alkali is 4.8×10^4 hm^2[2]. Therefore, appropriate development and utilization of saline-alkali land will provide strong support for the sustainable development of advantageous and characteristic industries, the ecological protection of the Yellow River Basin and the construction of high-quality development pilot areas.

The low organic matter content in saline-alkali soil is the main factor leading to its low productivity[3]. As an important part of organic matter, increasing soil total organic carbon (TOC) storage has multiple positive effects on maintaining the sustainable development of agriculture, maintaining ecosystem balance and mitigating climate change. Among many agricultural management measures, the application of organic fertilizer has a significant effect on the soil carbon pool. Many studies have shown that the application of organic fertilizer is an economic and environmental measure to maintain or improve soil fertility and crop productivity[4]. The application of organic fertilizer can significantly increase the soil TOC content, reduce carbon loss and offset the decrease of soil TOC content caused by continuous excessive application of chemical fertilizers[5]. In addition, the combined application of organic and chemical fertilizers can significantly increase soil surface carbon storage and improve soil carbon sequestration potential, which is an important way to increase soil TOC storage in farmland[6,7]. Furthermore, the change of soil TOC is closely related

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to its humus composition. As part of humus, humic acid (HA) is crucial to the formation of soil structure, while fulvic acid (FA) directly affects microbial activity and participates in the transformation, migration and degradation of organic and inorganic substances in soil, which has a positive effect on soil fertility[8].

To sum up, organic fertilizer plays an important role in the carbon pool in the soil ecosystem. but crop growth is inseparable from the supply of chemical fertilizer. Therefore, three scientific hypotheses have been proposed: 1) The replacement of chemical fertilizer with different proportions of organic fertilizer can impact the carbon emissions and carbon balance of the soil ecosystem; 2) the extent of salinization will influence the proportion of organic fertilizer substitution; 3) Soil water, salt, gas, and heat all have an impact on the soil carbon balance. The aim is to identify the optimal substitution ratio that increases the soil carbon sink without compromising yield, and the results will provide a practical and theoretical guide on sustainable agricultural activities and greenhouse gas emissions.

2 Materials and methods

2.1 Field experiment

2.1.1 Experiment site

A field experiment of replacing chemical fertilizer nitrogen with organic fertilizer nitrogen was established over two seasonal freeze-thaw periods from 2021 to 2022 in Baofeng Village (106.7332°E, 39.0606°N), Pingluo County, Ningxia (Figure 1). The area has four distinct seasons and a continental climate. It is dry, rainy and windy all year round. In recent years, the average annual rainfall in the region is less than 200 mm, evaporation is close to 1800 mm, and prevailing northwest winds have an average wind speed of 2 m/s. The average annual sunshine hour is 3009 h, the average frost period is 195 d and the frost-free period is 171 d. The landform is alluvial plain with low-lying terrain. The soil types of the test site are mild, moderate and severe salinized soil. The cultivated land area of the soil salt content level accounts for 63.50% of the cultivated land area of Shizuishan City, Ningxia. The background value of the basic soil sample showed that, according to the international standard of soil mechanical composition, the soil texture is silty loam. The soil pH value was 8.23-8.75, which was alkaline to strongly alkaline. The total salt content was 1.12-6.02 g/kg, and was divided into three different salinization levels: mild, moderate and severe. Analysis of soil salt composition showed that the main cation was Na^+, accounting for 33.63% of the total salt content on average, and the main anions were SO_4^{2-} and Cl^-, accounting for 22.53% and 26.21%, respectively, indicating a chloride-sulfate saline soil. The second census classification of soil in China showed that the contents of organic matter and available nitrogen were at a low level of grades 4 and 5, respectively, available phosphorus was at a medium level of grade 3 and available potassium was at a rich level of grade 2. The basic physical and chemical properties of the tested soil are listed in Tables 1 and 2.

a. Experiment site of organic fertilizer returning to field in saline-alkali land in Baofeng Village, Pingluo County, Ningxia

b. The fertilization treatment of experimental plot

c. The aerial view of silage corn experimental planting

Figure 1 Experiment site of organic fertilizer returning to field in saline-alkali land

Table 1 Basic physical properties of soil (0-25 cm)

Salinization level	Mechanical composition/mm·%			Bulk density/ g·cm^{-3}	Field water capacity/%	Organic matter/g·kg^{-1}	Available nitrogen/mg·kg^{-1}	Available phosphorus/mg·kg^{-1}	Available potassium/mg·kg^{-1}
	Sand	Silt	Clay						
Mild	13.56	75.62	10.82	1.46	17.86	11.45	54.20	10.65	217.91
Moderate	10.67	68.76	20.57	1.47	18.65	6.89	45.54	11.54	178.78
Severe	12.12	66.54	21.34	1.55	17.03	6.24	35.54	12.54	175.32

Table 2 Basic chemical properties of soil (0-25 cm)

Salinization level	Ion composition/g·kg^{-1}								pH	Total salt/ g·kg^{-1}
	Cation				Anion					
	Ca^{2+}	Mg^{2+}	K^+	Na^+	HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}		
Mild	0.04	0.04	0.02	0.35	0.07	0.01	0.23	0.32	8.75	1.12
Moderate	0.20	0.21	0.04	1.52	0.14	0.02	1.21	0.90	8.43	4.25
Severe	0.44	0.36	0.10	2.04	0.18	0.04	1.36	1.30	8.23	6.02

2.1.2 Experimental design

This experiment was about replacing chemical fertilizer (CF) nitrogen with organic fertilizer (OF) nitrogen. the experiment was completed in September 2021 to return organic fertilizer to the field. Organic fertilizer was composted using fully decomposed cattle and sheep manure, including 2.0% total nitrogen, 0.92% total phosphorus, 0.85% total potassium and 26.68% OC. All organic fertilizers were applied to the soil at one time. In addition, based on the soil background value, all experimental plots had desulfurized gypsum (DG) and $FeSO_4$ uniformly applied, calculated according to the theoretical application amount of desulfurized waste to improve alkaline soil[9]. The severely saline experimental field had been abandoned in the previous year, and showed serious soil compaction. In-situ deep vertical rotary tillage was used to break soil compaction and improve the seedling emergence rate. The crop was silage maize “Denghai silage 3930”. According to the principle of equal nitrogen input, based on conventional fertilizer type (N-P_2O_5-K_2O=450-150-75), the experiment included five treatments: conventional fertilization (F_{100}), 15% organic fertilizer nitrogen+85% chemical fertilizer nitrogen ($O_{15}F_{85}$), 30% organic fertilizer nitrogen+70% chemical fertilizer nitrogen ($O_{30}F_{70}$), 45% organic fertilizer nitrogen+55% chemical fertilizer nitrogen ($O_{45}F_{55}$) and 100% organic fertilizer nitrogen (O_{100}). Each experiment was repeated three times, making a total of 18 plots. Chemical fertilizers were urea (46% N), calcium superphosphate (16% P_2O_5) and potassium sulfate (50% K_2O). The basal fertilizer was 40% chemical (nitrogen, phosphorus and potassium) fertilizers applied at one time, and the remaining 60% of chemical fertilizer nitrogen was applied as topdressing at the jointing and filling stages. During the whole growth period, the plots were irrigated with Yellow River water at about 5250 m^3/hm^2. The experimental design is listed in Table 3.

