



**Full Length Article**

# Biomass Composting Combined with Dicyandiamide Lowered Greenhouse Gas Emissions and Grain Quality of Winter Wheat

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Received 18 December 2019; Accepted 06 January 2020; Published 03 March 2020

## Abstract

Straw compost replacement with chemical fertilizers along with dicyandiamide (DCD) can reduce greenhouse gas emissions and improved wheat yield and quality. The experiment was conducted to explore the impact on greenhouse gas emissions of biomass compost combined with DCD. In this research, the influence of combination of compost with nitrification inhibitor on dynamic change in the emission fluxes of nitrous oxide (N<sub>2</sub>O), carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and yield & quality of wheat was investigated. Wheat was sown using ten treatments: CKN: 225 kg N, 75 kg P and 225 kg K ha<sup>-1</sup>; CK0: 0 kg N, 0 kg P and 0 kg K ha<sup>-1</sup>; T<sub>1</sub>D<sub>1</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>2</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>3</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>4</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 80 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>1</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>2</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>3</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>4</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 80 kg DCD ha<sup>-1</sup>. Results showed that the total greenhouse gas emissions in T<sub>2</sub>D<sub>3</sub> (202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 60 kg DCD ha<sup>-1</sup>) and T<sub>1</sub>D<sub>3</sub> treatments (180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup>) treatments were reduced by 15.7 and 32.2% compared with the traditional application of nitrogen fertilizer. The grain protein content and amylopectin contents were increased in T<sub>1</sub>D<sub>3</sub> (180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup>) by 8–14% compared with control. Moreover, the yield didn't have significant different compared with traditional fertilization. In conclusion, straw compost replacement with chemical fertilizers along with DCD can reduce greenhouse gas emissions. The use of 15 t ha<sup>-1</sup> straw compost + 60 kg ha<sup>-1</sup> DCD reduced chemical fertilizer demand by 20%. © 2020 Friends Science Publishers

**Keywords:** Straw compost; Nitrification inhibitor; Winter wheat; Greenhouse gases; Grain yield

## Introduction

Anhui is an important food production base in China with average annual planting area of wheat (*Triticum aestivum* L.) of 2.4 million ha (Zhang *et al.* 2018). The amount of chemical fertilizers used in Anhui is 33.86% higher than that regulated by China's ecological township construction (Dong and Liu 2018). However, the excessive use of chemical fertilizers gradually decreases the marginal effect of production, slightly increases the crop yield while increase greenhouse gas emissions and cause environmental pollution. The contribution rate of nitrous oxide (N<sub>2</sub>O), carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>) to global warming in the atmosphere reaches 80%, and N<sub>2</sub>O emitted by the

application of chemical fertilizers accounts for 25–82% of the total N<sub>2</sub>O emissions of the soil. The global warming potential of N<sub>2</sub>O is 298-fold higher than of CO<sub>2</sub>, and that of CH<sub>4</sub> is 25-fold higher than that of CO<sub>2</sub> (Li *et al.* 2018).

Research on reducing the application of chemical fertilizers and greenhouse gas emissions has become a hot topic. Using slow-release fertilizers, adding nitrification inhibitors, incorporating organic fertilizers, returning straw to the fields, and using biochar and precision agriculture are the main research areas (Ali *et al.* 2017; Hussain *et al.* 2017). The high-temperature compost of crop straw is one of the effective methods used to treat the combination of rural breeding industry. It cannot only prevent pests and diseases but also replace fertilizers. Straw returning to the

soil can replace fertilizer and reduce CH<sub>4</sub> emissions by 23.6%, but it will increase N<sub>2</sub>O gas emissions (Li *et al.* 2018). Nitrification inhibitors are used to reduce the emission of N<sub>2</sub>O. Dicyandiamide (DCD) is a chemical nitrification inhibitor that can reduce nitrogen oxide emissions by 49.3–79.4%. DCD is widely used in the US, Europe, and other countries, but its application in China is still at the preliminary research stage (Wang *et al.* 2017). No reports have reported on the combination of compost and DCD. The present study combines compost with several chemical fertilizers and DCD to determine the optimal dosage and its effects on greenhouse gas emissions and wheat yield. Thus, the objectives of this study were to clarify the green ecological agriculture model suitable for winter wheat production with environmental-friendliness.

