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Full Length Article

Organic Fertilizer Regulates Soil Carbon, Nitrogen Balance and Greenhouse Gas Emissions in Tobacco Production System

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Abstract

The impact of organic fertilizers on the carbon source/sink balance of tobacco soil ecosystem remains controversial. A two-year field experiment was conducted to investigate the effects of different fertilization treatments (no fertilizer, chemical fertilizer, chemical fertilizer and organic fertilizer) on greenhouse gas (GHG) emissions including soil carbon dioxide (CO_2), nitrous oxide (N_2O), ammonia volatilization and comprehensive greenhouse effects. The results showed that tobacco soil ecosystem can be carbon source or sink, depending mainly on the carbon sequestration of the plant. Comparing with chemical fertilizer, the combined application of chemical fertilizer and organic fertilizer increased the CO_2 emission flux and C emission from soil, and significantly increased the carbon sequestration of tobacco plants. The carbon sequestration function of organic fertilizer was closely related to the carbon accumulation of tobacco plants. Compared with the chemical fertilizer, soil ammonia volatilization and N_2O emission flux were increased by adding organic fertilizer. Both the soil N emission and the biological nitrogen fixation were increased by organic fertilizer. The greenhouse gas emission intensity (GHGI) of organic fertilizer treatment decreased by 14.60%, a remarkable emission reduction, while the tobacco yield of organic fertilizer treatment increased 19.12%. Therefore, increasing organic fertilizer in tobacco planting fields is an important way to promote tobacco yield, carbon sequestration and emission reduction. © 2021 Friends Science Publishers

Keywords: Organic fertilizer; Tobacco (; Carbon nitrogen balance; Greenhouse gas emission

Introduction

Climate change is the most serious global environmental problem facing humanity in the world today. The main reason for the global greenhouse effect is the greenhouse gases (GHG), including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) (Tian *et al.* 2016) produced by agricultural production activities, such as land-use change, agriculture and waste management. According to United States Environmental Protection Agency (USEPA 2006), CH_4 and N_2O emissions from agricultural land use activities account for 50% and 75% of total global emissions, respectively. Therefore, agricultural GHG emission reduction plays an important role in controlling global climate change. Soil is a huge carbon pool in terrestrial ecosystems. Soil can be carbon source or carbon sink and affects the concentration of CO_2 in the atmosphere (Duiker and Lal 1999). Many studies around the world have shown that soil carbon sequestration can be facilitated by appropriate land use and agricultural management (Poeplau and Don 2015; Lange *et al*. 2015; Gao *et al*. 2018). According to the Intergovernmental Panel on Climate Change (IPCC), the technological potential of global agricultural emissions reduction is as high as 5500–6000 Mt CO_2 equivalent per year (Smith *et al*. 2007). Of these, 89% came from reducing soil CO_2 emissions (*e.g.*, soil carbon sequestration). Therefore, improving fertilizer use efficiency through reasonable farming measures and increasing carbon sequestration in crop soil systems are important ways to reduce GHG emissions in agriculture.

The carbon sink capacity of crop systems has attracted the attention of researchers. As crop soil ecosystems are net source or net sink of atmospheric CO_2? Many studies have reported the carbon sink function of crops, such as wheat-maize-soybean rotation systems in black soils (Liang *et al.* 2012), paddy field system for long-term application of organic fertilizer (Hu *et al*. 2017), and no-till corn/soybean ecosystem (Bernacchi *et al.* 2005). Studies have also demonstrated that most of Chinese cropping systems are net source of GHG emissions (Wen *et al.* 2010). Hence, there are large variations of net GHG balance between different cropping systems or cultivation management. Thus, the carbon source/sink balance of tobacco soil ecosystem is rarely studied.