Table 3 Experimental design

Treatment	OF application/ kg·hm^{-2}	C_{input}/ kg·hm^{-2}	N_{input}/ kg·hm^{-2}	CF application/ kg·hm^{-2}			DG application/ kg·hm^{-2}	$FeSO_4$ application/ kg·hm^{-2}
				N	P_2O_5	K_2O		
F_{100}	0	0	0	450	150	75	7500	1500
$O_{15}F_{85}$	3375	900	68	383	150	75	7500	1500
$O_{30}F_{70}$	6750	1800	135	315	150	75	7500	1500
$O_{45}F_{55}$	10 125	2700	203	248	150	75	7500	1500
O_{100}	22 500	6003	450	0	150	75	7500	1500

2.2 Sampling and measurements

2.2.1 Soil sample collection

Soil samples were collected before and after fertilization in September of both 2021 and 2022. The sampling method was to collect five points for each plot, and sampling depth was 0-25 cm tillage layer. The soil samples for each point were mixed into one soil sample and then bagged, marked and brought back to the laboratory, where they were dried and sieved.

2.2.2 Determination of soil salt composition and nutrient content

Soil mechanical composition was determined by gravimetry and calculated using the international system. Soil bulk density was measured by ring knife method, pH was measured with a pH meter (water:soil=2.5:1), Soil electrical conductivity and water salinity were determined by a DDS-11 (Shanghai Leici, China) conductivity meter and the total salt content was deduced from the relationship between conductivity and salt concentration. Contents of Ca^{2+} and Mg^{2+} were determined by ethylene diamine tetraacetic acid (EDTA) titration, K^+ and Na^+ were determined by flame photometer, HCO_3^- and CO_3^{2-} were determined by double indicator-neutralization titration, Cl^- was determined by $AgNO_3$ titration and SO_4^{2-} was determined by EDTA indirect complexometric titration. Organic matter was determined by potassium dichromate-concentrated sulfuric acid heating method. Available nitrogen was determined by alkali solution diffusion method. Available phosphorus was determined by 0.5 mol/L sodium bicarbonate extraction-molybdenum antimony colorimetric method and available potassium was determined by 1 mol/L ammonium acetate solution extraction-flame photometer method[10].

2.2.3 Extraction and determination of soil humus carbon components

The fulvic acid (FA), humic acid (HA) and humin (HM) were extracted by humus composition modification method[11]. Soil samples (5 g) were weighed in a centrifuge tube and extracted with distilled water for 1 h at (70±2)°C. After centrifugation, the water-soluble impurities were discarded. Then a mixture of 0.1 mol/L $NaOH+Na_4P_2O_7$ was added and extracted for 1 h at (70±2)°C. The humic acids were obtained by centrifugation. The pH was adjusted to 1.0-1.5 with 0.5 mol/L H_2SO_4, and kept in a thermostatic water bath for 1-2 h at (70±2)°C. After standing overnight, the supernatant was FA and the precipitate was HA. The residue in the centrifuge tube was HM.

Contents of soil OC and HM carbon (HMC) were determined by potassium dichromate oxidation-external heating method (GB7857-87). Dissolved organic carbon (DOC) content was determined by K_2SO_4 extraction using a multi N/C 3100 analyzer (Jena, Germany). Microbial biomass carbon (MBC) content was determined by chloroform fumigation method[11,12].

2.2.4 Determination of soil CO_2 emission flux

Soil CO_2 emission rate was measured by an LI-8100A soil carbon flux automatic analyzer (Li-Cor, Lincoln, NE, USA). Two or three days before the measurement, a soil ring was evenly inserted into the soil to minimize the error of the experimental measurement caused by soil disturbance. Each treatment had three replicates and each replicate was measured three times. From 15 May 2022 to 1 September 2022, the measurements were made every 15 days. The period 08:00-11:00 in mornings with sunny weather was selected to measure the soil gas, temperature and water content.

$$CE = \sum_{i=1}^{n}\left[\frac{F_{i+1}+F_i}{2}(t_{i+1}-t_i)\times 0.1584\times 24\times 10\right] \quad (1)$$

where, CE is the soil CO_2 emission flux, kg/hm^2); F_i is the soil CO_2 emission rate measured for the first time, $\mu mol/(m^2\cdot s)$; $(t_{i+1}-t_i)$ is the interval between two consecutive measurements, d; n is the number of measurements; 0.1584×24×10 is the coefficient for converting the carbon emissions unit $\mu mol/(m^2\cdot s)$ to kg/hm^2[13].

2.2.5 Determination of plant nutrients, biomass and yield

During the harvest period of silage maize, fresh aboveground yield was measured (5 cm above the ground) for each plot. Five maize plants were taken from each plot. After cleaning the roots, they were put into a net bag, labeled and brought back to the laboratory and divided into roots, aboveground parts and grain. After being deactivated for 30 min at 105°C by air blast drying box (DHG-9023A, Shanghai Dute, China), the temperature was adjusted to 60°C and dried to constant weight, and biomass was weighed. Finally, crushed by high speed pulverizer (LFJ-20B, Guangzhou DAxiang, China) and sieved 0.25 mm, then determined its nutrient content. The plant samples were treated by H_2SO_4-H_2O_2 digestion, and total nitrogen was determined by Kjeldahl method, total phosphorus by ultraviolet spectrophotometer, total potassium by flame photometry and the total carbon was determined by a carbon analyzer apparatus (Elem entar, Vario M A X CN, Germany)[14,15].

2.2.6 Carbon balance calculation

Woodwell et al.[16] proposed net ecosystem productivity carbon (NEPC) and organic carbon input (C_{input}) to calculate soil carbon balance (SCB). A positive SCB indicates that the farmland is a “sink” for atmospheric CO_2, otherwise, it is a “source” of atmospheric CO_2. The equations are as follows:

$$SCB = NEPC + C_{input} \quad (2)$$

$$NEPC = NPPC - R_mC \quad (3)$$

$$R_mC = CEC \times 0.865 \quad (4)$$

$$\mathrm{CEC} = \mathrm{CE} \times 0.2727 \tag{5}$$

$$\mathrm{CEE} = \frac{\mathrm{CEC}}{Y} \tag{6}$$

where, the net primary productivity (NPP) (kg/hm^2) is the sum of aboveground biomass and root biomass when the maize is harvested; 0.4045 is the carbon content coefficient of the whole plant silage maize obtained by experimental determination; NPPC is the abbreviation of net primary productivity carbon, (kg/hm^2); NEPC is the abbreviation of net ecosystem productivity carbon, (kg/hm^2); R_mC is the abbreviation of carbon emission by soil microbial heterotrophic respiration, (kg/hm^2); CEC is the abbreviation of carbon emission during maize growth period (kg/hm^2)[15]; 0.865 is the conversion coefficient of soil microbial heterotrophic respiration; 0.2727 is the ratio of C to CO_2 molecular weight; CEE is the abbreviation of carbon emission efficiency on silage maize, (%) and *Y* is the abbreviation of silage maize yield, (kg/hm^2).

