IMPACT OF AGRICULTURAL WASTE RETURN ON SOIL GREENHOUSE GAS EMISSIONS

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(Received 12th Oct 2018; accepted 20th Dec 2018)

Abstract. The effects of agricultural waste return on the emissions of greenhouse gases (CO_2, N_2O and CH_4) from corn farmland in the black soil region of Northeast China and its potential to increase temperature were studied to provide a theoretical basis for formulating reduction measures of agricultural greenhouse gas emissions. This study was conducted at the Experimental Station of China Agricultural University in Quanyangou, Lishu County, Siping City, Jilin Province. Static greenhouse gas chromatography was used to monitor soil greenhouse gas fluxes under different fertilization measures, and the different fertilization treatments were analyzed for comprehensive differences in greenhouse effects among corn fields. The results showed that the average CO_2 fluxes and total emissions in response to the straw return treatment were the highest, reaching 388.96 $mg \cdot m^{-2} \cdot h^{-1}$ and 14718.97 $kg \cdot hm^{-2}$, respectively, and nitrogen topdressing fertilizer significantly increased CO_2 emissions. With respect to CH_4 emissions, single fertilizer-treated plots had the highest average absorbed flux and total absorption—0.042 $mg \cdot m^{-2} \cdot h^{-1}$ and 1.36 $kg \cdot hm^{-2}$, respectively, and with respect to N_2O fluxes, the highest flux and amount were 0.153 $mg \cdot m^{-2} \cdot h^{-1}$ and 5.75 $kg \cdot hm^{-2}$, respectively. The global warming potential of the straw *in situ* treatment was significantly higher than that of the other treatments, and the global warming potential of the cattle manure treatment was lower than that of the single chemical fertilizer treatment, but the differences were not significant. Moreover, straw mulch increased CO_2 emissions from black soils, and dry soils were shown to be important sinks of atmospheric CH_4. Combinations of organic and inorganic fertilizers and individual fertilizers can reduce N_2O emissions from soils. Therefore, to achieve higher corn yields and to reduce greenhouse gas emission intensities simultaneously, applications of organic and inorganic fertilizers constitute an ideal soil fertility method in the black soil region of Northeast China.
Keywords: *CO_2, N_2O, CH_4, global warming potential, emission intensity*

Introduction

With the increasing attention of the international community on climate change, food security and reduced greenhouse gas emissions, research on grain production and reducing greenhouse gas emissions from farmlands has received unprecedented attention from the scientific community (Intergovernmental Panel on Climate Change, 2013). It is estimated that CO_2, CH_4 and N_2O emissions from agriculture account for approximately 12%, 50%, and 60% of the global anthropogenic greenhouse gas emissions, respectively (Ge et al., 2014). The contribution of these three major

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1701_13211335

greenhouse gases combined to global warming has been reported to be as high as 80% (Yuan et al., 2017). Agricultural activities are one of the major sources of greenhouse gas emissions (Yue et al., 2017). Among them, CH_4 emissions from animal manure have reached 2.86×10^6 t, and N_2O emissions from animal manure have reached 2.66×10^5 t, accounting for 28.35% of the total N_2O emissions from agricultural activities; moreover, N_2O emissions from compost account for 5.2% of the N_2O emissions animal manure (National Development and Reform Commission, 2013). Agricultural soils contribute greatly to greenhouse gas emissions (Krobel et al., 2016; Zhang et al., 2017). Fertilization of agricultural soils has a crucial influence on soil greenhouse gas emissions (Cheng et al., 2016; Zhang et al., 2012). Agricultural management techniques such as planting patterns, farming practices, grain filling, and stubble application strongly affect agricultural greenhouse gas emissions. Among all these techniques, fertilization has the greatest impact on greenhouse gas emissions (Qin et al., 2016; Salehi et al., 2017; Zhang et al., 2016a). With the gradual increase in worldwide population, the demand for food will increase, and the amount of greenhouse gas emissions from excessive agricultural activities (such as fertilization) will increase. Thus, the contradiction between food security and greenhouse gas emissions will need to be eliminated; that is, under the premise of ensuring food security, the effective reduction in farmland greenhouse gas emissions will be needed, which is a major problem for the sustainable development of agriculture.

China currently produces the largest agricultural waste output worldwide. The amount of crop straw produced is approximately 650 million tons, and the amount of livestock and poultry manure is approximately 1.73 billion tons (Lozano et al., 2017; Xu et al., 2018; Zhao et al., 2016). These agricultural wastes are not being properly used, which has resulted in a waste of resources and has caused a severe threat to the environment. Researchers in China and abroad have reported that the return of agricultural waste to the field can not only reduce resource waste, reduce the application of chemical fertilizers, improve soil structure, increase soil fertility, and reduce environmental pollution but also affect greenhouse gas emissions by altering soil carbon (C) sequestration potential, which then slows the contribution to global climate change (Epps et al., 2016; Mitran et al., 2016; Zhang et al., 2016). Therefore, replacing some chemical fertilizers with organic fertilizers is an inevitable trend concerning fertilizer applications in the future in China (Ding et al., 2016). This experiment takes corn farmland on black soil in the central part of Jilin Province as a research object and adopts the static box method to study how applications of cow manure, chicken manure, straw and chemical fertilizer under conditions of high organic fertilizer substitution, as well as nitrogen (N), phosphorus (P), potassium (K) and other nutrients, impact greenhouse gas emissions and the warming potential of those emissions. The purpose of this study is to provide a theoretical basis for the resource utilization of agricultural waste and a scientific evaluation of its role in greenhouse gas emissions.