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It is generally believed that application of organic fertilizer is an effective way to improve the soil and promote the growth of plants. The application of organic fertilizer can increase the number of soil microorganisms (Jannoura *et al*. 2014), improve the physical and chemical properties of soil, and regulate soil carbon pools (Lazcano *et al*. 2013; Liu *et al*. 2013; Wei *et al*. 2019). However, there are complex trade-offs between soil organic carbon (SOC) sequestration and GHG emissions, and the greenhouse effects of organic fertilizers remain controversial for field crops. Although organic fertilizers play an important role in increasing soil carbon sequestration and crop yield, their effects on GHG emissions cannot be ignored. Studies have shown that the application of organic fertilizer can promote the emission of CO_2 and N_2O, and significantly enhance GHG warming potential (Zhu *et al*. 2013; Das and Adhya 2014). There are also reports on the use of organic fertilizers to increase soil carbon sinks (Sekhon *et al*. 2009; Yang *et al*. 2015; Hu *et al*. 2017). Therefore, the carbon sink effect of organic fertilizer varies among different crops and environment and few reports are available on the effect of organic fertilizers on soil carbon and nitrogen balance and GHG emissions in tobacco fields. To this end, the effects of different fertilization treatments on carbon and nitrogen gas emissions and comprehensive greenhouse effects of tobacco soil ecosystems are studied under the field condition, to provide a basis for tobacco field soil cultivation and GHG emission reduction.

Materials and Methods

Experimental site and materials

The experiment was conducted in Xiangcheng county, Xuchang city, Henan Province, China (N33°51′, E113°25′), from 2016 to 2017. The soil type was cinnamon with basic physical and chemical properties with pH 7.89, organic matter 17.20 $mg \cdot kg^{-1}$, total nitrogen 1.10 $mg \cdot kg^{-1}$, alkali nitrogen 76.54 $mg \cdot kg^{-1}$, available phosphorus 23.16 $mg \cdot kg^{-1}$, and available potassium 102.22 $mg \cdot kg^{-1}$. The variety of flue-cured tobacco tested was Zhongyan 100. The fertilizer applied was a special one for local tobacco, organic fertilizer (sesame cake fertilizer, 5.0% N content, 1.0% K_2O content), compound fertilizer ($N{:}P_2O_5{:}K_2O=10{:}10{:}10$), and potassium sulfate (50% K_2O content).

Experimental design

The two-year randomized block experimental design was consistent. The experiment was comprised of three treatments: no fertilizer (CK), single application of chemical fertilizer (T1), combined application of chemical fertilizer and organic fertilizer (T2). The single application of chemical fertilizer was 375 $kg \cdot hm^{-2}$ as compound fertilizer and 225 $kg \cdot hm^{-2}$ as potassium sulfate. The combined application of chemical and organic fertilizer was 375 $kg \cdot hm^{-2}$ as organic fertilizer, 375 $kg \cdot hm^{-2}$ as compound fertilizer and 225 $kg \cdot hm^{-2}$ as potassium sulfate. The experiment used three replications, and the plot size of 100 m^2.

All fertilizers were applied once before ridging. In 2016, fertilization and ridging were carried out on May 9, GHG collection began on May 10, and tobacco seedling transplanting was carried out on May 11. In 2017, the fertilization and ridging were performed on May 1, GHG collection on May 2, tobacco seedlings were transplanted on May 3. Other field management carried out was in accordance with local high quality tobacco production practices.

Sample collection and analysis methods

GHG were collected and measured using static chamber-weather chromatography. The volume of the static box base (length × width × height) was 60 cm × 50 cm × 30 cm, and the volume of the box (length × width × height) was 60 cm × 50 cm × 15 cm. Gas collection began after fertilization and ridging, which was carried out at 9:00–11:00 am at day 1, 3, 5, 7, 9, 11, 13, 15, 30, 45, 60, 75, 90, and 115. The CO_2 and N_2O concentrations of the samples were determined using a GC7890 gas chromatograph (Agilent, U.S.A.).