2.3 Data analysis and processing

The experimental data were collated using Excel 2003 software. At the same time, SPSS 17.0 software was used to obtain statistical eigenvalues, data analysis and Pearson correlation analysis. Analysis of variance and least significant test were used to test the significance of data difference ($p<0.05$, $n=5$), and Origin 9.0 software was used for drawing.

3 Results

3.1 Effects of organic nitrogen replacing chemical fertilizer nitrogen on soil water and heat status and physical and chemical factors

Replacing chemical fertilizer nitrogen with organic nitrogen had positive effects on the water and heat conditions and physical and chemical factors during the growth period (Table 4). For the mild salinization level, the soil total salt content of the $O_{15}F_{85}$ treatment was 17.09% lower than for F_{100} treatment. There were no significant differences in soil total salt content among the $O_{45}F_{55}$, O_{100} and F_{100} treatments ($p>0.05$). There was no significant difference in soil total salt content under moderate and severe salinization levels ($p>0.05$). Compared with F_{100} treatment, the $O_{15}F_{85}$ treatment reduced the soil total salt content overall, while the soil total salt content under O_{100} treatment had an increasing trend. The reason may be that the organic fertilizer itself contained salt. Although organic fertilizer plays an important role in improving soil structure and accelerating salt leaching, high amounts of organic fertilizer can introduce salt stress, and salt accumulation ability is stronger than salt discharge ability. Compared with the $O_{15}F_{85}$ treatment, the salt content of the O_{100} treatment was increased by 19.58%. Therefore, high amount of organic fertilizer returned to the field may easily increase the salt content in short-term.

Table 4 Effects of substituting organic fertilizer nitrogen for chemical fertilizer nitrogen on soil hydrothermal status and physicochemical factors during growth period

Salinization level	Treatment	Total salt/g·kg^{-1}	pH	Bulk density/g·cm^{-3}	Moisture content/%	Ground temperature/°C
Mild	F_{100}	1.17 ± 0.19^{a}	8.37 ± 0.04^{a}	1.45 ± 0.01^{a}	12.96 ± 0.51^{b}	19.80 ± 0.17^{c}
	$O_{15}F_{85}$	0.97 ± 0.10^{b}	8.34 ± 0.10^{a}	1.44 ± 0.01^{ab}	13.69 ± 0.16^{ab}	20.50 ± 0.12^{b}
	$O_{30}F_{70}$	0.99 ± 0.03^{b}	8.33 ± 0.04^{a}	1.43 ± 0.01^{b}	13.55 ± 0.14^{ab}	20.30 ± 0.00^{b}
	$O_{45}F_{55}$	1.12 ± 0.14^{a}	8.32 ± 0.02^{a}	1.42 ± 0.00^{bc}	14.38 ± 0.83^{ab}	20.93 ± 0.15^{a}
	O_{100}	1.16 ± 0.12^{a}	8.29 ± 0.06^{a}	1.41 ± 0.00^{c}	14.67 ± 0.41^{a}	21.10 ± 0.17^{a}
Moderate	F_{100}	4.27 ± 0.26^{a}	8.43 ± 0.09^{a}	1.47 ± 0.00^{a}	13.13 ± 0.40^{b}	19.40 ± 0.06^{c}
	$O_{15}F_{85}$	3.98 ± 0.01^{a}	8.41 ± 0.10^{a}	1.46 ± 0.01^{ab}	15.15 ± 0.70^{a}	19.60 ± 0.06^{c}
	$O_{30}F_{70}$	4.19 ± 0.34^{a}	8.42 ± 0.05^{a}	1.45 ± 0.00^{b}	14.67 ± 0.53^{a}	19.47 ± 0.15^{c}
	$O_{45}F_{55}$	4.13 ± 0.42^{a}	8.41 ± 0.04^{a}	1.45 ± 0.01^{b}	15.16 ± 0.30^{a}	20.13 ± 0.03^{b}
	O_{100}	4.26 ± 0.25^{a}	8.48 ± 0.04^{a}	1.43 ± 0.01^{c}	14.78 ± 0.33^{a}	20.47 ± 0.09^{a}
Severe	F_{100}	5.05 ± 0.14^{a}	8.53 ± 0.08^{a}	1.54 ± 0.01^{a}	13.91 ± 0.67^{a}	19.10 ± 0.00^{c}
	$O_{15}F_{85}$	4.74 ± 0.62^{a}	8.56 ± 0.02^{a}	1.50 ± 0.01^{b}	14.44 ± 0.81^{a}	19.40 ± 0.06^{b}
	$O_{30}F_{70}$	4.80 ± 0.32^{a}	8.49 ± 0.08^{a}	1.51 ± 0.01^{b}	15.03 ± 0.10^{a}	20.07 ± 0.03^{a}
	$O_{45}F_{55}$	4.82 ± 0.17^{a}	8.42 ± 0.08^{ab}	1.49 ± 0.01^{c}	14.70 ± 0.62^{a}	20.07 ± 0.03^{a}
	O_{100}	5.27 ± 0.33^{a}	8.37 ± 0.11^{b}	1.49 ± 0.00^{c}	14.91 ± 1.24^{a}	20.20 ± 0.06^{a}

Note: different lowercase letters in the same column indicate significant difference at $p<0.05$, the same as below.

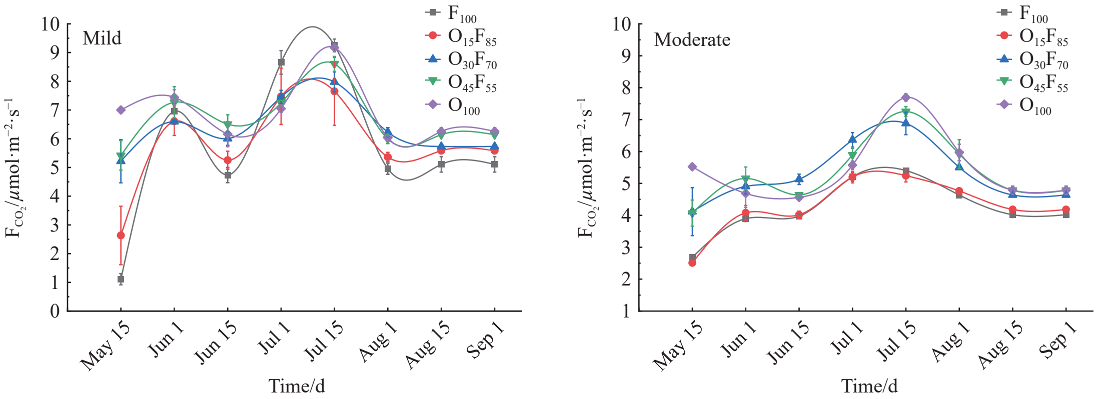
There was no significant difference in soil pH among treatments for the moderate and severe salinization levels ($p>0.05$). For severe salinization level, soil pH was lowest under the O_{100} treatment, significantly lower by 1.87% compared with F_{100} treatment. Bulk density indicates the level of soil compaction, and there were significant differences in bulk density under each treatment ($p<0.05$). Overall, replacing chemical fertilizer nitrogen with organic nitrogen reduced soil bulk density to varying degrees compared with the F_{100} treatment. Among them, the O_{100} treatment had the largest decrease compared with F_{100} treatment, and the decreases for mild, moderate and severe salinization levels were 2.07%, 2.72% and 3.25%, respectively. Compared with F_{100} treatment, the O_{100}, $O_{45}F_{55}$ and $O_{30}F_{70}$ treatments can increase the soil water content for mild, moderate and severe salinization level, respectively.