Material and methods

Study site

This experiment was conducted at the Experimental Station of China Agricultural University in Quanyangou, Lishu County, Siping City, Jilin Province, in 2014. The location of the sampling site is given in *Figure 1*. The area had been used to grow monoculture corn under conventional management for more than 10 years, which is

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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harvested annually, and the soil at the site is black soil. The annual average temperature is 6.5°C, the sunshine duration is 2393-2928 h·year^{-1}, the frost-free period is 115-188 days, and the annual cumulative temperature >10°C is 2900-3100°C. The average annual rainfall is 577 mm and is concentrated mainly in June-August, accounting for approximately 65% of the annual precipitation, and the average annual evaporation is 790-820 mm. The basic physical and chemical properties of the 0-20 cm soil layer are as follows: pH of 6.69, 19.90 g·kg^{-1} organic matter, 1.26 g·kg^{-1} total N, 90.72 mg·kg^{-1} alkaline hydrolysis N, 21.27 mg·kg^{-1} available P, and 186.18 mg·kg^{-1} available K.

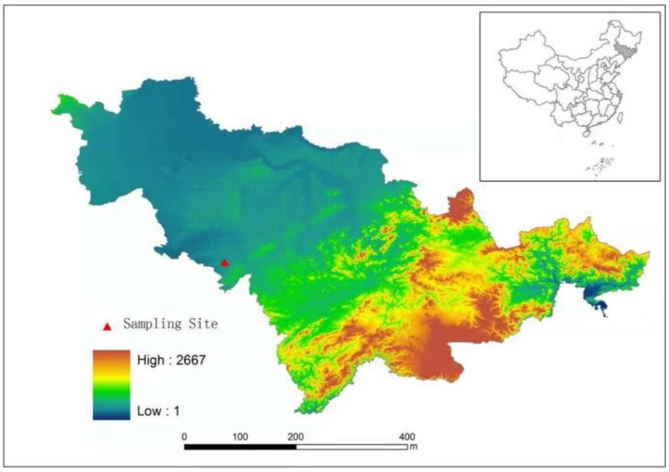

***Figure 1.** Sampling site*

Experimental material

The tested corn variety Liangyu 11 was planted at a ridge spacing of 60 cm, a density of 65000 plants·ha^{-1} and an intended plant spacing of 25.6 cm. With respect to the tested inorganic fertilizers, N was supplied as urea (46% N), P was supplied as diammonium phosphate (18% N, 46% P_2O_5) or heavy superphosphate (46% P_2O_5), and K was supplied potassium sulfate (K_2O 50%), and agricultural waste included cow manure, chicken manure and corn stalks. The nutrient contents of the different agricultural wastes are shown in *Table 1*.

***Table 1.** Nutrient contents of different agricultural wastes (w/%)*

Organic material	Organic matter	Nitrogen	Phosphorus	Potassium
Cow manure	30.34	1.5	0.96	1.23
Chicken manure	34.38	2.87	1.56	1.68
Corn stalks	58.9	0.72	0.25	1.5

Experimental design

The experiment consisted of 5 treatments, 5 test plots, 3 gas collection boxes placed in each treatment plot, and 3 replicates. Each plot was 76 m^2, and the area received natural rainfall and no artificial irrigation. This experiment adopts the principle of equal N, P, and K nutrient contents for the experimental design. The N, P, and K contents in the agricultural waste were converted to pure N, pure P, and pure K for analysis. To

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generate straw for returning to the field, plants were planted at a density of 65000 plants·hm^{-2}. One hundred percent of the straw produced was returned to the field, and cow manure and chicken manure were applied to the field at 50% of the total N application rate (240 kg·hm^{-2}). The remaining amounts of N, P, and K in the organic fertilizers remained in the treatments, and the nutrient content deficiencies were compensated with chemical fertilizers. In other words, it was ensured that the total N, P and K nutrient components applied to the soil in all fertilization treatments were equal, namely, 240 kg·hm^{-2} pure N, 100 kg·hm^{-2} P_2O_5 and 120 kg·hm^{-2} K_2O. The nitrogen and phosphorus nutrients contained in the straw are insufficient, and the rest is supplemented by chemical fertilizer. The excess potassium in the straw does not need to be supplemented. The five treatments were: CK, no fertilization; S1: single chemical fertilizer application, N 240 kg·hm^{-2}, P_2O_5 100 kg·hm^{-2}, K_2O 120 kg·hm^{-2}; S2: straw totally returned to the field, fertilizer nitrogen accounted for nearly 90% of the nitrogen application rate. S3: cow manure returned to the field, the manure nitrogen and chemical fertilizer nitrogen both accounted for 50% of the nitrogen application rate; S4: chicken manure returned to the field, chicken nitrogen and fertilizer nitrogen both accounted for 50% of the nitrogen application rate.

