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Pot Experiment on Mitigation of N_2O Emissions from Phaeozem Paddy Field under Optimum Water and Fertilizer Management

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Abstract

This experiment takes phaeozem paddy field as the object of study to research for the optimum water and fertilizer application scheme for mitigation of N_2O emissions. The effects of nitrogen, phosphorus, potassium and irrigation rate on N_2O emissions in growing season under controlled irrigation was analyzed by four-factor quadratic saturation D-optimum design scheme, using the method of static chamber-gas chromatographic techniques. The results showed that nitrogen had most significant effects for N_2O emissions in growing season and the increase of nitrogen showed promotion effects for N_2O emissions; the effects of phosphorus and potassium were not obvious; the increase of irrigation promoted N_2O emissions at an earlier stage but inhibited it latter. In consideration of yield, an optimum management plan of water and fertilizer was suggested for N_2O reduction by 0%~20%, that was 114.72 kg/hm^2 for nitrogen, 50.25 kg/hm^2 for potassium, 17.64 kg/hm^2 for phosphorus, 80% for relative soil water content at late tilling stage. Under this scheme, the yield was 79.23 g/pot, with an increase rate of about 19.6% (compared with the control group); the emission load was 0.095 g/m^2 in growing season, with an reduction rate of about 8% (compared with the control group).

***Keywords**: water and fertilizer management, N_2O, phaeozem, paddy*

1. Introduction

N_2O is one of the key greenhouse gases in the atmosphere. It can stay in the atmosphere for as long as 120 years and its Global Warming Potentia (GWP) on a century scale is 296 times as great as that of CO_2. Recently, the concentration of N_2O in atmosphere increased at an average annual rate of 0.25% [1]. Soil is the main source of N_2O emissions. Many chemical reactions (*e.g.* nitrification, denitrification, dissimilatory nitrate reduction to ammonium, chemical denitrification) taking place in the soil may generate N_2O and nearly 60% of the global N_2O emissions is from soil [2-3], among which the agricultural soil is the leading source [4-5]. According to early research results, N_2O emissions from paddy field is rare, however, its strong GWP and growth rate shows that N_2O emissions from paddy field shall not be overlooked [6]. Among all the factors affecting N_2O emissions from paddy field, the major factor is field water content and fertilizer management [7-12]. Therefore, it seems more important to find the optimum water and fertilizer management model for N_2O emissions reduction in paddy field. At present, many in-depth researches conducted by scholars mostly focus on the effects of water or fertilizer management in paddy field on N_2O emissions separately [13-16] and rare researches on the effects of water and fertilizer integrated management on N_2O emissions (Coupling Effect) have been carried out. Researches on N_2O emissions reduction combined with yield are even less. This experiment was designed to research on water and fertilizer management technology integrated with

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irritation and fertilizer control. It applied quadratic saturation D-optimum design scheme, conduct key analysis on the water and fertilizer application scheme for nitrogen, phosphorus, potassium and irrigation rate (the irrigation low limit at late tillering stage under controlled irrigation) under controlled irrigation and put forward optimum schemes to provide some water and fertilizer management technology on N_2O emissions reduction in phaeozem paddy field for reference.

2. Materials and Methods

2.1 General Information on the Experimental Field

The experiment was conducted in the gardening experiment station of Northeast Agricultural University in manner of pot experiment. The rice variety for experiment was Dongnong 427, and the soil for experiment was phaeozem taken from the rice field at Xiangfang Botany Experiment Practice Base of Northeast Agricultural University, which is 5km away from the experiment station. The soil fertility: the mass fractions of organic matter, total nitrogen, total phosphorus, total potassium, available nitrogen, available phosphorus and available potassium were respectively 28.56g/kg, 1.45g/kg, 0.78g/kg, 20.76g/kg, 115.82g/kg, 54.3g/kg, 182.6g/kg; the pH value was 6.52; the saturated water content rate for soil under a volume of 0~20cm was 51.42%. Climatic characteristics: cold and temperate continental climate, the annual precipitation varies from 500mm to 550mm, the frost-free season lasts about 140d, and the effective accumulative temperature change (≥10℃) is 2700℃.