There were significant differences in soil temperature among treatments ($p<0.05$). Replacing chemical fertilizer nitrogen with organic nitrogen significantly increased soil temperature for mild salinization level. The O_{100} treatment increased temperature by 1.3°C compared with F_{100} treatment. For moderate salinization level, soil temperature was highest for the O_{100} treatment, followed by $O_{45}F_{55}$ treatment. For severe salinization level, the $O_{15}F_{85}$ treatment significantly increased soil temperature by 0.3°C, the treatment of $O_{30}F_{70}$ and $O_{45}F_{55}$ by 0.97°C. Compared with F_{100} treatment, soil temperature under the O_{100} treatment increased significantly by 1.1°C. Thus, the use of organic fertilizer significantly raised soil temperature.

3.2 Effects of organic nitrogen replacing chemical fertilizer nitrogen on carbon emission rate

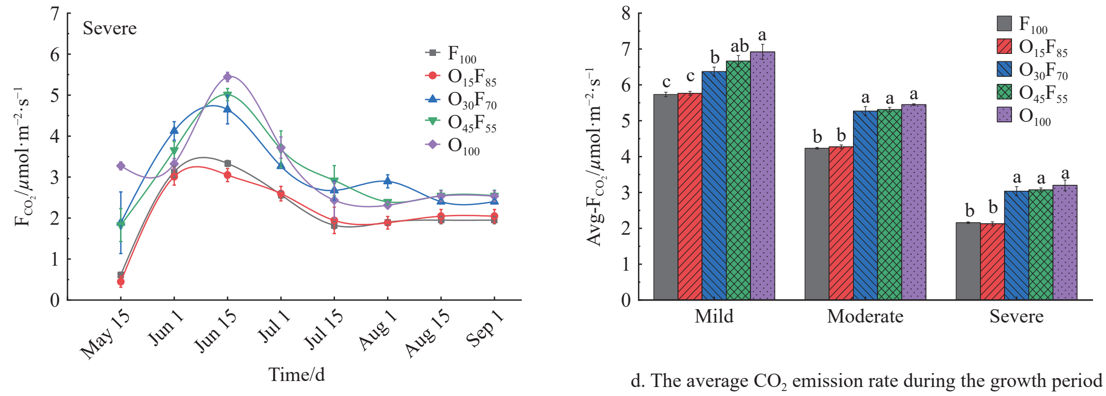
The soil CO_2 emission rates significantly differed for mild, moderate and severe salinization levels (Figure 2). The soil CO_2 emission rate for mild and moderate salinization levels showed a typical "high and low bimodal" curve with the plant growth process. The minimum was in early June, and the peak was in mid-July. For severe salinization level, there was a "single peak" curve, with the peak in mid-June in advance, earlier than for mild and moderate salinization levels. The reason was that for severe salinization, soil texture was relatively good due to the early "deep vertical rotary tillage" agricultural machinery measures. In addition, the soil CO_2 emission rate was higher under the topdressing measures in early June, then, under the action of irrigation, the soil aggregate destruction rate increased and was more stabilized, and the porosity and CO_2 emission rate decreased (Figures 2a-2c).

The replacement of different proportions of chemical fertilizer nitrogen with organic nitrogen had a great impact on soil CO_2 emission rate. Overall, compared with 100% chemical fertilizer nitrogen treatment, replacing chemical fertilizer nitrogen with organic nitrogen increased the soil CO_2 emission rate, and with the increased substitution rate there was a gradual increasing trend in CO_2 emission rate. There were significant differences among treatments for moderate and severe salinization. Among them, the O_{100} treatment significantly increased the peak of soil CO_2 emission rate, followed by the treatment of $O_{45}F_{55}$, $O_{30}F_{70}$, $O_{15}F_{85}$ and F_{100}. Comparing the average soil CO_2 emission rate during the whole growth period showed no significant differences between $O_{15}F_{85}$ and F_{100} treatments for mild, moderate and severe salinization levels (p>0.05). Compared with $O_{15}F_{85}$ and F_{100} treatment, other treatments significantly increased the average soil CO_2 emission rate. Among them, the O_{100} treatment significantly increased the average soil CO_2 emission rate by 20.68%, 28.79% and 48.52% compared with F_{100} for mild, moderate and severe salinization levels, respectively (Figure 2d).



a. CO_2 emission rate under different treatments of mild salinization level

b. CO_2 emission rate under different treatments of moderate salinization level



c. CO_2 emission rate under different treatments of severe salinization level

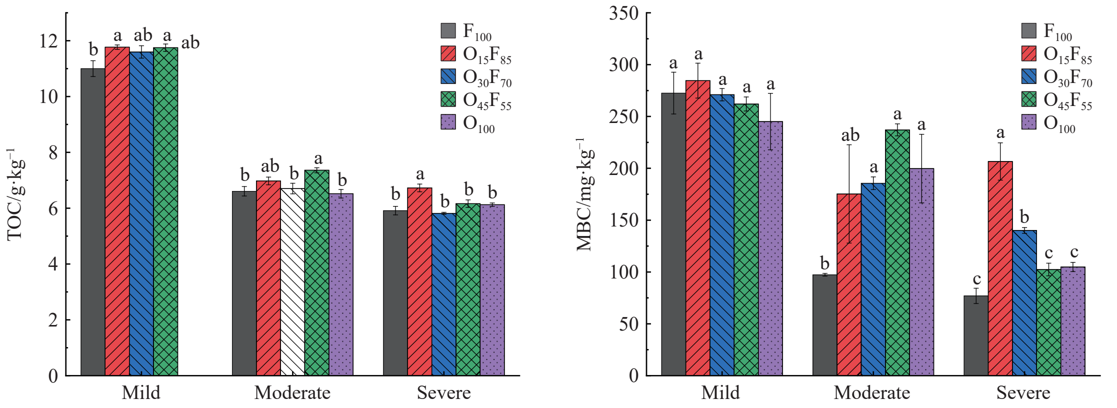
d. The average CO_2 emission rate during the growth period under different treatments of mild, moderate, severe salinization level

Figure 2 Effect of substitution of organic fertilizer nitrogen for chemical fertilizer nitrogen on carbon emission