Thirty percent of the N fertilizer application amount was supplied as a basal fertilizer, 40% was applied as topdressing, and 30% was also applied as topdressing. The agricultural wastes as well as the P and potash fertilizers were applied as basal fertilizers at the same time. The specific fertilization schemes are listed in *Table 2*.

On April 27, the agricultural waste was applied to the test plots; it was evenly mixed with the soil to cover the ground surface. On April 28, after mechanical ridging, the surface soil covered the agricultural waste. Manual sowing was conducted on April 29, and the first gas collection was performed on April 30. Fertilization occurred on June 27 and July 28 at the jointing stage and tasseling stages, respectively.

Table 2. *Experimental treatment and fertilizer amounts*

Treatment		Organic Fertilizer (t·hm^{-2})	Organic material (kg·hm^{-2})			Fertilizer (kg·hm^{-2})		
			Amount of N	Amount of P_2O_5	Amount of K_2O	N application rate	P_2O_5 application rate	K_2O application rate
CK	No fertilization	0	0	0	0	0	0	0
S1	Fertilizer	0	0	0	0	240	100	120
S2	Straw return	12.9	24.38	22.58	135.45	215.62	77.43	0
S3	Cow manure applied to the field	26.67	120	76.8	98.4	120	23.2	21.6
S4	Chicken manure applied to the field	13.29	120	65.22	70.24	120	34.78	49.76

Gas sampling

Greenhouse gas samples were collected using the static box method (Yuan et al., 2017). The gas collection box consisted of stainless steel plates welded together. When gas is collected, water is injected into the gas tank, forming a liquid seal with the gas box lid to ensure that the gas in the tank is closed. Gas samples were collected four times between 9:00 a.m. and 11:00 a.m. for 0, 15, 30, and 45 min, after which 100 ml of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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each sample was then pumped into a 100 ml syringe. The sample was subsequently injected into a gas collection bag for storage, which was returned to the laboratory. The temperature inside the box, the soil temperature at a 5 cm depth, the atmospheric temperature, and the atmospheric pressure were recorded to correct the gas mass error caused by the increase in the temperature during the sampling process. The gas sample in the collection bag was ultimately injected into a designated vacuum flask as a sample of the greenhouse gas and sent to the Institute of Applied Ecology, Chinese Academy of Sciences, for testing. The experiment was started on April 29, and the plants were harvested on September 28. The whole growth period was 153 days. Because of the continuous use of basal fertilizers, samples were collected for 7 days, and the N fertilizer topdressings were applied on June 27 and July 28. After continuous sampling for 3 days, the remaining samples were collected once a week. However, due to the large amount of rainfall that occurred on the sample collection day, the gas could not be collected normally, and the gas collection time was delayed. Sampling was performed a total of 29 times. The specific sampling time is shown in *Table 3*.

Table 3. *Date and number of sampling*

Number	Date	Number	Date	Number	Date
1	Apr.30	11	Jun.4	21	Jul.30
2	May.1	12	Jun.12	22	Jul.31
3	May.3	13	Jun.19	23	Aug.7
4	May.4	14	Jun.28	24	Aug.18
5	May.5	15	Jun.29	25	Aug.27
6	May.6	16	Jun.30	26	Sep.3
7	May.7	17	Jul.7	27	Sep.10
8	May.14	18	Jul.14	28	Sep.17
9	May.21	19	Jul.22	29	Sep.25
10	May.28	20	Jul.29		

Test items and methods

Determination of greenhouse gases (CO_2, N_2O, CH_4): Gas samples were collected from a static chamber, and the contents of the greenhouse gases were determined by gas chromatography. An Agilent gas chromatograph instrument 7890A (Agilent Technologies Co., Ltd, USA) was used, and the CO_2 and CH_4 were determined by a hydrogen flame detector (FID). N_2O was determined using an electron capture detector (ECD). The measurement conditions were as follows: for the FID, the temperature was 300°C, the H2 gas flow rate was 100 $ml \cdot min^{-1}$, the practical air flow rate was 200 $ml \cdot min^{-1}$, and the carrier gas was N_2; for the ECD, the temperature was 330°C, and the carrier gas was N_2 at a flow rate of 2 $ml \cdot min^{-1}$.