Soil ammonia volatilization was measured by continuous chamber evacuation followed by titration. The closed chamber was made of transparent plexiglass material with an inner diameter of 20 cm and a device height of 30 cm. There were two vent holes at the top of the chamber. One of the vents (30 mm in diameter) was connected to the vent tube containing the boric acid absorbing liquid filter bottle to reduce the influence of surface air exchange on the determination of ammonia volatilization. The other vent (11 mm in diameter) was connected to a gas cylinder containing boric acid absorbing liquid. The air in the sealed chamber was passed through a boric acid absorbing liquid by means of suction and decompression to absorb and fix the ammonia therein, and the collected solution was measured by a standard dilute sulfuric acid titration method. Samples were collected every day at 9:00–11:00 a.m. and 3:00–5:00 p.m. after fertilization. The cumulative amount of ammonia volatilization for a total of 15 days was used as the total emission.

At the maturity, samples of roots, stems and leaves of the plants were collected, dried and pulverized, and the carbon content of the plants was analyzed by Vario MARCO cube elemental analyzer (Elementar, Germany), and then the carbon fixation of the whole plant was calculated.

Index calculation method

The amount of change in CO_2 was calculated using the formula:

$$\Delta SOC = \text{the carbon output} - \text{the carbon input}$$

Where, the carbon output is CO_2 emission ($kg \cdot hm^{-2}$); the carbon input is carbon from organic fertilizer ($kg \cdot hm^{-2}$).

Organic fertilizer carbon input (in terms of CO_2) = (amount of organic fertilizer applied × carbon content in organic fertilizer × 44) / 12.

Nitrogen emissions = ammonia volatilization + N_2O emissions

The overall greenhouse effect of CO_2 and N_2O production in this study was characterized by CO_2 equivalent, calculated as:

$CO_2\text{-eq}\ (kg\cdot hm^{-2}) = N_2O\ \text{emission}\ (kg\cdot hm^{-2})\times 298 + \Delta SOC\ (kg\cdot hm^{-2})$.

The greenhouse gas emission intensity (GHGI) is the CO_2 equivalent per unit of production, and the formula is:

$GHGI\ (kg\cdot kg^{-1}) = CO_2\text{-eq}\ (kg\cdot hm^{-2}) / \text{crop yield}\ (kg\cdot hm^{-2})$.

Statistical analysis

Differences among different treatments were determined though one-way analysis of variance (ANOVA) and Least Significant Difference (LSD) test using S.P.S.S. 21.0 (S.P.S.S. software Inc., U.S.A.). Differences were considered significant at $P < 0.05$.

Results

Effect on soil CO_2 emission flux

Soil CO_2 emission flux was largely affected by fertilization (Fig. 1). In 2016, within the first 15 days after fertilization, soil CO_2 emission flux was at a relatively high level, and then decreased. The CO_2 emission flux increased gradually 45 days after fertilization, and reached the highest at 90 days after fertilization followed by a rapid decline. In 2017, within 15 days after fertilization, the soil CO_2 emission flux remained at a high level, and began to decline gradually after 75 days. The difference in soil CO_2 emission flux during the year may be closely related to temperature and rainfall differences. Compared with the control, soil CO_2 emission flux of chemical fertilizer treatment and combined chemical and organic fertilizer treatment increased significantly, and combined chemical and organic fertilizer treatment was slightly higher than chemical fertilizer treatment. Therefore, increasing application of organic fertilizer can promote soil CO_2 emissions to a certain extent.

Effect on soil carbon balance

Compared with the control, the soil CO_2 and C emissions of chemical fertilizer treatment and combined chemical and organic fertilizer treatment increased significantly, and the average increase reached 32.90% and 42.14% respectively (Table 1). Compared with chemical fertilizer treatment, both soil CO_2 and C emissions increased in combined chemical and organic fertilizer treatment, with an average increase of 7.0%, which may be closely related to organic fertilizers promoting soil microbial activity and improving soil physical and chemical properties. The carbon fixation of different treatments showed combined chemical and organic fertilizer treatment > chemical fertilizer treatment > no fertilizer, which was consistent for two years. In 2016, under no fertilizer condition, the tobacco soil ecosystem is a carbon source to the atmosphere (net carbon output), while under normal fertilization conditions, it is a weak carbon sink (net carbon input). In 2017, due to the increase of carbon emissions and reduction of plants carbon sequestration, the tobacco soil system showed a carbon source. Compared with the application of chemical fertilizer alone, adding organic fertilizer significantly increased the carbon sequestration by plants and significantly increased the system carbon input.