## Materials and Methods

### Description of experimental site

This study was conducted in the plantation of Anhui Science and Technology University (E117° 33' 39" , W32° 52' 49" ) from October 2018 to June 2019. The annual average temperature of the plantation was 15°C, the annual average rainfall was 1200 mm and the frost-free period was 230 days. The previous crop sown was peanut (*Arachis hypogaea* L.). The soil was yellow cinnamon soil that contains 20.8 g kg<sup>-1</sup> organic matter, 110.9 mg kg<sup>-1</sup> available nitrogen, 25.8 mg kg<sup>-1</sup> available phosphorus, and 115.2 mg kg<sup>-1</sup> available potassium in the 0–20 cm surface soil layer. The winter wheat variety tested was Luomai 23. The sampling black box was 50 cm<sup>3</sup> and the 50 cm relay box was used later.

### Experimental treatment and methods

Wheat was sown using ten treatments: CKN: 225 kg N, 75 kg P and 225 kg K ha<sup>-1</sup>; CK0: 0 kg N, 0 kg P and 0 kg K ha<sup>-1</sup>; T<sub>1</sub>D<sub>1</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>2</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>3</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>4</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 80 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>1</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>2</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>3</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>4</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 80 kg DCD ha<sup>-1</sup>. Experiment was laid out following randomized complete block design (RCBD) and replicated three times with net plot size of 4 m × 4 m. Sowing was conducted on October 27, 2018 with 15 cm line spacing using seed rate of 300 kg ha<sup>-1</sup>. Wheat was harvested on June 1, 2019. Compost was the product of the aerobic fermentation of rice (*Oryza sativa* L.) straw and cow dung. The NPK content was 3.25%, the organic matter content was 47.8%, and the pH

was 6.67. The experiment was performed in triplicate, and arranged randomly. The farming, sowing, irrigation, pest control and other field operations of each treatment were consistent with the local traditional way.

### Determined items and methods

**Greenhouse gas collection, measurement, and emission calculations:** Gas was collected using static black box sampling method according to seasonal temperature. Gas was collected once a week from November to December, once every 2 weeks from January to March and once a week from April to June. Gas was collected every 10 min during sampling for a total of three times. The gas was recorded while recording the temperature inside the static dark box and surface. After gas samples were collected in each plot, the gas syringe was brought to the laboratory and measured by gas chromatograph Agilen7890A by using Porapak Q packed column at the oven temperature of 70°C with N<sub>2</sub> as carrier gas. The device was equipped with electron capture detector, and the operating temperature was 330°C. The CO<sub>2</sub> and CH<sub>4</sub> were measured by the FID detector at the operating temperature of 250°C. Three of these greenhouse gas emissions were measured. Interpolation was used to calculate the unobserved daily emission flux. The daily measured and calculated values were added to calculate the total emission of CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub>.

### Global warming potential (GWP) of soil-emitted gas

The influence of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O emitted by wheat field on atmospheric greenhouse effect was quantitatively evaluated by the combined action of three greenhouse gases emitted by soil and was regarded as GWP. In 100-year scale, the global warming effects of 1 kg of CH<sub>4</sub> and 1 kg of N<sub>2</sub>O were 25- and 298-folds higher than that of 1 kg of CO<sub>2</sub>, respectively (Li *et al.* 2018).

### Grain yield and quality

At the maturity stage, a row of wheat was collected from each plot, and the number of productive tillers and the plant height were recorded. The average grain number per spike was calculated by randomly selecting 20 spikes in each plot. The 1000-grain weight and the total grain yield of each plot were calculated by drying and threshing. Grain quality was measured by a NIR grain quality tester (PM-8188).

### Data processing and statistical analysis

WPS office 2007 was used to perform data processing and chart drawing. One-way ANOVA of SPSS 20.0 was used to check the overall significance of data while least significant test (LSD) was used to compare treatments means at  $P < 0.05$ . The data in the figure were the average value ± standard error of three repeated measurements.