The greenhouse gas emission flux was calculated as

$$F = \rho \bullet \mathrm{h} \bullet \mathrm{dc/dt} \bullet 273/(273+\mathrm{T}) \quad \text{(Eq.1)}$$

where F is the greenhouse gas flux ($\mu g \cdot m^{-2} \cdot h^{-1}$); ρ is the density of CO_2, N_2O, or CH_4 in the standard state ($kg \cdot m^{-3}$); h is the height of the sampling box (m); dc/dt is the concentration of greenhouse gases in the sampling tank; and T is the average temperature (°C) in the sampling chamber during sampling.

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Data analysis

Statistical analyses were carried out using SPSS (version 11.5, SPSS Inc., Chicago, IL, USA), and the treatment means were compared using the least significant difference (LSD) test at a significance level of $P<0.05$ (Liang et al., 2016).

Results

Atmospheric Temperature, Soil Temperature, and Rainfall During Greenhouse Gas Collection

The environmental conditions on the gas sampling day during the corn growth period in 2014 is shown in *Figure 2*. From April 29 to September 28 (autumn), measurements were taken on a total of 153 days. The atmospheric temperature in the figure is the temperature from 9:00 a.m. to 11:00 a.m. on the collection day. The maximum temperature was 33.03°C, the minimum temperature was 8.00°C, and the average temperature was 22.33°C. The 5 cm belowground temperature represents the mean ground temperature measured by the three gas collection boxes after gas collection on the sampling days; the maximum temperature was 25.33°C, the minimum temperature was 6.23°C, and the average temperature was 18.00°C. During the growth period, the cumulative rainfall was 354.86 mm, and the greatest daily rainfall amounts occurred on June 7 and August 25, which were 38.63 mm and 37.83 mm, respectively.

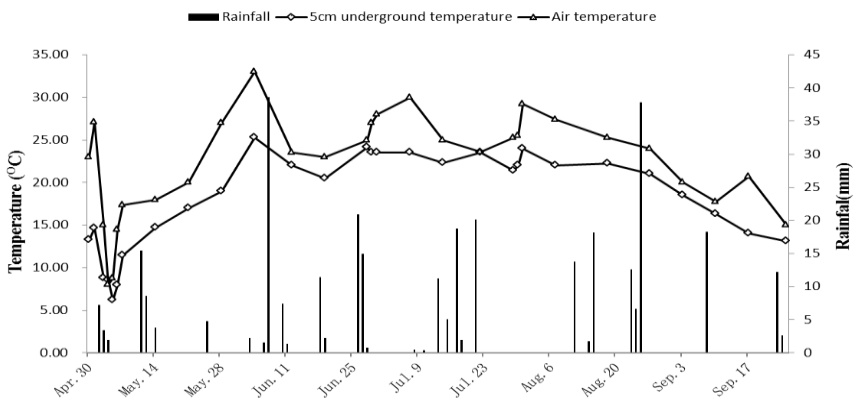

Figure 2. *Variation in temperature and rainfall from April 28, 2014, to September 28, 2014*

Effects of Agricultural Waste on CO_2 Emission Dynamics

As shown in *Figure 3*, the CO_2 emissions during the whole growth period of corn were essentially the same across all treatments and showed clear seasonal changes; that is, the CO_2 emission flux at the beginning and end of the growth period was relatively low (39.9 to 126.5 $mg \cdot m^{-2} \cdot h^{-1}$). The medium-term emission flux was the highest and peaked at the end of June and at the end of July. Between May 28 and July 31, CO_2 emissions in the control (CK) treatment exceeded 200.00 $mg \cdot m^{-2} \cdot h^{-1}$ and accounted for 81.64% of the total CO_2 emissions during the entire growth period. After each fertilization treatment, the CO_2 emissions increased. Under conditions of equal nutrient concentrations, the average CO_2 flux in each treatment was greater than 200 $mg \cdot m^{-2} \cdot h^{-1}$. Excluding the CK treatment, the other treatments each presented two peaks of CO_2

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emissions after N fertilizer was topdressed at the end of June and at the end of July. As shown in *Table 4*, the greatest difference between the average CO_2 emission flux and the total emissions in each treatment was significant, and the average emission flux and total emissions of CO_2 in the straw return treatment (S2) were the highest among the treatments, 0.77% higher (P<0.05) than S1, 8.95% higher (P<0.05) than S3, 3.76% higher (P<0.05) than S4. With the exception of those in the CK treatment, the cumulative CO_2 emissions in the cow manure treatment were the lowest, 3.07% lower (P<0.05) than S1, 9.43% lower (P<0.05) than S2, and 4.49% lower (P<0.05) than S4.