Effect on ammonia volatilization

The ammonia volatilization of soil is mainly concentrated within the first 15 days after fertilization. In this study, the ammonia volatilization of all fertilization treatments fluctuated within the first 15 days of fertilization (Fig. 2). Compared with control, the ammonia volatilization level of chemical fertilizer treatment and combined chemical and organic fertilizer treatment increased significantly. Five days after fertilization, the ammonia volatilization level of combined chemical and organic fertilizer treatment was significantly higher than chemical fertilizer treatment.

Effect on soil N_2O emission flux

The soil N_2O emission mainly occurred within the first 15 days after fertilization (Fig. 3). Compared with control, the soil N_2O emission fluxes from chemical fertilizer treatment and combined chemical and organic fertilizer treatment were significantly higher. There was an annual difference in the emission differences between chemical fertilizer treatment and combined chemical and organic fertilizer treatment. The N_2O emission from chemical fertilizer treatment was higher than combined chemical and organic fertilizer treatment in 2016, while the difference between the two was smaller in 2017.

Effect on soil nitrogen balance

Soil N emission mainly comes from N_2O and NH_3.Compared with control, both the soil N emissions of chemical fertilizer treatment and combined chemical and organic fertilizer treatment increased significantly. The average increase of N emissions reached 74.72% and 93.86%, respectively (Table 2). Compared with chemical fertilizer treatment, the N emission of combined chemical and organic fertilizer treatment was increased significantly, with an average increase of 11.79% in two years. The nitrogen accumulation of different treatments showed combined chemical and organic fertilizer > chemical fertilizer treatment > control, which was consistent during two years. In 2017, due to the weak growth of tobacco plants and the low dry matter accumulation, the nitrogen accumulation of plants was significantly lower than 2016.

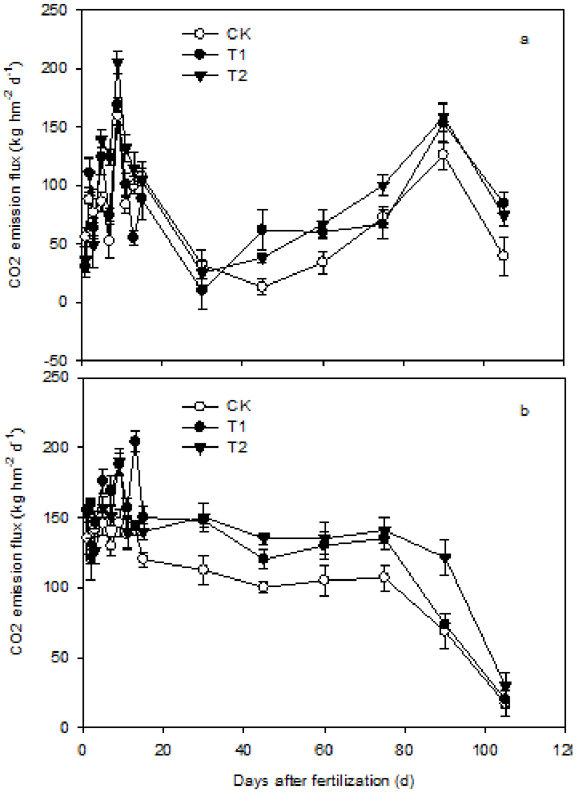

Fig. 1: Soil CO_2 emission flux of different treatments during 2016 (**a**) and 2017 (**b**)
CK: no fertilizer, T1: chemical fertilizer, T2: chemical fertilizer + organic fertilizer