## Results

### Emission characteristics of N<sub>2</sub>O in soil

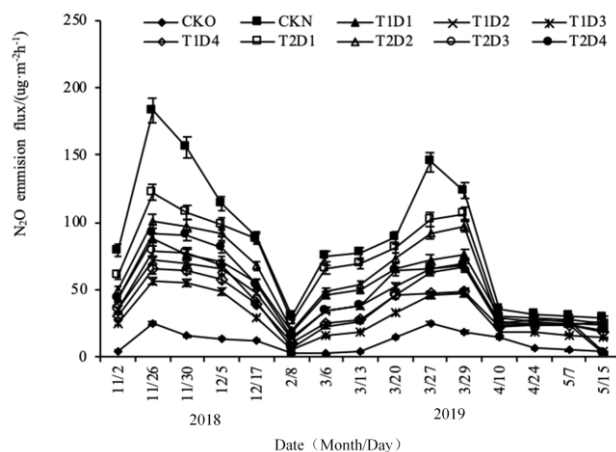
Different treatments had significant effect on greenhouse gas emissions (Figs. 1–3). The N<sub>2</sub>O emission was significantly higher in plots where alone chemical fertilizers (225 kg N, 75 kg P and 225 kg K ha<sup>-1</sup>; CKN) were applied compared with all other treatments while the N<sub>2</sub>O emission was low where no fertilizers or organic amendments (0 kg N, 0 kg P and 0 kg K ha<sup>-1</sup>; CK0) were applied. The N<sub>2</sub>O emission was decreased by DCD. Such as the N<sub>2</sub>O emission of 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup> (T<sub>1</sub>D<sub>3</sub>) was 65.2 and 35.5% lower than (CKN) and (T<sub>1</sub>D<sub>1</sub>) within 34 d after sowing, respectively (Fig. 1). The emission flux of N<sub>2</sub>O in the soil accounted for a large proportion in the sowing–tillering period. The emission of each treatment reached the peak 30 d after sowing. In late November, wheat entered the overwintering stage, and the emission of each treatment showed a slow change trend. When wheat entered the regreening period on March 26, the emission of each treatment increased significantly. Compared with CKN, which showed the second emission peak 151 d after sowing, the other treatments showed the second emission peak 153 d after sowing. After mid-April, the N<sub>2</sub>O emission of different treatments was relatively flat (Fig. 1).

### Emission characteristics of CO<sub>2</sub> in soil

As shown in Fig. 2, the CO<sub>2</sub> emission of CKN treatment was the highest in each stage while the application of DCD by biomass composting reduced the emission of CO<sub>2</sub> to the atmosphere, but the overall trend was relatively consistent. The CO<sub>2</sub> emission of T<sub>1</sub>D<sub>3</sub> was 16.9 and 7.8% lower than the N<sub>2</sub>O emission in CKN and T<sub>1</sub>D<sub>1</sub> treatments on March 27, respectively (Fig. 2); however, the CO<sub>2</sub> emission of CK0 was still lowest. At 34 d after wheat sowing, CO<sub>2</sub> emission showed the peak value. After the peak, wheat entered the wintering period, and the emission flux of CO<sub>2</sub> was low. In March, wheat entered the regreening period. As the temperature increased, the growth rate of wheat and the CO<sub>2</sub> emission flux increased. The CO<sub>2</sub> emission gradually decreased after April. The CO<sub>2</sub> emissions of each treatment were always higher than that of CK0, thereby indicating that the use of fertilizer increased the emission of CO<sub>2</sub> (Fig. 2).

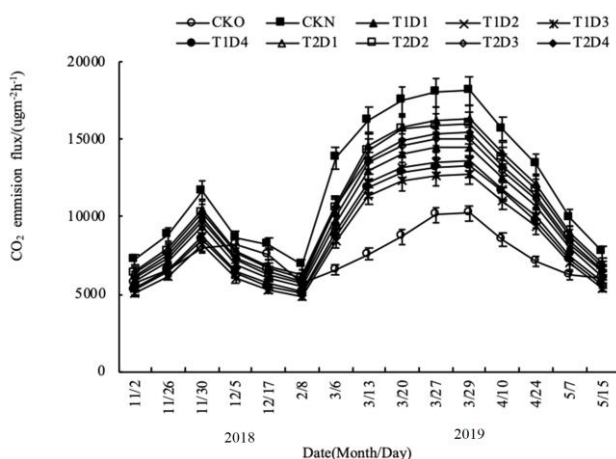
### Emission characteristics of CH<sub>4</sub> in soil

The CH<sub>4</sub> emissions didn't have significant different in biomass compost and DCD treatments as shown in Fig. 3. The CH<sub>4</sub> emissions in the wheat growth stage were mostly negative, and the absorption and emission of CH<sub>4</sub> in each treatment were low at the end of February of the next year. From the beginning of March, the first peak of the absorption of CH<sub>4</sub> appeared in each treatment. After the end