3.3 Effects of organic nitrogen replacing chemical fertilizer nitrogen on TOC fractions

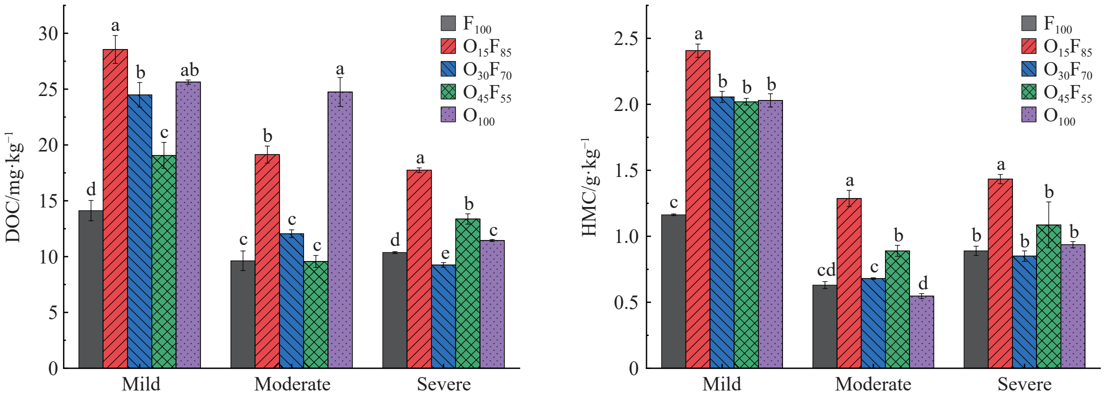
There were significant differences in soil TOC content among treatments (p<0.05), and soil TOC content under mild salinization was significantly higher than under moderate and severe salinization (Figure 3). Compared with F_{100} treatment, the $O_{15}F_{85}$ treatment significantly increased soil TOC content, and there was no significant difference in TOC content between F_{100} treatments under O_{100} treatment (p>0.05). The reason may be that 'Nitrogen starvation' led to a slowdown in microbial activity, which in turn reduced the organic carbon accumulation. (Figure 3a). There was no significant difference in MBC content among treatments for mild salinization. For severe salinization level, the $O_{15}F_{85}$ treatment had significantly higher MBC content than F_{100} treatment, while there were no significant differences in MBC content among $O_{45}F_{55,}$ O_{100} and F_{100} treatments (Figure 3b). Compared with F_{100}, treatment other treatments had significantly increased DOC content. Among them, the $O_{15}F_{85}$ treatment significantly increased the soil DOC content for mild and severe salinization, and had a significant positive effect on plant nutrient transport (Figure 3c).

Humus is the core part of soil organic matter. Compared with F_{100}, replacing chemical fertilizer nitrogen with organic nitrogen significantly increased the content of the inert substance HMC. The HMC content of $O_{15}F_{85}$ treatment was significantly higher than other treatments at mild, moderate and severe salinization levels, it was 2.07, 2.04 and 1.61 times that of F_{100} treatment, respectively (Figure 2d). The content of HAC of $O_{15}F_{85}$ treatment was 1.05, 2.96 and 2.53 times higher than F100 treatment under mild, moderate and severe salinization levels (Figure 2e). The mobility of fulvic acid carbon (FAC) is high, which plays a large role in soil nutrient leaching and deposition. The FAC content when replacing chemical fertilizer nitrogen with organic nitrogen for mild salinization level was 5.21-6.61 times that of the F_{100} treatment. Compared with F_{100} treatment, $O_{30}F_{70}$ and O_{100} treatments significantly reduced the content of FAC under moderate and severe salinization levels (Figure 3f).



a. Effects of different treatments on soil total organiccarbon (TOC) content under different salinization level

b. Effects of different treatments on microbial biomass carbon (MBC) content under different salinization level



c. Effects of different treatments on soil dissolved organic carbon (DOC) content under different salinization level

d. Effects of different treatments on humin carbon (HMC) content under different salinization level

Figure 3 Effect of substitution of organic fertilizer nitrogen for chemical fertilizer nitrogen on carbon composition

3.4 Effects of organic nitrogen replacing chemical fertilizer nitrogen on biomass

Biomass reflects the concentrated expression of plant energy acquisition. The biomass of silage maize was in the descending order of stem-leaf, grain, root (Table 5), which was closely related to the accumulation of nutrients among organs. Regarding the salinization levels, the biomass was mild>moderate>severe, which was related to the inhibition of nutrient transport by salt stress. For mild salinization level, root biomass was greatest under the $O_{15}F_{85}$ treatment, and there was no significant difference between F_{100} and O_{100} treatments ($p>0.05$), but a significant difference between $O_{30}F_{70}$ and $O_{45}F_{55}$ ($p<0.05$). For moderate salinization level, $O_{45}F_{55}$ and O_{100} treatments significantly reduced root biomass compared with other treatments, while the $O_{15}F_{85}$ treatment had higher aboveground biomass compared with other treatments, and was 9.09% higher than F_{100} treatment. Compared with F_{100} treatment, grain biomass decreased significantly under $O_{30}F_{70}$, $O_{45}F_{55}$ and O_{100} treatments, with a decrease of 12.91%, 18.80% and 20.39%, respectively. For severe salinization level, O_{100} treatment significantly reduced root, shoot and grain biomass compared with other treatments, while $O_{45}F_{55}$ treatment significantly reduced root and grain biomass compared with the $O_{15}F_{85}$ treatment. In summary, a 15% replacement of chemical fertilizer nitrogen by organic nitrogen could increase the silage maize biomass under mild and severe salinization level. At the same time, this treatment led to a decrease in root and grain biomass for moderate salinization, but increased aboveground biomass and created a good foundation for increasing plant carbon sequestration.

Table 5 Effect of organic fertilizer nitrogen replacing chemical fertilizer nitrogen on silage maize biomass

Salinization level	Treatment	Biomass /kg·hm^{-2}		
		Root	Stem-leaf	Grain
Mild	F_{100}	1551.15±23.13^{ab}	12 608.78±237.85^{a}	9751.50±376.38^{a}
	$O_{15}F_{85}$	1615.50±77.20^{a}	12 836.93±322.81^{a}	9853.20±406.64^{a}
	$O_{30}F_{70}$	1356.53±15.08^{b}	11 576.25±396.70^{b}	8976.15±818.16^{a}
	$O_{45}F_{55}$	1357.99±58.37^{b}	11 431.13±103.63^{b}	8111.70±108.37^{a}
	O_{100}	1341.91±80.59^{b}	10 361.25±202.65^{c}	8138.05±572.76^{a}
Moderate	F_{100}	1379.44±78.95^{a}	9340.20±658.6^{ab}	7203.15±216.35^{a}
	$O_{15}F_{85}$	1262.30±63.68^{a}	10 189.13±227.10^{a}	7057.35±514.17^{ab}
	$O_{30}F_{70}$	1296.90±68.72^{a}	9237.60±169.37^{ab}	6273.45±113.17^{bc}
	$O_{45}F_{55}$	1070.66±35.89^{b}	8772.30±257.59^{b}	5848.88±185.55^{c}
	O_{100}	934.93±18.10^{b}	8523.68±254.27^{b}	5734.35±117.57^{c}
Severe	F_{100}	1209.15±24.86^{a}	6644.93±107.06^{a}	4435.2±335.58^{ab}
	$O_{15}F_{85}$	1233.68±51.30^{a}	6530.18±155.03^{a}	5091.30±120.83^{a}
	$O_{30}F_{70}$	1177.20±22.61^{a}	5468.63±765.90^{a}	4572.45±53.73^{ab}
	$O_{45}F_{55}$	832.73±4.29^{b}	5379.08±149.38^{a}	4297.28±138.07^{b}
	O_{100}	632.69±32.54^{c}	3761.78±258.58^{b}	3951.45±302.74^{b}