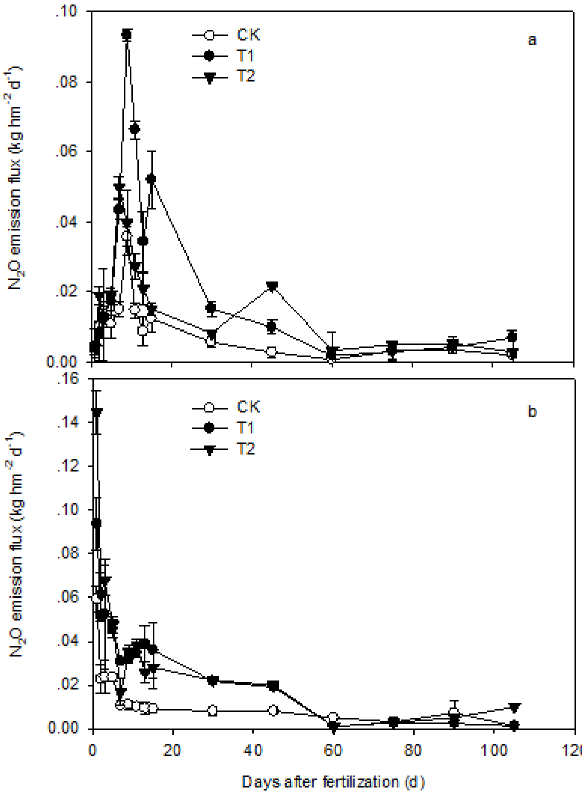

Fig. 3: Soil N_2O emission flux of different treatments in 2016 (**a**) and 2017 (**b**)
CK: no fertilizer, T1: chemical fertilizer, T2: chemical fertilizer + organic fertilizer

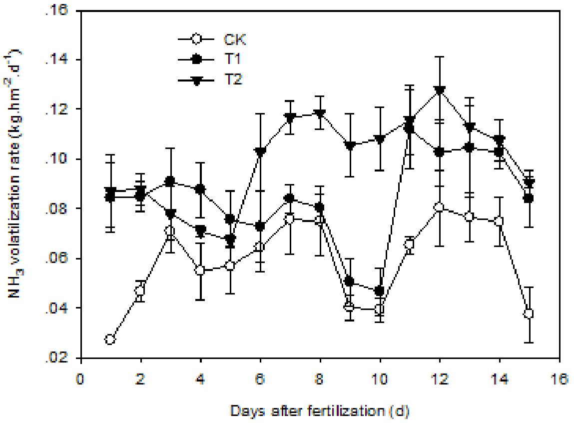

Fig. 2: Effect of different fertilization treatments on ammonia volatilization (two-year average)
CK: no fertilizer, T1: chemical fertilizer, T2: chemical fertilizer + organic fertilizer

Effect on soil carbon emission intensity

Compared with control, the CO_2 change and the comprehensive greenhouse effect of chemical fertilizer treatment and combined chemical and organic fertilizer treatment increased significantly, but there was no significant difference between the two treatments (Table 3). Compared with control, chemical fertilizer treatment and combined chemical and organic fertilizer treatment significantly increased tobacco yield, and combined chemical and organic fertilizer treatment was significantly higher than chemical fertilizer treatment. The GHGI is the CO_2 equivalent of the unit output, which is a comprehensive reflection of the economic benefits and environmental benefits brought by the fertilization measures. It can be seen that compared with control, the GHGI of chemical fertilizer treatment was significantly increased. So, the application of chemical fertilizer significantly increased the GHGI. Compared with chemical fertilizer treatment, the GHGI of combined chemical and organic fertilizer treatment decreased by 14.60% on average. It can be seen that the application of organic fertilizer was beneficial to increase the carbon sequestration and tobacco yield and slow down the greenhouse effect.