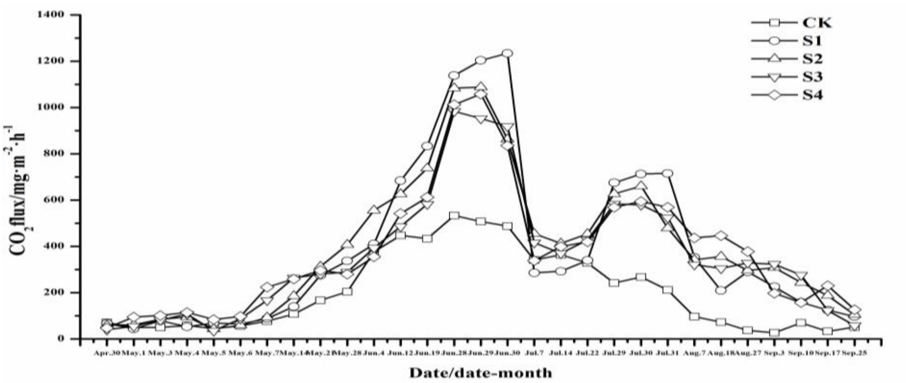

Figure 3. *Emission flux of CO_2 under conditions of agricultural waste returned to the field*

Table 4. *Average emission flux and total cumulative emissions of CO_2, N_2O and CH_4*

	Treatment	Average emission flux ($mg \cdot m^{-2} \cdot h^{-1}$)	Cumulative emission flux ($kg \cdot hm^{-2}$)
CO_2	CK	200.20d	7538.85e
	S1	385.97b	13753.68c
	S2	388.96a	14718.97a
	S3	357.02c	13330.94d
	S4	374.83b	13957.28b
N_2O	CK	0.049c	2.07c
	S1	0.153a	5.75a
	S2	0.139b	5.51b
	S3	0.137b	5.35b
	S4	0.136b	5.21b
CH_4	CK	–0.035ab	–1.32ab
	S1	–0.042a	–1.36a
	S2	–0.025b	–0.81d
	S3	–0.030b	–1.05c
	S4	–0.034ab	–1.23b

Values followed by the same letter within a column indicate no significant difference at 0.05 level for CO_2, N_2O and CH_4

Effects of Agricultural Waste on the Dynamic Characteristics of N_2O Emissions

The N_2O flux from the farmland during the corn growth period is shown in *Figure 4*. All treatments presented positive values, indicating that dryland soil is a source of N_2O emissions. The figure shows that, in the CK treatment, the N_2O fluctuated widely, ranging from 5.43 $\mu g \cdot m^{-2} \cdot h^{-1}$ to 116.10 $\mu g \cdot m^{-2} \cdot h^{-1}$; moreover, the N_2O emissions peaked at 95.38 $\mu g \cdot m^{-2} \cdot h^{-1}$, 116.10 $\mu g \cdot m^{-2} \cdot h^{-1}$ and 97.17 $\mu g \cdot m^{-2} \cdot h^{-1}$ on June 26, July 21 and

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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August 25, respectively, which may be related to the occurrence of relatively large amounts of rainfall. From June 12 to August 27, the N_2O emissions in the CK treatment exceeded 50.00 $\mu g \cdot m^{-2} \cdot h^{-1}$, and the average N_2O emission flux in the CK treatment was 49.32 $\mu g \cdot m^{-2} \cdot h^{-1}$. During the whole growth period, the N_2O emission flux in each fertilizer treatment ranged from 11.90 $\mu g \cdot m^{-2} \cdot h^{-1}$ to 374.72 $\mu g \cdot m^{-2} \cdot h^{-1}$. Under conditions of equal N, P and K nutrient contents, the maximum N_2O emissions (374.72 $\mu g \cdot m^{-2} \cdot h^{-1}$) occurred on June 29 in response to a single application of chemical fertilizer (S1 treatment), most likely due to rainfall that occurred on June 26 and June 27. With respect to the topdressing results, the single fertilizer application (S1) treatment also presented N_2O emission peaks on June 12 and July 30, which may be related to rainfall events that occurred on June 10 and fertilizer applied on July 28. As shown in *Table 4*, the average N_2O emission flux and total emissions between the agricultural waste treatments followed the order of S1>S2>S3>S4, the average emission flux of S1 treatment N_2O is 10.07%, 11.68%, 12.5% higher ($P<0.05$) than S2, S3 and S4, respectively, the difference between S2, S3 and S4 was not significant; however, the total emissions in S2, S3 and S4 significantly differed from those in S1, and the average N_2O emissions were the highest in the S1 treatment, the cumulative emissions of S1 treatment are 4.35%, 7.48%, 10.36% higher ($P<0.05$) than S2, S3 and S4, respectively.