**Fig. 1:** N<sub>2</sub>O Emission flux in wheat soil under crop residue compost added nitrification inhibitor

Here CKN: 225 kg N, 75 kg P and 225 kg K ha<sup>-1</sup>; CK0: 0 kg N, 0 kg P and 0 kg K ha<sup>-1</sup>; T<sub>1</sub>D<sub>1</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>2</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>3</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>4</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 80 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>1</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>2</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>3</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>4</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 80 kg DCD ha<sup>-1</sup>; DCD: Dicyandiamide



**Fig. 2:** CO<sub>2</sub> Emission flux in wheat soil under crop residue compost added nitrification

Here CKN: 225 kg N, 75 kg P and 225 kg K ha<sup>-1</sup>; CK0: 0 kg N, 0 kg P and 0 kg K ha<sup>-1</sup>; T<sub>1</sub>D<sub>1</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>2</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>3</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>4</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 80 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>1</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>2</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>3</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>4</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 80 kg DCD ha<sup>-1</sup>; DCD: Dicyandiamide

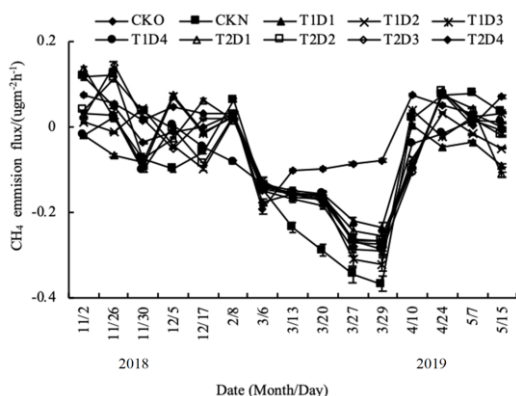
of the regreening period at mid-April, the absorption rate of CH<sub>4</sub> tended to be stable. The emission law of CH<sub>4</sub> was not evident, indicating that the effect of alternative use of compost on CH<sub>4</sub> emissions was not significant (Fig. 3).

**Table 1:** Total emission of greenhouse gas in wheat field with compost return added nitrification inhibitor replaces part of chemical fertilizer

Treatments	Total CO <sub>2</sub> emission (kg ha <sup>-1</sup> )	Total CH <sub>4</sub> emission (kg ha <sup>-1</sup> )	Total N <sub>2</sub> O emission (kg ha <sup>-1</sup> )	Total GWP (kg ha <sup>-1</sup> )
CKN	363.3 ± 1.8i	7.4 ± 0.0a	0.5 ± 0.0i	697.3d
CK0	521.7 ± 3.8a	-17.4 ± 0.1f	3.7 ± 0.0a	1189.3a
T <sub>1</sub> D <sub>1</sub>	408.3 ± 2.8f	-21.6 ± 0.1g	2.3 ± 0.0c	553.7e
T <sub>1</sub> D <sub>2</sub>	382.7 ± 4.9g	-32.1 ± 0.4j	1.9 ± 0.0e	146.4g
T <sub>1</sub> D <sub>3</sub>	357.2 ± 5.8j	-14.0 ± 0.2d	1.3 ± 0.0h	394.6f
T <sub>1</sub> D <sub>4</sub>	373.3 ± 3.5h	-31.6 ± 0.3i	1.6 ± 0.0g	60.1h
T <sub>2</sub> D <sub>1</sub>	459.4 ± 0.9b	-21.2 ± 0.0b	3.2 ± 0.0a	883.0c
T <sub>2</sub> D <sub>2</sub>	449.5 ± 1.8c	-23.9 ± 0.1h	2.7 ± 0.0b	656.6d
T <sub>2</sub> D <sub>3</sub>	423.7 ± 5.0e	-14.4 ± 0.2e	1.8 ± 0.0f	600.1e
T <sub>2</sub> D <sub>4</sub>	434.4 ± 3.5d	-5.7 ± 0.1c	2.1 ± 0.0d	917.7b

Means (± standard deviation) sharing same letters differ non-significantly at  $P \leq 0.05$

Here CKN: 225 kg N, 75 kg P and 225 kg K ha<sup>-1</sup>; CK0: 0 kg N, 0 kg P and 0 kg K ha<sup>-1</sup>; T<sub>1</sub>D<sub>1</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>2</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>3</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>4</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 80 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>1</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>2</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>3</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>4</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 80 kg DCD ha<sup>-1</sup>; DCD: Dicyandiamide; GWP: Global warming potential