2.2. Test Design

The experiment applied saturation D416-optimum design scheme [17], and studied the effects of nitrogen, phosphorus, and potassium and irrigation rate on N_2O emissions in growing season under controlled irrigation. Refer to Table 1 for details. Take the low limit of the relative soil water content (%) at late tillering stage as the basic design parameter for irritation rate (W), and the proportion relationship of irritation rate low limits at other growth stages was: tillering stage (early stage: mid stage: late stage) : jointing and booting stage (early stage: late stage): heading and flowering stage : milk stage = (1.3:1.15:1): (1.15:1.3):1.3:1.15. Refer to Table 2 for details on water content control standard at different growth stages.

The soil was filtered by a 60-mesh screen and fully mixed before taken into the pots. The experiment pots were enclosed barrels made of renewable materials with a height of 30cm and a diameter of 30cm. Fill 15kg soil in each pot, and place 4 rice seedlings in each soil hole. Fill in all pots with soil to ensure that the soil conditions in the pot was identical with those in the field and the variety between different pots is narrowed. The transplanting date was May 27, 2012 and the harvest date was September 25, 2012. Fertilizers used in this experiment were urea (mass fraction of N: 46%), potassic fertilizer (mass fraction of K_2O: 40%), diammonium phosphate (mass fraction of N: 18%, mass fraction of P_2O_5: 46%). The fertilizing proportion of N fertilizer was base fertilizer: tillering fertilizer: earing fertilizer: grain fertilizer= 3:3:2:1. The fertilizing date of base fertilizer was May 18; fertilizing dates of tillering fertilizer, earing fertilizer and grain fertilizer were respectively June 7, June 22 and August 20. The fertilizing proportion of K fertilizer was base fertilizer: earing fertilizer= 1:1. P fertilizer was applied as base fertilizer at one time. There were totally 16 treatments in this experiment and each treatment was repeated for 3 times. The experiment was randomly arranged. In view that the water supply in Treatment 1 was more sufficient than other treatments, the fertilizing level was 0 and the experiment conditions on whole was basically identical with normal irrigation conditions, therefore, Treatment 1 was taken as the control group of this experiment.

Table 1. Experimental Design, Emissions of N_2O in Growing Season and Yield

Treat-ment	Code				Indexes on water and fertilizer application				N_2O (g/m^2)	Yield (g/pot)
	x_1 N	x_2 K_2O	x_3 P_2O_5	x_4 W	X_1 (g/pot)	X_2 (g/pot)	X_3 (g/pot)	X_4 (%)		
1	0	0	0	1.784	0.53	0.36	0.27	80	0.104	66.21
2	0	0	0	-1.494	0.53	0.36	0.27	60	0.092	48.31
3	-1	-1	-1	0.644	0.22	0.14	0.11	75	0.08	39.51
4	1	-1	-1	0.644	0.84	0.14	0.11	75	0.195	45.36
5	-1	1	-1	0.644	0.22	0.56	0.11	75	0.091	56.78
6	1	1	-1	0.644	0.84	0.56	0.11	75	0.130	95.29
7	-1	-1	1	0.644	0.22	0.14	0.42	75	0.101	49.05
8	1	-1	1	0.644	0.84	0.14	0.42	75	0.179	75.70
9	-1	1	1	0.644	0.22	0.56	0.42	75	0.094	55.02
10	1	1	1	0.644	0.84	0.56	0.42	75	0.226	82.34
11	1.685	0	0	-0.908	1.06	0.36	0.27	65	0.249	68.42
12	-1.685	0	0	-0.908	0	0.36	0.27	65	0.066	30.71
13	0	1.685	0	-0.908	0.53	0.71	0.27	65	0.119	51.54
14	0	-1.685	0	-0.908	0.53	0.00	0.27	65	0.098	49.01
15	0	0	1.685	-0.908	0.53	0.36	0.53	65	0.114	57.60
16	0	0	-1.685	-0.908	0.53	0.36	0	65	0.100	41.16

Table 2. Soil Water Management at Root Layer for Different Growth Stages

Water treatment		Tillering stage			Jointing and booting stage		Heading and flowering stage	Milk stage	Yellow ripe stage
		Early stage	Middle stage	Late stage	Early stage	Late stage			
Upper limit of irrigation		100	100	100	100	100	100	100	
Lower limit of irrigation	W1	100	92	80	92	100	100	92	Drying
	W2	100	85	75	85	100	100	85	
	W3	85	75	65	75	85	85	75	
	W4	80	70	60	70	80	80	70	

Note: (1) Water layer height of field irrigation in returning green stage: 10 to 30 mm.

(2) The numbers in Table 2 is the relative soil water content rate refers to the proportion of the soil water content rate in the saturated water content rate of soil.