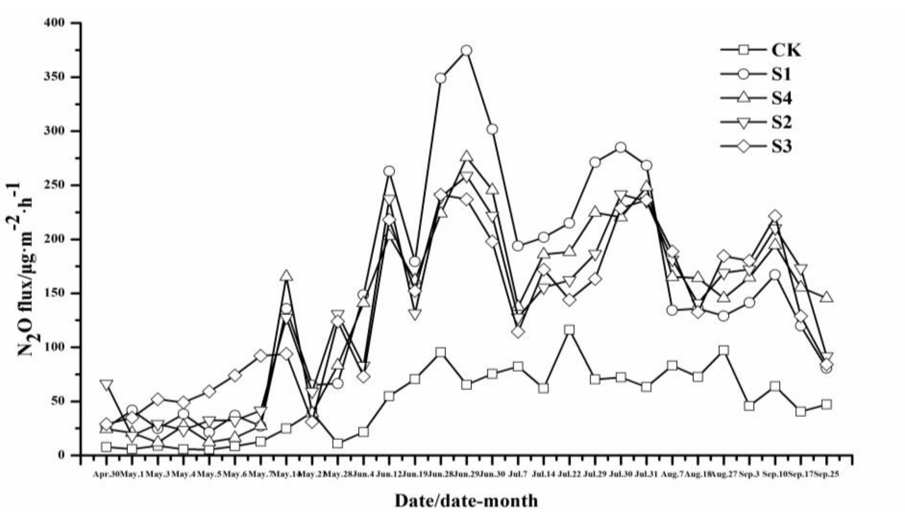

***Figure 4.** Emission flux of N_2O under conditions of agricultural waste returned to the field*

Effects of Agricultural Waste on the Dynamic Change Characteristics of CH_4 Emissions

The CH_4 emission flux in this study is shown in *Figure 5*. The figure shows that each treatment presents a negative value; that is, the atmospheric CH_4 was absorbed by the soil. However, the single application of chemical fertilizer (S1) treatment on August 27 and the 100% straw return (equal to the application of pure N at 215.62 $kg \cdot hm^{-2}$; S2) treatment presented positive values of 15.04 $\mu g \cdot m^{-2} \cdot h^{-1}$ and 8.80 $\mu g \cdot m^{-2} \cdot h^{-1}$, respectively. This result may be due to three days of continuous rainfall that occurred from August 23 through August 25; furthermore, the cumulative rainfall of 57.00 mm, soil moisture content, and suitable conditions for methanogens were inhibited. Similarly, the absorption of CH_4 on June 12 fluctuated, which may be related to the rainfall on June 10 and June 11. Two peaks of 117.55 $\mu g \cdot m^{-2} \cdot h^{-1}$ and 95.02 $\mu g \cdot m^{-2} \cdot h^{-1}$

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occurred on June 29 and July 30, respectively. Under conditions of equal N, P and K, the single application of chemical fertilizer (S1) treatment presented the largest absorption of CH_4 from the atmosphere, and there was no large fluctuation after the S2, S3 or S4 organic and inorganic fertilizer applications. As shown in *Table 4*, the average absorption flux and Cumulative emission flux were in the S1 treatment were significantly higher than those in the three agricultural waste treatments, the average emission flux S1 treatment absorbed 68% more than the S2 treatment ($P<0.05$), 40% more than the S3 treatment ($P<0.05$), and 23.53% more than the S4 treatment ($P<0.05$), the average emission flux difference of the three kinds of agricultural waste is not significant, and comparison among these three agricultural waste treatments, cumulative emission flux were the largest in S4, 51.85% more than S2 ($P<0.05$) and 17.14% more than S3 ($P<0.05$), and the differences are significant between S4 and both S2 and S3.

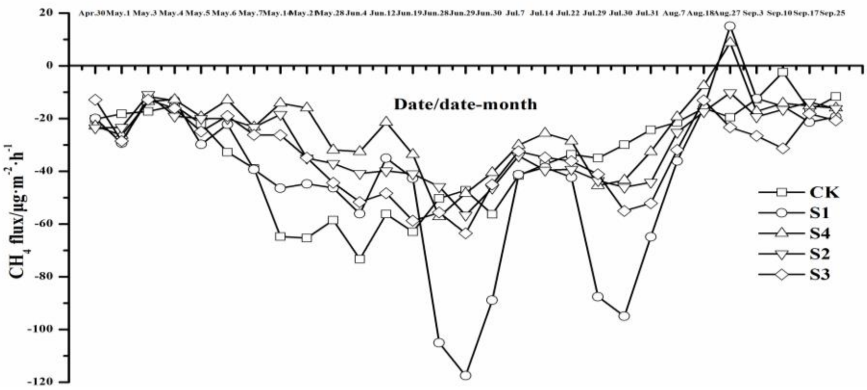

Figure 5. *Emission flux of CH_4 under conditions of agricultural waste returned to the field*

Impact of Agricultural Waste Disposal on the Global Warming Potential (GWP)

The GWP from corn fields is derived mainly from N_2O emissions, as N_2O is a global greenhouse gas with a dominant warming potential. However, the offset of CH_4 from the GWP of corn fields is only a very small proportion. In this experiment, the fixed C in the soil, which constitutes the offset ratio of the GWP within the corn field, accounts for a large proportion. As shown in *Table 5*, the GWP from the cutting and returning of straw to the field (S2 treatment) was significantly higher than that from the other treatments. In addition, the GWP from returning cow manure to the field (S3) was lower than that from the S1 treatment, which significantly differed from the other treatments. The greenhouse gas emission intensity (GHGI) in the S3 treatment was significantly the lowest among all the treatments.