**Fig. 3:** CH<sub>4</sub> Emission flux in wheat soil under crop residue compost added nitrification

Here CKN: 225 kg N, 75 kg P and 225 kg K ha<sup>-1</sup>; CK0: 0 kg N, 0 kg P and 0 kg K ha<sup>-1</sup>; T<sub>1</sub>D<sub>1</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>2</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>3</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>4</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 80 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>1</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>2</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>3</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>4</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 80 kg DCD ha<sup>-1</sup>; DCD: Dicyandiamide

### Total emission of greenhouse gas

Applied treatments had significant effect on total emissions of CH<sub>4</sub>, CO<sub>2</sub> and N<sub>2</sub>O as well as global warming potential (GWP) (Table 1). Total emissions of CH<sub>4</sub>, CO<sub>2</sub> and N<sub>2</sub>O as well as GWP were higher in CKN compared with all treatments and lower in CK0 (Table 1). The application of DCD by biomass composting reduced the emission of CO<sub>2</sub>, N<sub>2</sub>O. The CO<sub>2</sub> and N<sub>2</sub>O emissions in T<sub>1</sub>D<sub>3</sub> were 31.5 and 64.7 lower than CKN and T<sub>1</sub>D<sub>1</sub>, respectively. The total GWP of T<sub>1</sub>D<sub>3</sub> was the highest and DCD treatment significantly decreased GWP (Table 1).

### Analysis of wheat yield and yield composition

According to the actual weighing and measurement of wheat after harvest, the interaction between nitrogen-

reducing compost replacement and DCD was significant, with the highest T<sub>2</sub>D<sub>3</sub> of 5998 kg ha<sup>-1</sup>. In the two nitrogen reduction treatments, the yield increased with increasing nitrification inhibitors. The highest yield exceeded the fertilization mode, but D<sub>4</sub> did not exceed the yield D<sub>3</sub>. Hence, DCD of >60 kg ha<sup>-1</sup> cannot play a good role. In terms of yield composition, organic fertilizer replacement increased the grain number per spike, 1000-grain weight, and plant height. However, the grain number per spike did not increase due to the replacement of organic fertilizers (Table 2).

### Wheat quality analysis

The use of organic fertilizers along with DCD, instead of chemical fertilizers, significantly improved the quality of wheat (Table 3). The increase was significant compared with the situation without fertilizer application and chemical fertilizer application, especially T<sub>1</sub>D<sub>3</sub>, which led to the highest protein and amylopectin contents. The protein content and amylopectin contents of T<sub>1</sub>D<sub>3</sub> wheat were increased by 7.9–13.9% and 7.9–14.0% than CH<sub>0</sub>, respectively (Table 3).

### Discussion

The addition of nitrification inhibitor DCD significantly reduced the emission peak and total discharge of N<sub>2</sub>O and CO<sub>2</sub> by 11.9–31.5% compared with traditional fertilizer control treatment, consistent with previously reported findings (Xu *et al.* 2016). Nitrogen in urea exists in the form of ammonium N, and the absorption of wheat is mainly nitrate N. Therefore, the ammonium nitrogen of urea must undergo nitrification in the soil, and N<sub>2</sub>O is one of the important intermediate products of nitrification.

Conventional straw returning to the field increased the N content in the soil, thereby promoting nitrification and denitrification and further increasing N<sub>2</sub>O emissions. Moreover, the N<sub>2</sub>O emission of straw returning to the field