3.5 Effects of organic nitrogen replacing chemical fertilizer nitrogen on yield and soil CO_2 emissions

Maize yield was the most direct expression of each treatment. For mild salinization, the $O_{15}F_{85}$ treatment had a 7.79% higher yield compared with F_{100}; however, $O_{30}F_{70}$, $O_{45}F_{55}$ and O_{100} had 11.70%, 22.93% and 25.87% lower yields compared with F_{100}, respectively. The order of yields for moderate and severe salinization levels was in descending of F_{100}>$O_{15}F_{85}$>$O_{30}F_{70}$>$O_{45}F_{55}$>O_{100} treatments. However, the $O_{15}F_{85}$ treatment increased the yield under mild salinization levels, but under moderate and severe salinization levels, the treatment of different organic fertilizer nitrogen instead of chemical fertilizer nitrogen ratio will reduce the yield of silage maize. The soil CO_2 emission flux (CE) in the whole growth period was in the descending order of mild>moderate>severe salinization, and the CEC under the three salinization levels was in the descending order of O_{100}>$O_{45}F_{55}$>$O_{30}F_{70}$>$O_{15}F_{85}$≈F_{100} treatment. The total biomass of roots, stem-leaf and grain of silage maize were used as NPP, which were in the descending order of mild> moderate>severe salinization. Among treatments, NPP was highest under $O_{15}F_{85}$ treatment, followed by F_{100} treatment, with no significant difference between the two treatments (p>0.05), but they were significantly higher than for the other treatments. Compared with O_{100} treatment, F_{100} and $O_{15}F_{85}$ treatments significantly increased plant CEE under mild and severe salinization levels (Table 6).

Table 6 Effect of organic fertilizer nitrogen replacing chemical fertilizer nitrogen on yield and CO_2 emissions

Salinization level	Treatment	Yield/ 10^3 kg·hm^{-2}	CE/ 10^3 kg·hm^{-2}	NPP/ 10^3 kg·hm^{-2}	CEE/%
Mild	F_{100}	55.22±4.59^{a}	25.94±0.27^{c}	23.91±0.56^{a}	12.81±0.14^{c}
	$O_{15}F_{85}$	59.52±2.61^{a}	26.09±0.97^{c}	24.31±0.39^{a}	11.96±0.44^{c}
	$O_{30}F_{70}$	48.76±1.6^{ab}	28.8±0.57^{b}	21.91±1.18^{b}	16.11±0.31^{b}
	$O_{45}F_{55}$	42.56±2.96^{b}	30.14±0.71^{ab}	20.90±0.02^{b}	19.32±0.45^{a}
	O_{100}	40.93±1.06^{b}	31.31±0.24^{a}	19.84±0.35^{b}	20.86±0.12^{a}
Moderate	F_{100}	44.02±4.76^{a}	19.14±0.09^{b}	17.92±0.76^{ab}	11.85±0.05^{e}
	$O_{15}F_{85}$	37.38±1.41^{ab}	19.33±0.09^{b}	18.51±0.470^{a}	14.10±0.06^{d}
	$O_{30}F_{70}$	34.43±1.33^{ab}	23.85±0.57^{a}	16.81±0.12^{bc}	18.89±0.45^{c}
	$O_{45}F_{55}$	31.36±1.48^{bc}	24.03±0.27^{a}	15.69±0.15^{cd}	20.9±0.23^{b}
	O_{100}	28.57±1.44^{c}	24.65±0.24^{a}	15.19±0.31^{d}	23.52±0.23^{a}
Severe	F_{100}	36.25±4.09^{a}	9.76±0.09^{b}	12.29±0.24^{ab}	7.34±0.06^{d}
	$O_{15}F_{85}$	33.86±0.81^{ab}	9.75±0.67^{b}	12.86±0.13^{a}	7.85±0.54^{d}
	$O_{30}F_{70}$	30.56±1.26^{bc}	13.74±0.57^{a}	11.22±0.70^{bc}	12.26±0.50^{c}
	$O_{45}F_{55}$	26.05±1.31^{c}	13.9±0.25^{a}	10.51±0.45^{c}	14.55±0.25^{b}
	O_{100}	19.76±1.79^{d}	14.47±0.24^{a}	8.35±0.33^{d}	19.97±0.33^{a}

Note: abbreviation: CE, CO_2 emission; NPP, net primary productivity; CEE, carbon emission efficiency.

3.6 Effect of organic nitrogen replacing chemical fertilizer nitrogen on ecosystem carbon balance

There was a significant effect on NPPC of replacing chemical fertilizer nitrogen with organic nitrogen (p<0.05). The trend was consistent with the change of total NPP, and the order for NPPC between treatments was in descending of $O_{15}F_{85}$>F_{100}>$O_{30}F_{70}$>$O_{45}F_{55}$>O_{100}. The variation trend of R_mC was consistent with that of CEC. Compared with F_{100} treatment, O_{100} treatment increased by 20.59%, 28.82% and 48.26% respectively under mild, moderate and severe salinization levels. The NEPC also significantly differed among treatments (p<0.05). Compared with F_{100} treatment, the $O_{15}F_{85}$ treatment had a higher NEPC content under mild, moderate and severe salinization levels, but the NEPC of other treatments was significantly lower than that of F_{100} treatment. Among them, the O_{100} treatment had the greatest decreases of 81.69%, 88.32% and 97.75% for mild, moderate and severe salinization levels, respectively. All treatments had positive carbon balances, indicating that farmland was a "sink" for atmospheric CO_2. Compared with F_{100} treatment, the other treatments had a significantly enhanced carbon sink effect. Among them, the O_{100} treatment had the greatest carbon sink, followed by $O_{15}F_{85}$ treatment. Compared with F_{100} treatment, the carbon sinks of O100 treatment under mild, moderate and severe salinization increased by 32.11%, 39.05% and 41.57%, respectively (Table 7).