2.3. Experiment Indexes and Methods

Static chamber method generally selected by scholars was used for gas sampling [18-20]. The chamber was a cuboid made of organic glass and its side length of the cross section was 18cm. The outer surface of the chamber was covered with thermal insulation materials (sponge and the aluminum foil) to reduce the temperature change in chamber due to solar radiation during the sampling. At the early growth stage, the height of the chamber was 90cm; the height turned 130cm after heading stage. Three-way valve adopt holes was set 30cm away from the chamber top on its side for connection with three-way valve and for easy gas collection. A fan was set at the inner top of the sampling chamber to fully mix the gases. Before transplanting, a wooden base was placed in the sampling basin to ensure that the basin was at the same level with the mud surface. During sampling, the sampling chamber was placed carefully on the square base, and the water in the base served to isolate the gases inside and outside the chamber. A test was conduct a week after the transplanting. Test time was 10:00—12:00 [21-22]. Three parallel acquisitions were conducted for each treatment, once one week until the last week before the harvest. For gas sampling, an injector was used to collect about 100mL of gas in the chamber at 0, 5, 10 and 15min respectively. The collected gas was transferred to a sample bag made of aluminum foil, which was taken back to the laboratory timely for test.

Daojin GC-14B gas chromatograph was used to detect the concentration of N_2O. The detector was a thermal conductivity detector (TCD), the temperature was 100℃, the parting material was Porapak Q and the column temperature was 55℃. The standard gas was provided by the National ResearchC enter for Certified Reference Material.

2.4. Calculation Methods and Data Analysis

N_2O emission flux was calculated by Eq. (1):

$$F = \rho \cdot h \cdot \mathrm{d}c / \mathrm{d}t \cdot 273 / (273 + T) \quad (1)$$

Where, F means gas emission flux (mg·m^{-2}·h^{-1}), ρ means gas density (kg·m^{-3}) in standard state, h means chamber height (m), $\mathrm{d}c/\mathrm{d}t$ means rate of concentration change (mL·m^{-3}·h^{-1}) of gas in sampling chamber, 273 means gaseous equation constant, and T means mean temperature (℃) in sampling chamber during sampling [23]. The integral interpolation method was used to obtain the monthly rice field N_2O emission flux, and the sum of all monthly emission fluxes is the total N_2O emission amount through the whole growth stage of rice [24].

The experimental data received statistical analysis by using Excel2003 和 SPSS17.0.

3. Results and Analysis

3.1. Effect Function of N_2O Emissions in Growing Season

Conduct quadratic regression polynomial analysis, taking the code values in Table 1 (x_1 (N), x_2 (K_2O), x_3 (P_2O_5), x_4 (W)) as independent variables and the average N_2O emissions in growing season in Table 1 (Y_1) as dependent variables, and get the regression equation between N_2O emissions and N fertilizer, K fertilizer, P fertilizer and irrigation rate.

$$Y_1 = 0.0833 + 0.0491x_1 + 0.0016x_2 + 0.0094x_3 + 0.0055x_4 - 0.0029x_1x_2 + 0.0069x_1x_3 - 0.0056x_1x_4 + 0.0117x_2x_3 - 0.0052x_2x_4 + 0.0057x_3x_4 + 0.0197x_1^2 + 0.0026x_2^2 + 0.0020x_3^2 - 0.0086x_4^2$$

Check the regression equation:

$$F = 3.9225 > (F_{0.01}(15, 30) = 2.78)$$

The result was: the above equation clearly reflected the relationship between N_2O emissions in growing season and nitrogen, phosphorus, potassium and irrigation rate.

3.1.1. Signal-Factor Effect Analysis

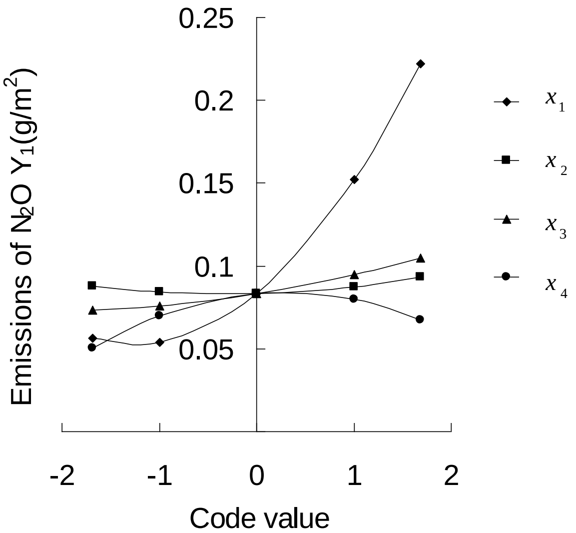
The method of "Dimensionality Reduction" was adopted to calculate the effects of single factors on N_2O emissions in growing season. Select three factors randomly and set them as the code value of 0, then get the following single-factor effect equations:

$$Y_1 = 0.0833 + 0.0491x_1 + 0.0197x_1^2$$

$$Y_1 = 0.0833 + 0.0016x_2 + 0.0026x_2^2$$

$$Y_1 = 0.0833 + 0.0094x_3 + 0.0020x_3^2$$

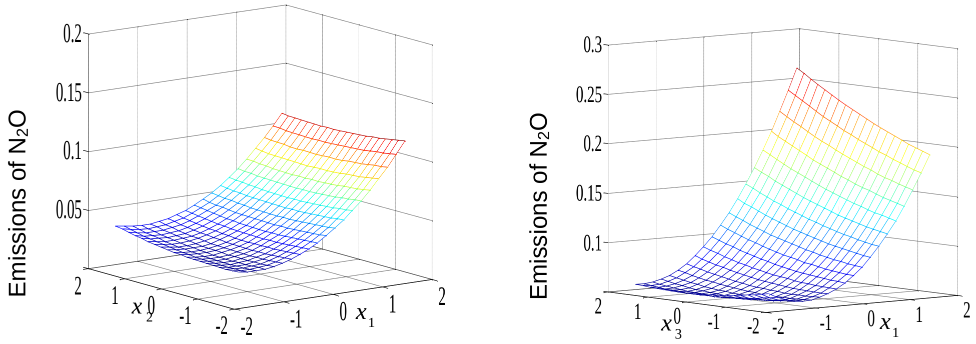
$$Y_1 = 0.0833 + 0.0050x_4 - 0.0086x_4^2$$



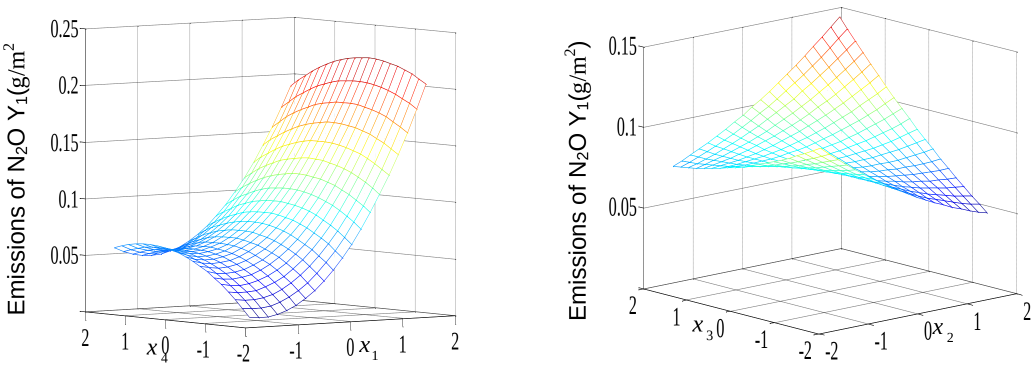
Note: Single-Factor Effect, other Factors Fixed at Level 0