**Table 2:** Effects of composting return and nitrification inhibitors on wheat grain yield

Treatments	Plant height (cm)	Number of productive tillers (m <sup>-2</sup> )	Number of grains per spike	1000-grain weight (g)	Grain yield (kg ha <sup>-1</sup> )
CKN	72.1 ± 2.3c	528.6 ± 3.5a	34.6 ± 1.2b	42.3 ± 3.5b	5946 ± 25.5a
CK0	65.0 ± 0.5d	461.3 ± 3.6c	29.0 ± 0.8c	39.7 ± 2.3b	5023 ± 32.2c
T <sub>1</sub> D <sub>1</sub>	73.2 ± 1.5b	525.4 ± 2.3a	34.4 ± 1.1b	42.6 ± 0.6b	5887 ± 23.8b
T <sub>1</sub> D <sub>2</sub>	73.8 ± 2.1a	522.1 ± 1.2a	34.8 ± 1.5b	42.7 ± 0.6b	5907 ± 18.9a
T <sub>1</sub> D <sub>3</sub>	74.5 ± 1.2a	514.3 ± 1.3b	35.9 ± 0.6a	43.1 ± 1.4a	5929 ± 62.1a
T <sub>1</sub> D <sub>4</sub>	73.6 ± 0.4b	514.6 ± 1.3b	35.5 ± 0.6a	42.9 ± 1.3b	5908 ± 8.2a
T <sub>2</sub> D <sub>1</sub>	72.5 ± 1.0c	521.3 ± 0.9a	35.1 ± 1.4a	42.2 ± 1.7b	5865 ± 92.2b
T <sub>2</sub> D <sub>2</sub>	72.8 ± 0.6b	514.6 ± 1.1b	35.8 ± 0.1a	42.4 ± 0.4b	5901 ± 12.9a
T <sub>2</sub> D <sub>3</sub>	73.6 ± 1.1b	518.2 ± 1.3b	35.7 ± 1.1a	42.8 ± 0.6b	5998 ± 32.9a
T <sub>2</sub> D <sub>4</sub>	73.1 ± 1.1b	525.5 ± 1.2a	34.9 ± 0.6b	42.4 ± 0.9b	5916 ± 54.4a

Means (± standard deviation) sharing same letters differ non-significantly at  $P \leq 0.05$

Here CKN: 225 kg N, 75 kg P and 225 kg K ha<sup>-1</sup>; CK0: 0 kg N, 0 kg P and 0 kg K ha<sup>-1</sup>; T<sub>1</sub>D<sub>1</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>2</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>3</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>4</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 80 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>1</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>2</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>3</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>4</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 80 kg DCD ha<sup>-1</sup>; DCD: Dicyandiamide

**Table 3:** Effects of composting return and nitrification inhibitors on quality of wheat

Treatments	Protein (%)	Unit weight (g l <sup>-1</sup> )	Gluten (%)	Sedimentation value (ml)	Amylopectin (%)
CKN	10.7 ± 0.2b	810.5 ± 0.1b	21.0 ± 0.1a	5.45 ± 0.32b	55.8 ± 0.15b
CK0	9.5 ± 0.1c	790.5 ± 0.1c	19.1 ± 0.2b	3.75 ± 0.07c	50.1 ± 0.03c
T <sub>1</sub> D <sub>1</sub>	11.8 ± 0.1a	899.7 ± 1.4a	23.3 ± 0.1a	6.05 ± 0.03a	61.9 ± 0.01a
T <sub>1</sub> D <sub>2</sub>	12.0 ± 0.1a	907.8 ± 0.2a	23.6 ± 0.2a	6.10 ± 0.05a	62.5 ± 0.05a
T <sub>1</sub> D <sub>3</sub>	12.2 ± 0.1a	924.0 ± 1.2a	23.9 ± 0.1a	6.21 ± 0.03a	63.6 ± 0.03a
T <sub>1</sub> D <sub>4</sub>	12.1 ± 0.1a	915.9 ± 0.1a	23.7 ± 0.0a	6.16 ± 0.02a	63.1 ± 0.01a
T <sub>2</sub> D <sub>1</sub>	11.5 ± 0.1a	875.3 ± 1.0a	22.7 ± 0.0a	5.89 ± 0.01a	60.3 ± 0.01a
T <sub>2</sub> D <sub>2</sub>	11.6 ± 0.2a	883.4 ± 2.3a	22.9 ± 0.1a	5.94 ± 0.02a	60.8 ± 0.03a
T <sub>2</sub> D <sub>3</sub>	11.7 ± 0.2a	891.5 ± 0.1a	23.1 ± 0.0a	5.99 ± 0.03a	61.4 ± 0.02a
T <sub>2</sub> D <sub>4</sub>	11.7 ± 0.4a	887.5 ± 0.1a	23.1 ± 0.0a	5.97 ± 0.03a	61.1 ± 0.03a

Means (± standard deviation) sharing same letters differ non-significantly at  $P \leq 0.05$