Table 7 Effect of organic fertilizer nitrogen replacing chemical fertilizer nitrogen on ecosystem carbon balance (10^3 kg·hm^{-2})

Salinization degree	Treatment	NPPC	CEC	R_mC	NEPC	SCB
Mild	F_{100}	9.67±0.23^{a}	7.08±0.07^{c}	6.12±0.06^{c}	3.55±0.18^{ab}	3.55±0.18^{c}
	$O_{15}F_{85}$	9.83±0.16^{a}	7.11±0.29^{c}	6.04±0.25^{c}	3.79±0.46^{a}	4.69±0.46^{b}
	$O_{30}F_{70}$	8.86±0.48^{b}	7.86±0.15^{b}	6.79±0.13^{b}	2.06±0.05^{bc}	3.86±0.05^{bc}
	$O_{45}F_{55}$	8.45±0.01^{b}	8.22±0.19^{ab}	7.11±0.17^{ab}	1.34±0.18^{cd}	4.04±0.18^{b}
	O_{100}	8.03±0.14^{b}	8.54±0.07^{a}	7.38±0.06^{a}	0.65±0.08^{d}	6.65±0.08^{a}
Moderate	F_{100}	7.25±0.31^{ab}	5.22±0.03^{b}	4.51±0.02^{b}	2.74±0.33^{a}	2.74±0.33^{d}
	$O_{15}F_{85}$	7.48±0.19^{a}	5.28±0.03^{b}	4.57±0.02^{b}	2.91±0.17^{a}	3.81±0.17^{b}
	$O_{30}F_{70}$	6.80±0.08^{bc}	6.51±0.15^{ab}	5.63±0.13^{ab}	1.17±0.09^{b}	2.97±0.09^{c}
	$O_{45}F_{55}$	6.34±0.06^{cd}	6.55±0.07^{a}	5.67±0.06^{a}	0.68±0.11^{c}	3.38±0.11^{b}
	O_{100}	6.13±0.13^{d}	6.72±0.06^{a}	5.81±0.06^{a}	0.32±0.14^{d}	6.32±0.14^{a}
Severe	F_{100}	4.97±0.10^{ab}	2.66±0.03^{b}	2.30±0.02^{b}	2.67±0.11^{a}	2.67±0.11^{d}
	$O_{15}F_{85}$	5.20±0.05^{a}	2.68±0.23^{b}	2.32±0.20^{b}	2.88±0.24^{a}	3.78±0.24^{b}
	$O_{30}F_{70}$	4.54±0.28^{bc}	3.75±0.15^{a}	3.24±0.13a	1.29±0.15^{b}	3.09±0.15^{c}
	$O_{45}F_{55}$	4.25±0.02^{c}	3.79±0.07^{a}	3.28±0.06^{a}	0.97±0.07^{b}	3.67±0.07^{b}
	O_{100}	3.37±0.14^{d}	3.95±0.07^{a}	3.41±0.06^{a}	0.06±0.03^{c}	6.06±0.03^{a}

Note: abbreviation: NPPC, net primary productivity carbon; CEC, carbon emission; RmC, carbon emission by soil microbial heterotrophic respiration; NEPC, net ecosystem productivity carbon; SCB, soil carbon balance (SCB).

3.7 Correlations of soil hydrothermal conditions and key physical and chemical factors with soil humus carbon components and carbon balance

The correlation matrix for soil hydrothermal conditions and key physical and chemical factors with soil humus carbon components and carbon balance are listed in Table 8. Total salt was significantly negatively correlated with MBC (r=−0.836**), DOC (r=−0.658**), HMC (r=−0.709**), FAC (r=−0.636*), CEC (r=−0.884**) and NPPC

Table 8 Correlation analysis of soil hydrothermal status and key physicochemical factors with soil humus carbon components and carbon balance

Index	MBC	DOC	HMC	HAC	FAC	CEC	CEE	NPPC	SCB
Total salt	−0.836**	−0.658**	−0.709**	−0.419	−0.636*	−0.884**	−0.144	−0.946**	−0.178
pH	−0.692**	−0.536*	−0.386	-0.007	−0.442	−0.917**	−0.676**	−0.635*	−0.332
Bulk density	−0.791**	−0.530*	−0.499	−0.185	−0.495	−0.941**	−0.672**	−0.674**	−0.551*
Moisture	−0.470	−0.601*	−0.307	−0.218	−0.259	−0.361	0.059	−0.485	0.169
Temperature	0.501	0.269	0.635*	0.021	0.723**	0.615*	0.475	0.264	0.674**

Note: **, at level 0.01 (two-tailed), the correlation was significant; *, at level 0.05 (two-tailed), the correlation was significant.

(r=−0.946**). There were significant negative correlations of pH with MBC (r=−0.692**), CEC (r=−0.884**), CEE (r=−0.676**), DOC (r=−0.536*) and NPPC (r=−0.635*). Bulk density was significantly negatively correlated with MBC (r=−0.791**), CEC (r=−0.941**), CEE (r=−0.672**), NPPC (r=−0.674**), DOC (r=−0.530*) and SCB (r=−0.551*). Moisture was negatively correlated with DOC (r=−0.601*). Temperature was significantly positively correlated with FAC (r=0.723**), SCB (r=0.674**), HMC (r=0.635*) and CEC (r=0.615*). Thus, total salt and bulk density were closely correlated with carbon composition and carbon balance.

4 Discussion

4.1 Effects of replacing chemical fertilizer nitrogen with organic nitrogen on carbon emission and carbon balance of yield

Nitrogen is the most critical nutrient element for the growth and yield improvement of silage maize. This study used organic fertilizer nitrogen to replace different proportions of chemical fertilizer nitrogen. Under the mild salinization level, $O_{15}F_{85}$ treatment increased the yield of silage maize by 7.79 % compared with F_{100} treatment, while under the moderate and severe salinization levels, different proportions of organic fertilizer nitrogen instead of chemical fertilizer nitrogen treatment reduced the yield of silage maize. The reason for this may be that, for mild salinization, substituting chemical fertilizer nitrogen with organic nitrogen improved the supply process of nitrogen in soil, so that soil nutrients were released smoothly, while for moderate and severe salinization, the ion antagonism effect of soil salt ions on the transport of nutrient elements exceeded the capacity of organic fertilizer to improve supply of soil nutrient elements[17,18]. In addition, many previous organic fertilizer substitution experiments on black, loessial and purple soil showed that the substitution rate could reach 37.5%-50.0% without affecting yield, which was closely related to the rich background value of soil[19-21].

Soil carbon emissions play an important role in the change of global atmospheric CO_2 concentration. In this study, there was no significant difference in carbon emissions between organic nitrogen substitution of 15% chemical fertilizer nitrogen and 100% chemical fertilizer nitrogen treatments, while carbon emissions for substitution rates of 30%, 45% and 100% were significantly higher than those for 100% chemical fertilizer nitrogen treatment. The main reason was that organic fertilizer improved the soil pore channels and accelerated soil respiration. Furthermore, a higher C/N ratio or relatively insufficient nitrogen source in the soil can promote the microbial utilization of easily oxidized carbon and increase the CO_2 emissions.[22,23].