Figure 1. Curve of Single-Factor Effect on the N_2O Emissions in Growing Season

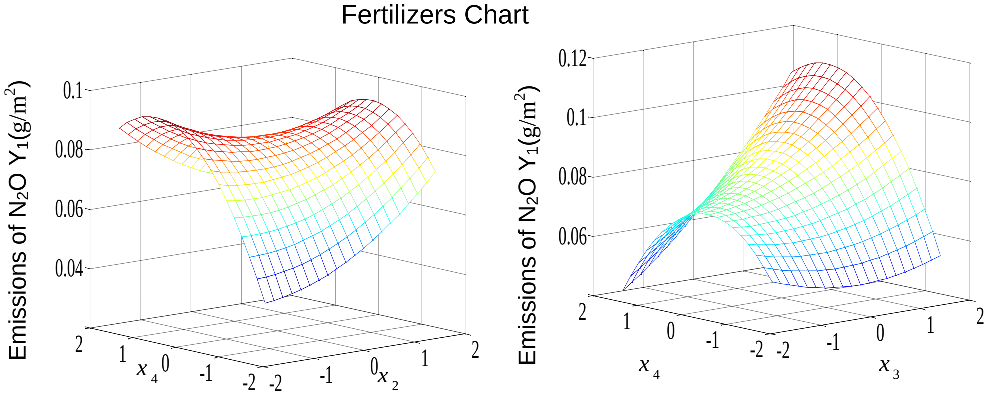
According to the single-factor effect curve of nitrogen, phosphorus, potassium and irrigation rate on N_2O emissions in growing season (see Figure1), under smaller rate of fertilizer application, the increase of potassium promoted N_2O emissions, the application of nitrogen and phosphorus inhibited N_2O emissions in growing season; under greater rate of fertilizer application, the increase of nitrogen, phosphorus and potassium promoted N_2O emissions in growing season, and nitrogen had the most significant effect. The increase of irrigation promoted N_2O emissions at an earlier stage but inhibited it latter.



a) Interaction Between N and K Fertilizers Chart b) Interaction Between N and P Fertilizers Chart



c) Interaction Between N Fertilizer and W Chart d) Interaction Between K and P Fertilizers Chart



e) Interaction Between K Fertilizer and W Chart f) Interaction Between P Fertilizer and W Chart

Figure 2. The Analysis of Two-Factor Interactive Effect on the N_2O Emissions in Growing Season

3.1.2. Factor Interaction Effect Analysis

Select two factors randomly and set them as the code value of 0, then get the other two factors' interaction effect equations. For example, $x_3 = x_4 = 0$, then get the sub-model between N_2O emissions (Y_1) and nitrogen (x_1) and potassium (x_2):

$$Y_1 = 0.0833 + 0.0491x_1 + 0.0016x_2 - 0.0029x_1x_2 + 0.0197x_1^2 + 0.0026x_2^2$$

The other 5 sub-models (omitted) can be got with such method. Refer to Figure2 for the chart of such two-factor interaction effect equation. According to (a), (b) and (c) in Figure2, within the experiment code range, the cases where N_2O emissions in growing season was relatively low were uniformly under low nitrogen. Nitrogen had major effects on N_2O emissions in growing season and the interaction effects of nitrogen and potassium, nitrogen and phosphorus, nitrogen and irritation rate were not obvious. According to (d) in Figure2, under low potassium, the increase of phosphorus inhibited N_2O emissions in growing season; while under high potassium, it promoted N_2O emissions in growing season. The above showed that the interaction effects of potassium and phosphorus was obvious. According to (e) in Figure2, under low irritation rate, the increase of potassium promoted N_2O emissions in growing season; while under high irritation rate, it inhibited N_2O emissions in growing season. The above showed that the interaction effects of potassium and irritation rate was obvious. According to (f) in Figure2, under low phosphorus, the over-increase of irritation rate inhibited N_2O emissions in growing season; while under high phosphorus, the increase of irritation rate promoted N_2O emissions in growing season. The above showed that the interaction effects of phosphorus and irritation rate was less significant than that of potassium and phosphorus.

3.1.3. Optimum Water and Fertilizer Application Scheme Analysis

Frequency analysis method was used to search optimum model. Within the designed experiment range, the code values were divided into 5 levels (-1.784, -0.8920, 0, 0.8920, 1.784) with T=54=625 treatment combinations. Under the case that N_2O emissions reduction rate was 0%-20% in growing season (80%~100% of the emissions of the control group), the one where N_2O emissions in growing season was 0.08~0.104 g/m^2 was selected for frequency analysis. Refer to Table 3 for the searching result of water and fertilizer management simulation equation of N_2O emissions in growing season.

As the yield must be secured during greenhouse emissions reduction in paddy field, further combination of the water and fertilizer coupling production model below in this experiment was necessary[25].

$$Y_2 = 56.03 + 11.82x_1 + 6.14x_2 + 3.86x_3 + 7.03x_4 + 18.36x_1x_2 - 12.99x_1x_3 + 9.85x_1x_4$$
$$- 3.10x_3^2 - 6.08x_4^2 - 6.82x_2x_3 + 5.94x_2x_4 - 1.12x_3x_4 - 3.03x_1^2 - 2.78x_2^2$$

Among the 46 results in search optimum models, a group was found to meet the requirements on yield (Y_2>66.21g/pot, compared with the control group) within the experiment code range and the code values (nitrogen, potassium, phosphorus and irrigation rate) of it are: 0.8920, 0, -0.8920, 1.7840. Therefore, we found a comprehensive and optimum water and fertilizer application scheme, which secured a N_2O reduction in growing season as well as a stable yield, *i.e.* 114.72 kg/hm^2 for nitrogen, 50.25 kg/hm^2 for potassium, 17.64 kg/hm^2 for phosphorus, 80% for relative soil water content at late tilling stage. Under this scheme, the yield was 79.23 g/pot, with an increase rate of about 19.6% (compared with the control group); the emission load was 0.095 g/m^2 in growing season, with an reduction rate of about 8% (compared with the control group).