Here CKN: 225 kg N, 75 kg P and 225 kg K ha<sup>-1</sup>; CK0: 0 kg N, 0 kg P and 0 kg K ha<sup>-1</sup>; T<sub>1</sub>D<sub>1</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>2</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>3</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>1</sub>D<sub>4</sub>: 180 kg N, 60 kg P, 180 kg K, 15 t biomass compost and 80 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>1</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 20 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>2</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 40 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>3</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 60 kg DCD ha<sup>-1</sup>; T<sub>2</sub>D<sub>4</sub>: 202.5 kg N, 67.5 kg P, 202.5 kg K, 7.5 t biomass compost and 80 kg DCD ha<sup>-1</sup>; DCD: Dicyandiamide

was ~25% higher than that of not returning (Li *et al.* 2018). In the present study, the addition of DCD to straw compost for replacing chemical fertilizer significantly inhibited the nitrification and denitrification reactions. The N<sub>2</sub>O emission after DCD addition was lower than that of conventional fertilizer application, similar to a previous study that reported that the application of organic fertilizer and decomposed manure can also reduce N<sub>2</sub>O emissions (Ren *et al.* 2019). Organic fertilizer and decomposed manure undergo full aerobic fermentation of organic matter. Thus, N is relatively stable, and straw directly returning to the field has not become thoroughly decomposed. The process of decomposition mainly includes carbon–nitrogen conversion. When microorganisms decompose cellulose, hemicellulose, lignin, and other organic matter, N undergoes numerous nitrification and denitrification cycles. This process also exacerbates nitrification and denitrification in the soil, thereby promoting N<sub>2</sub>O emission. However, decomposed straw compost and manure reduce nitrification and denitrification and decrease the emission of N<sub>2</sub>O.

As a nitrification inhibitor, DCD is widely used in Europe and the US. In this study, the effect of 60 kg ha<sup>-1</sup> DCD was the most remarkable among the treatments. Many researchers locally and internationally have suggested that DCD can reduce the emission of greenhouse gases.

Research found that adding 5% nitrification inhibitor DCD and 0.5% urease inhibitor reduced the N<sub>2</sub>O emission by 40.6% compared with traditional fertilization, and the yield increased by ~21% (Maiké *et al.* 2017). This study did not achieve such a significant effect probably because the application of compost was relatively slow and long-term positioning may obtain improved results. In each treatment, the application of chemical fertilizer treatment of 225 kg N ha<sup>-1</sup>, 75 kg P ha<sup>-1</sup>, 225 kg K ha<sup>-1</sup> increased the wheat yield compared with 0 kg N ha<sup>-1</sup>, 0 kg P ha<sup>-1</sup>, 0 kg K ha<sup>-1</sup>, but the effect was not superior to the treatment of DCD supplemented with straw compost. Compared with that of 225 kg N ha<sup>-1</sup>, 75 kg P ha<sup>-1</sup>, 225 kg K ha<sup>-1</sup>, the yields of the other treatments didn't have significant difference; but the quality increased by 7.9–13.8%. The compost returning to field combined with DCD will inevitably affect microbes, which can explain the mechanism of gas emission in this study. The mechanism of action of microorganisms needs to be further studied.

Green agricultural products are one of the research hotspots in recent years. The reduction of chemical fertilizer and the substitution of organic fertilizer can improve the quality of agricultural products, but also bring about the reduction of yield. While nitrification inhibitor can reduce the gas emission, it can also increase the yield. It has been

reported that adding 5% nitrification inhibitor DCD and 0.5% urease inhibitor can reduce the N<sub>2</sub>O emission by 40% compared with traditional fertilization 60%, and the yield increased by 21% (Zhu *et al.* 2019). This experiment did not achieve such a significant effect; maybe because the application effect of compost is relatively slow, long-term positioning should get better effect.

## Conclusion

Straw compost replacement with chemical fertilizers along with DCD reduced greenhouse gas emissions and improved wheat yield and quality. The use of 15 t ha<sup>-1</sup> straw compost + 60 kg ha<sup>-1</sup> DCD reduced chemical fertilizer demand by 20%. Compared with commercial organic fertilizer, the cost of compost can be greatly reduced. Compost can replace chemical fertilizers in the production and reduce the transportation cost of straw and organic fertilizers and, therefore, compost can be widely used in wheat production.

## Acknowledgements

The first author acknowledges the financial grant from Science and Technology Major Projects of Anhui Province (18030701190); National Key R&D Program of China (2018YFF0213500); Natural science Research Program in Universities in Anhui (KJ2018A0527, KJ2019A0810); The Dean fund project (562016Y-4686); Anhui Provincial Education Department's Revitalization Program for 2019 (gxyq2019061); Anhui Science and Technology University student innovation training project (201810879X037, S201910879049, 201910879026S).

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