Discussion

Agricultural soil carbon source/sink balance and carbon sequestration potential have always been the focus of attention worldwide (Piao *et al.* 2009; Hadden and Grelle 2016; Miettinen *et al*. 2017). Studies have shown that there are significant differences in carbon sink capacities between different cropping systems. This study reported a significant annual variation in the carbon input in the tobacco

Table 1: Effect of different fertilization treatments on carbon balance in tobacco production system

Year	Treatment	CO_2 emission (kg hm^{-2})	C emission (kg hm^{-2})	Plant carbon sequestration (kg hm^{-2})	Carbon input (kg hm^{-2})
2016	CK	7198.98 ± 295.65b	1963.36 ± 80.63b	1308.57 ± 60.32b	-654.79 ± 20.32c
	T1	10072.57 ± 427.01a	2747.06 ± 116.45a	2877.22 ± 120.15ab	130.16 ± 3.69b
	T2	10679.05 ± 211.73a	2912.47 ± 57.74a	2970.85 ± 150.32a	656.53 ± 92.58a
2017	CK	10588.9 ± 356.78c	2887.88 ± 97.30c	1295.77 ± 246.19c	-1592.11 ± 203.14b
	T1	13328.45 ± 443.15b	3635.03 ± 120.85b	1969.97 ± 203.58b	-1665.16 ± 313.64b
	T2	14394.45 ± 467.52a	3925.76 ± 127.50a	2647.46 ± 176.67a	-680.14 ± 49.30a

CK: no fertilizer, T1: chemical fertilizer, T2: chemical fertilizer + organic fertilizer
Means showing the different letter are significantly different ($P < 0.05$) according to the LSD test

Table 2: Effect of different fertilization treatments on nitrogen balance in soil a tobacco production system

Year	Treatment	N_2O emission (kg hm^{-2})	N emission (kg hm^{-2})	Plant nitrogen accumulation/ (kg hm^{-2})
2016	CK	0.51 ± 0.05b	0.92 ± 0.08b	73.97 ± 6.88b
	T1	1.36 ± 0.11a	1.82 ± 0.13a	161.43 ± 10.96a
	T2	1.16 ± 0.10a	1.92 ± 0.16a	169.30 ± 15.23a
2017	CK	0.74 ± 0.15c	1.24 ± 0.09c	43.69 ± 7.99c
	T1	1.34 ± 0.12b	1.88 ± 0.07b	91.00 ± 9.81b
	T2	1.62 ± 0.15a	2.22 ± 0.09a	115.87 ± 12.52a

CK: no fertilizer, T1: chemical fertilizer, T2: chemical fertilizer + organic fertilizer
Means showing the different letter are significantly different ($P < 0.05$) in the LSD test

Table 3: Effects of different fertilization treatments on tobacco yield and soil carbon emission intensity

Year	Treatment	CO_2 change ΔSOC (kg hm^{-2})	Integrated greenhouse effect (kg hm^{-2})	Tobacco yield (kg hm^{-2})	Greenhouse gas emission intensity GHGI (kg kg^{-1})
2016	CK	7198.97 ± 295.65b	7352.14 ± 213.65b	1708.85 ± 150.75c	4.30 ± 0.20b
	T1	10072.57 ± 427.01a	10478.32 ± 420.12a	2190.09 ± 217.54b	4.78 ± 0.28a
	T2	10080.90 ± 211.73a	10425.85 ± 200.32a	2560.28 ± 154.50a	4.07 ± 0.16c
2017	CK	10588.90 ± 356.78b	10808.82 ± 401.48b	1436.25 ± 75.60c	7.53 ± 0.36b
	T1	13328.45 ± 443.15a	13727.74 ± 478.91a	1668.75 ± 103.20b	8.23 ± 0.45a
	T2	13796.30 ± 467.52a	14279.02 ± 521.16a	2025.00 ± 150.00a	7.05 ± 0.47b

CK: no fertilizer, T1: chemical fertilizer, T2: chemical fertilizer + organic fertilizer
Means showing the different letter are significantly different ($P < 0.05$) in the LSD test

production system, acting as carbon source or weak carbon sink. The annual variation of carbon sink capacity in the tobacco soil system was closely related to the variation of plant biomass and carbon sequestration (Table 2). Fertilization can increase plant biomass and carbon sequestration capacity, and significantly increase the system's carbon sequestration capacity. The carbon sink effect of organic fertilizer depends on the biomass and carbon sequestration of the plant in addition to carbon emissions (Gai *et al*. 2019).