The NEPC directly describes the nature and capacity of terrestrial ecosystem carbon sources/sinks. The NEPC for replacing 15% of chemical fertilizer nitrogen with organic nitrogen increased by 6.76%, 6.20% and 7.87% compared with that for the treatment of 100% chemical fertilizer nitrogen for mild, moderate and severe salinization levels, respectively, while the NEP content for the treatments of the 30%, 45% and 100% substitution rates were significantly lower than that for the 100% chemical fertilizer nitrogen treatment. An optimal amount of organic fertilizer input improved the carbon sequestration of NEP, whereas the excessive organic fertilizer led to the increase of the carbon loss through microbial heterotrophic respiration, ultimately reducing the carbon sequestration of NEP. These findings are consistent with a prior study on the carbon sink effect of maize farmland in the Hexi Corridor oasis irrigation area[24]. Calculations showed that all treatments had positive carbon balances, indicating that the farmland was a “sink” for atmospheric CO_2. When comparing the impact on SCB between using 100% chemical fertilizer nitrogen and substituting it with organic nitrogen, it was found that substituting organic nitrogen led to an increase in SCB. The most significant increase was observed in 100% organic fertilizer nitrogen treatment, followed by substituting organic nitrogen for 15% of the chemical fertilizer nitrogen treatment. The increase of SCB in the 100% organic fertilizer nitrogen treatment was due to the carbon input of 6003 kg/hm^2, while the carbon input in organic nitrogen substitution of 15% chemical fertilizer nitrogen was only 900.5 kg/hm^2, which produced an “excitation effect” to enhance the carbon sink effect of farmland while maintaining stable yield and emission. Although the high amount of organic fertilizer input treatment can help increase the soil carbon sink, the mineralization rate of nitrogen sources is slow. It can not effectively increase yield and will cause a waste of resources[25].

4.2 Effect of organic nitrogen replacing chemical fertilizer nitrogen on OC fractions

The OC in soil can regulate soil physical and chemical properties, which is an important index to measure the level of soil fertility[26]. This study showed that the OC content under 100% chemical fertilizer nitrogen treatment was decreased compared with that before the test, and replacing chemical fertilizer nitrogen with organic nitrogen effectively increased the soil OC content. It is believed that the combination of organic and inorganic fertilizers improves the adsorption capacity of soil for nitrogen, and the high effectiveness of nitrogen can promote the transformation of soil organic matter into humus[27]. The MBC is the main component of active organic matter, and can directly participate in the mineralization and humification process of soil organic residues. This study found that organic nitrogen effectively increased the MBC content when replacing chemical fertilizer nitrogen, especially for the 15% replacement rate. The effect was clear, mainly because the organic fertilizer can provide sufficient carbon sources for the growth of microorganisms, improving their living environment and accelerating their metabolic process[28]. Humus carbon components showed significant differences under the treatments with different proportions of organic and chemical fertilizers. This study suggested that organic nitrogen substituting for chemical fertilizer nitrogen increased the content of HMN and HA carbon compared with 100% chemical fertilizer nitrogen, and the effect of 15% substitution of chemical fertilizer nitrogen was best, consistent with results of long-term monitoring of fluvo-aquic soil by Wen[29]. This was mainly because organic fertilizer contained a certain amount of humus-like components, and a certain amount of humus was formed during organic fertilizer decomposition. Thus, the carbon content of soil humus components increased after the application of organic fertilizer[30].

4.3 Carbon emission mechanism of farmland

Farmland carbon emissions are affected by many factors. In this study, correlation analysis for carbon emission indicators, soil hydrothermal conditions and key soil factors showed that, of humus carbon components, MBC was particularly closely related to total salt, pH and bulk density of soil with significant negative correlations, indicating that soil MBC was easily affected by soil salinity and structural problems, consistent with the results of Ren at al.[31]. The DOC was mainly produced by litter leachate, root exudates and microbial degradation products. And it was significantly negatively correlated with soil total salt, pH, bulk density and water. Therefore, improving soil physical and chemical factors helps improve the dynamics of OC and accelerate nutrient cycling. The carbon content of inert humus HM was significantly negatively correlated with total salt, and significantly positively correlated with temperature, while the carbon content of relatively active FA was significantly negatively correlated with total salt, and significantly positively correlated with temperature. Thus, the high conductivity of soil affected the formation of humus carbon, and the increased temperature raised the respiration rate of humus and accelerated the accumulation of carbon. This is consistent with the results of Wang et al.[32], but temperatures exceeding 30°C will increase the risk of HA and humic molecule aliphatic content reduction.

Farmland carbon emissions were significantly negatively correlated with total salt, pH, bulk density and temperature. Soil total salt and pH will lead to more soil clay, poor structural stability and less soil carbon emissions. Soil temperature is the key factor in determining the carbon cycle process. Soil temperature affects all aspects of soil microbial respiration, and warming within a certain range affects OC mineralization, so soil temperature has a significant positive effect on soil carbon emissions[33-37]. The fixed carbon content of NPP was significantly negatively correlated with soil total salt, bulk density and pH, mainly due to the obstruction of nutrient transport caused by high saline-alkali factors in soil, which reduced silage maize biomass accumulation, resulting in a significant decrease in the fixed carbon content of NPP[38]. In summary, soil total salt and bulk density were closely related to carbon components and carbon balance. The multivalent cations in soil salt can increase the adsorption capacity of organic matter by soil particles, thereby reducing the solubility of humus compounds. Furthermore, soluble salt ions Cl^- and SO_4^{2-} reduce OC accumulation by changing the rate and pathway of OC mineralization, while soil bulk density reflects the smoothness of soil carbon emission channels and high bulk density reduces soil permeability, thereby affecting the soil carbon emission rate[39].

5 Conclusions

1) Compared to full chemical fertilizer nitrogen treatment, adding organic fertilizers increased the soil OC, MBC, HMC and HAC content at mild, moderate and severe salinization levels, the degree of salinization can not impact the proportion of the organic fertilizer nitrogen replacing the chemical fertilizer nitrogen.

2) Compared to full chemical fertilizer nitrogen treatment, the treatment of 15 % organic fertilizer nitrogen replacing chemical fertilizer nitrogen resulted in an increase of silage maize yield and the NEPC under mild, moderate, and severe salinization levels. This substitution also led to a reduction in CEE, although it did not significantly increase CEC. Substituting organic nitrogen for 30%, 45% and 100% of chemical fertilizer nitrogen significantly increased the soil carbon emissions. Carbon balance results showed that the farmland was a “sink” for atmospheric CO_2 under each treatment. Compared with 100% chemical fertilizer nitrogen treatment, organic nitrogen replacing 100% chemical fertilizer nitrogen had the greatest effect on increasing ecosystem carbon balance due to high OC input, but the nitrogen source mineralization rate was slow, which could not effectively increase the yield and would cause a waste of resources. The treatment of 15% organic fertilizer nitrogen replacing chemical fertilizer nitrogen enhanced the carbon sink effect of silage maize farmland under the premise of a stable production and low carbon emissions. Therefore, this is an appropriate substitution ratio of organic nitrogen for fertilizer nitrogen in the saline-alkali area of northern Yinchuan, Ningxia.

3) Comprehensive analysis of the correlations among carbon components, ecosystem carbon balance, soil water and heat conditions, and key soil factors showed that soil total salt, pH and bulk density affected the soil OC components and ecosystem carbon balance by changing OC mineralization path and soil permeability. Soil moisture mainly affected soil DOC, and temperature had the greatest impact on humus carbon components and carbon emissions. Therefore, in terms of the utilization of saline-alkali land, soil carbon sinks can be increased through salt inhibition, soil structure remodeling, water and temperature regulation.

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