Table 3. Water and Fertilizer Application Scheme of N_2O Emissions in Growing Season Between 0.08-0.104 g/m_2

Code value	nitrogen		potassium		phosphorus		Irrigation rate	
	Times	Frequency/%	Times	Frequency/%	Times	Frequency/%	Times	Frequency/%
-1.784	14	18.92	23	31.08	20	27.03	5	6.76
-0.8920	9	12.16	15	20.27	10	13.51	10	13.51
0	40	54.05	6	8.11	10	13.51	20	27.03
0.8920	10	13.51	13	17.57	19	25.68	21	28.38
1.784	1	1.36	17	22.97	15	20.27	18	24.32
Average value	-0.3014		-0.1688		-0.0121		0.4460	
Standard error	0.1019		0.1652		0.1578		0.1241	
95% confidence interval	-0.5012~-0.1015		-0.4926~0.1551		-0.3213~0.2972		0.2028~0.6892	
Optimum scheme	52.71~70.49		35.59~54.88		30.36~44.12		71.24%~74.21%	

Note: The unit of optimum dosage of N, P and K is kg/hm^2.

4. Discussion

(1) Water and fertilizer are two major factors affecting N_2O emissions. This experiment adopted a saturation D416-optimum design scheme, established mathematical models for effects of K fertilizer, N fertilizer and P fertilizer and irrigation rate on N_2O emissions from paddy field in growing season. Through significance test, the above models reflected the relationship between N_2O emissions and water & fertilizer to promote the quantitative research on water and fertilizer.

(2) It makes no sense conducting a research on greenhouse gas reduction from paddy field without combination with the yield. This experiment suggested a comprehensive and optimum water and fertilizer application scheme, which secured a N_2O reduction rate of 0%-20% in growing season as well as a stable yield. Under the above scheme, the yield increased about 19.6% (compared with the yield under conventional irrigation fertilization conditions); N_2O emissions decreased about 8% in growing season. All of these created a practical guiding significance in greenhouse gas reduction and rice cultivation. However, most of early researches merely focused on one factor of N_2O reduction and the rice yield and rarely succeed to realize combination of both.

(3) The comprehensive and optimum water and fertilizer application scheme under controlled irrigation is a water and fertilizer management technology for paddy field worth to be promoted and applied as it succeeds to reduce N_2O emissions and secures a stable yield, which not only saves water resource but also reduces air pollution. This paper shows a preliminary study on the coupling effects of water and fertilizer on N_2O emissions in growing season. Through further research, we will collect more data from multiple years and correct the models by introducing more rice rarities and the meteorological factor for improvement and greater practical guiding significance.

5. Conclusions

(1) The effects of nitrogen, phosphorus, potassium and irrigation rate on N_2O emissions from paddy field in growing season under controlled irrigation were different. According to the analysis, nitrogen had most significant effects on N_2O emissions and the increase of nitrogen promoted N_2O emissions much; the effects of potassium and phosphorus on N_2O emissions was not obvious; the increase of irrigation rate promoted N_2O emissions at an earlier stage but inhibited it latter. The coupling effects of potassium and phosphorus on

N_2O emissions was positive; that of potassium and irrigation rate on N_2O emissions was negative.

(2) The comprehensive optimum water and fertilizer application scheme was suggested to ensure that N_2O emissions in growing season was reduced by 0%~20% and the rice yield was not less than that of the control group: 114.72 kg/hm^2 for N fertilizer nitrogen, 50.25 kg/hm^2 for potassium, 17.64 kg/hm^2 for phosphorus, 80% for relative soil water content at late tilling stage.

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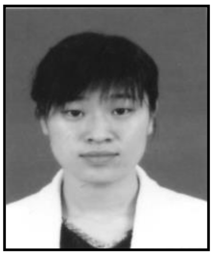

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