Soil carbon emissions from farmland are influenced by various factors such as fertilizer input, irrigation and conservation tillage (Gupta *et al*. 2016; Powlson *et al*. 2016; Zhong *et al*. 2016). Studies have shown that root respiration accounts for 20% of total soil respiration and microbial respiration accounts for 80% (Melillo *et al*. 2002). Organic fertilizers have an advantage in improving microbial activities (Francioli *et al*. 2016), which enhances soil respiration (Fernandez *et al*. 2016). Therefore, the higher CO_2 emission and ammonia volatilization level of organic fertilizer treatment in this study may be related to the promotion of soil microbial activities. Organic fertilizer will mineralize and release CO_2 if it is not applied to farmland. Hence, CO2 produced by organic fertilizer induced soil respiration does not increase atmospheric CO_2 concentration (Li *et al*. 2015). The release of CO_2 from the mineralization of the original organic matter in the soil is an important hazard affecting CO_2 in the atmosphere. Application of organic fertilizer is an effective measure to increase the soil carbon pool and reduce the greenhouse effect (Andreas *et al*. 2015). Under the conditions of this experiment, compared with single application of chemical fertilizer, the application of organic fertilizer increased the CO_2 emission flux and C emission of the soil to a certain extent, and significantly increased the carbon sequestration of the plant, thus improving the carbon sink capacity of the tobacco production system.

In terms of nitrogen balance, the source of soil N_2O was mainly the transformation from fertilizer nitrogen, and its emission was mainly occurred within the 15 days after fertilization. Compared with single application of chemical fertilizer, the application of organic fertilizer can increase the N_2O emission flux of soil to some extent. Meanwhile, the application of organic fertilizer can increase ammonia volatilization level from the soil, which may be related to the promotion of soil microbial activities. Studies have showed that N_2O emissions from conventionally managed soils seemed to be influenced mainly by total N inputs, whereas for organically managed soils other variables such as soil characteristics seemed to be more important (Wei *et al*. 2014). The application of organic fertilizer increased the N emission while significantly increased the nitrogen fixation of the plant, which significantly improved the nitrogen fixation capacity of the soil tobacco ecosystem.

GHGI is a comprehensive indicator of the economic and environmental benefits of fertilization measures. Compared with single application of chemical fertilizers, adding organic fertilizer significantly increased the yield of tobacco leaves, thus ensuring a lower GHGI value. Under the condition of this experiment, the GHGI of organic fertilizer application decreased by an average of 14.60%, and the emission reduction effect was significant. Therefore, proper application of organic fertilizer is an important way to ensure crop yield, improve soil quality, and achieve carbon sequestration.

Conclusion

Adding organic fertilizer can increase the CO_2 and N_2O emission flux of the soil to a certain extent, and increase the C and N emissions. However, organic fertilizer application can increase plant carbon sequestration and tobacco leaf yield, significantly reducing GHGI, and improving soil quality and carbon sequestration. The tobacco soil ecosystem is carbon source or weak carbon sink, which depends mainly on the carbon sequestration of the plant. The carbon sink effect of organic fertilizer is also closely related to the growth of the tobacco plant.

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Author Contributions

TL carried out experiments and wrote the paper. HD analyzed the data and wrote the paper. Q.L. contributed to the Figures. ZZ carried out experiments. AW contributed in Carbon analysis. YZ contributed to experiment design and research management.

Conflict of Interest

There is no conflict of interest among the authors and the institutions where the research has been conducted.

Data Availability

All data reported in this article are available with the corresponding author and will be produced on demand.

Ethics Approval

Not applicable

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