Table 5. *Global warming potential of the different treatments*

Treatment	E-CH_4 CO_2 (kg·hm^{-2})	E-N_2O CO_2 (kg·hm^{-2})	GWP(CH_4+N_2O) CO_2 (kg·hm^{-2})	Emission intensity CO_2 (kg·hm^{-2})
CK	-32.925a	616.86e	8122.79d	-
S1	-34a	1713.5a	15433.8b	0.129a
S2	-26.3c	1594.3c	16430.75a	0.114bc
S3	-30.775b	1552.58d	14898.4c	0.111c
S4	-20.2d	1641.98b	15479.09b	0.119b

E-CH_4 and E-N_2O are emissions of CO_2 in terms of CH_4 and N_2O, respectively
Values followed by the same letter within a column indicate no significant difference at 0.05 level

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Discussion

Applications of organic fertilizers increase source materials of CO_2 production and thus promote the rate of CO_2 release by soil–crop systems (Zhang et al., 2016b). A relatively high soil organic matter content promotes the growth of soil microbes, increases the bioavailability of soil C pools, and improves soil respiration (Xing et al., 2016). The application of organic fertilizers to agricultural soils is an effective method for increasing soil C pools and slowing the greenhouse effect but also increases the rate of CO_2 release from soil respiration (Li et al., 2013; Yang et al., 2017). The results of the present study show that the highest peak of soil CO_2 emissions in response to farmland fertilization treatment occurs on the 7th day after fertilizer application, at the jointing stage. This finding is due mainly to the combined effects of N topdressing fertilizers, increased rainfall after topdressing, and increased temperatures (Guo et al., 2016). Furthermore, soil CO_2 emission peaks occurred after each topdressing during the corn growing season. These peaks occurred because the application of N fertilizer provides corn and microorganisms with N needed for growth; consequently, root respiration increases, and the soil temperature increases. Moreover, N fertilizer promoted intense activity of soil microorganisms, resulting in a rapid increase in soil CO_2 flux (Afreh et al., 2018; Wang et al., 2016). The CO_2 emission flux of soil treated with organic fertilizer and inorganic fertilizer was significantly higher than that treated without fertilizer (CK). This phenomenon was especially true for the CO_2 emission flux from the treatment in which straw was combined with inorganic fertilizer, which is consistent with previous research results (Ping et al., 2018; Shah et al., 2016). Studies have shown that organic fertilizers have a significant impact on soil emissions. This impact occurs mainly because the application of organic fertilizers improves the physical and chemical properties of soils, increases the accumulation of soil organic matter, and promotes both the activity of soil microorganisms and the growth and vitality of the root system, thus increasing emissions (Nigussie et al., 2017). Applications of crop straw can significantly reduce the soil bulk density and can increase soil porosity, accelerating the release of CO_2 gas that was generated in the soil to the atmosphere; thus, the CO_2 emission flux from straw combined with inorganic fertilizer is greatest.

Soil N_2O is a product of nitrification and denitrification, which are performed by microorganisms. N_2O emissions from farmland are constrained by soil aeration conditions and the concentrations of the reaction substrates. The application of organic fertilizer to farmland provides exogenous C and N to the soil, which is also provided by the decomposition of organic matter. The energy required for the additional organic C affects the activity of soil microbes, which then affects nitrification and denitrification (Shi et al., 2017). The results of the present study show that the peak time of N_2O emissions from farmland soils in each fertilization treatment is consistent with the peak CO_2 emissions from the soil, both of which occurred on the 7th day after topdressing at the jointing stage. This result may be due to the rapid increase in soil N content caused by the N topdressing fertilizer. The average N_2O emissions and total emissions in response to the agricultural wastes were significantly lower than those in response to single fertilizers. This result is because single fertilizers increase crop biomass and then enter soils through rice stalks, roots and other residual biomass to promote soil microbial N activity, which in turn increases N_2O emissions. Moreover, the joint effects of increased rainfall and increased temperature during jointing may have been a factor. Guyader and Maris also concluded that the application of organic fertilizers to treat N_2O

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1701_13211335

emissions was significantly lower than that of inorganic fertilizers (Guyader et al., 2017; Maris et al., 2016). Giweta also conducted experiments on the long-term fertilization of cultivated red soil and pointed out that the combined application of chemical fertilizers and organic fertilizers could reduce N_2O emissions (Giweta et al., 2017). The substitution of organic fertilizers for chemical fertilizers (at equal N concentrations) can effectively reduce N_2O emissions from dryland fields (Nótás, 2014). Some previous studies have shown that the application of straw and cow manure can increase soil organic matter content, consume soil O_2 concentration, form anaerobic environment, and promote denitrification and increase N_2O emissions (Liu et al., 2008; Lu et al., 2011). However, the results of this study did not significantly increase N_2O emissions, probably due to the application of high C/N organic materials, stimulating soil heterotrophic microbial growth and reproduction, fixing free NH^{4+}-N in the soil, thereby inhibiting the activity of nitrifying microorganisms in the soil, thus failing to promote N_2O emissions (Recous et al., 1990).

In soils, CH_4 is released mainly by anaerobic methanogens during the process of transmission to the atmosphere, and only a portion of the CH_4 enters the atmosphere (Bansal et al., 2018). Some studies have reported that dryland soils have low CH_4 emissions and that there are many external factors, and dryland soils exhibit good permeability and do not easily produce anaerobic environments; the soil organic matter decomposition rate is high, and soil organic C does not easily accumulate and thus affects CH_4 production. Emissions are therefore considered an important sink of atmospheric CH_4 (Veretennikovn et al., 2017). Gao showed that dry soils with good permeability could inhibit the activity of methanogens and lead to lower CH_4 emissions (Gao et al., 2015). The results of the present study showed that, under conditions of equal nutrient concentrations, the characteristics of the different treatments affected the overall absorption and emissions of CH_4; that is, dryland soil serves as an important sink of atmospheric CH_4, and the single fertilizer treatment and straw return treatment presented emissions on August 27, which may be due to the continuous rainfall that occurred from August 23-25. On the 3rd day of rainfall, the soil moisture content increased, making the conditions suitable for methanogens. In this study, the CH_4 emission flux observed under different fertilization treatments has both positive and negative values, and other soils from the cultivated land or grassland (Omonode et al., 2007; Shimizu et al., 2007). The results of this study are consistent. The cumulative emissions during the entire growth period are negative, indicating that soil is the net absorption sink of CH_4. However, some researchers have concluded that the application of organic fertilizers or organic and inorganic fertilizers combined with the application of CH_4 absorption in dry soil (Dong et al., 2005; Yang et al., 2010). In the dryland fields, the effects of the applications of chemical fertilizers and organic fertilizers to soils on the absorption of CH_4 are not consistent, and additional research is needed.

Understanding the contribution of a specific agricultural measure to the greenhouse effect should help in calculating the effects of that measure in combination with others. Due to the different warming effects of the three greenhouse gases, CO_2, CH_4, and N_2O, their impact on global warming is also different. In this paper, the GWP is used to represent the combined effect of the three types of greenhouse gases, that is, to evaluate their comprehensive contribution by calculating the amount of CO_2 emissions equivalent to the cumulative amount of greenhouse gases emitted from the soil (Lin et al., 2016). From the data obtained from this experiment, the calculated GWP of the treatment in which straw was returned to the field was significantly higher than that of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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the other treatments, and the lowest GWP was in the treatment in which cattle manure was returned. However, to evaluate the comprehensive greenhouse effects of an agricultural ecosystem, not only must the equivalent CO_2 emissions from greenhouse gas emissions be calculated but also the CO_2 emissions caused by agricultural activities, such as irrigation, machinery and fertilizer applications, must be considered (Song et al., 2013; Sainju et al., 2016). Regarding the three types of agricultural waste treatments in this paper, the soil C sequestration potential and the contribution of different ratios to the greenhouse effect must be further studied.

Conclusion

The results of this study show that the average CO_2 flux and total discharge of the straw return treatment were the highest, reaching 388.96 $mg{\cdot}m^{-2}{\cdot}h^{-1}$ and 14718.97 $kg{\cdot}hm^{-2}$, respectively, and the N topdressing fertilizer effects were obvious. With respect to CH_4 emissions, the single fertilizer treatment presented the greatest average absorbed flux and total absorbed amount, which were 0.042 $mg{\cdot}m^{-2}{\cdot}h^{-1}$ and 1.36 $kg{\cdot}hm^{-2}$, respectively, and with respect to N_2O fluxes, the highest flux and amount were 0.153 $mg{\cdot}m^{-2}{\cdot}h^{-1}$ and 5.75 $kg{\cdot}hm^{-2}$, respectively. The GWP and GHGI of the straw return treatment were significantly higher than those of the other treatments, and the GWP and GHGI of the cattle manure return treatment were significantly lower than those of the other treatments. On the basis of the comprehensive greenhouse effect of the soils and GHGI, it was determined that, compared with the application of chemical fertilizers, the application of the combination of organic and inorganic fertilizers not only reduced the soil's comprehensive greenhouse effect (GWP) but also reduced the GHGI of the soil. Therefore, to achieve increased corn yields and to reduce the GHGI concurrently, the combination of organic and inorganic fertilizer applications (especially those comprising cow manure) represents an ideal soil fertility method in the black soil region of Northeast China.

Acknowledgements. This research was supported by the National Key R&D Program of China (2018YFD030020-3, 2017YFD0300604-2 and 2017YFC0504200); National Natural Science Foundation of China (41430857); Key Research Program of Frontier Sciences, Chinese Academy of Sciences (Grant No. QYZDB-SSW-DQC035); Youth Innovation Promotion Association, Chinese Academy of Sciences (2015183); and "135" project planning of Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences (Y6H2042001).

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