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Effect of Different Nitrogen Fertilizers with Reclaimed Water Irrigation on Soil Greenhouse Gas Emissions

Ning Ma^a, Shumei Ren^b, Peiling Yang^c, Yanbing Chi^d, Dawei Gao^e

College of Water Resources and Civil Engineering, China Agricultural University, Beijing 100083

^aningma90@163.com, ^brenshumei@126.com, ^cyangpeiling@126.com, ^dchiice@163.com, ^e18810395806@163.com

Abstract: In order to investigate the effect of using different nitrogen fertilizer with reclaimed water irrigation on the emissions of soil greenhouse gases (CO₂ and N₂O), plot experiments were conducted using clean water and reclaimed water combined with different nitrogen fertilizer (urea, ammonium sulfate, slow release fertilizer) for irrigation. No significant differences in CO₂ and N₂O emission flux was observed between the treatments irrigated with clean water and ones with reclaimed water. The soil CO₂ emission flux had no significant relationship with the application of nitrogen fertilizer, whereas the soil emission flux increased significantly as applied with nitrogen fertilizer. The N₂O emission flux reached its maximum in 2-5 days after irrigation.

Keywords: Reclaimed water, Nitrogen fertilizer, CO₂, N₂O, Emission flux

1 Introduction

Global warming is a critical issue challenging the security of the whole human society today. The main trigger of global warming is the excessive emission of greenhouse gas (i.e. CO₂, CH₄ and N₂O) and the contribution of these three to the greenhouse effect rate are up to 80%^[1]. CO₂ makes the greatest contribution to adding greenhouse effect, accounting for about 60%, which is the most important greenhouse gas^[2]. N₂O is long-lasting greenhouse gas and not only it has a warming effect, but also can damage the ozone layer. The N₂O warming effect is 296~310 times of CO₂^[3]. In the process of agricultural production, agricultural greenhouse gas emissions is one of the important causes for global warming, about 5%-20% CO₂, 15%-30% CH₄ and 80%-90% N₂O derives from soil every year, so agricultural emission reductions allows of no delay^[4].

China is one of the 13 countries under acute water shortage and per capita water resource is only about 1/3 of the world average level. In China, especially in the northern water shortage area, the use of reclaimed water has become an inevitable trend. The reclaimed water refers to the industrial wastewater or domestic sewage treated to non-potable water, which achieves a certain quality standard and can be repeatedly used in a certain extent. It is not affected by climate, convenient to use, stable, reliable and high guaranteed. It can not only reduce the discharge of sewage,

but also reduce demand on freshwater resources. The reclaimed water has become an important supplemental source of water for agricultural irrigation production [5]. Reclaimed water as a kind of irrigation water can increase soil fertility in some degree, and the application of reclaimed water irrigation has a certain degree of security in heavy metal [6]. Water shortage will be expected to reach $1.3 \times 10^{10} \text{ m}^3$ and the available quantity of reclaimed water will reach $7.67 \times 10^{10} \text{ m}^3$ by the year 2030 [7]. However, because the reclaimed water contains high concentration of nutrient, salinity, bacteria, organic matter and suspended solid particles, using reclaimed water will change soil micro environment and it may cause environmental problems including soil salinization, decreasing soil fertility and increasing agricultural greenhouse gas emission if used inappropriately [8]. In this case, the objective of this study is to investigate the effect of different nitrogen fertilizer with reclaimed water irrigation on soil greenhouse gas emissions, which may be used as a guideline for greenhouse gas emissions control in long-term sustainable use of reclaimed water.

2 Materials and Methods

2.1 Experimental Material

The experimental soil was vadose zone soil collected from the southeast suburb of Beijing irrigation area where the soil was loam at the upper 80 cm depth and sandy at the lower 40 cm. Basic physical characteristics of soil are shown in Table 1.

Table 1. The basic physical parameters of experimental soils

Soil depth cm	Particle size composition (%)			Soil texture	Bulk density $\text{g} \cdot \text{cm}^{-3}$	Field capacity $\text{cm}^3 \cdot \text{cm}^{-3}$	Initial water content %
	Clay <0.002mm	Silty sand 0.02~0.002mm	Sand 2~0.02mm				
0~80	9.11	37.85	54.04	Loam	1.40	0.36	16.1
80~120	3.39	8.13	88.49	Sand	1.40	0.33	11.2

The reclaimed water was secondary stage sedimentation effluent from the Qinghe sewage treatment plant. The basic parameters of irrigation water are shown in table 2.

Table 2. Irrigation water quality parameters

Water quality		Clean water	Reclaimed water
pH		7.56	7.97
EC	$\mu\text{S} \cdot \text{cm}^{-1}$	494	1010
BOD ₅	$\text{mg} \cdot \text{L}^{-1}$	<0.5	3.8
COD _{Cr}	$\text{mg} \cdot \text{L}^{-1}$	<5	16.5

Organic nitrogen	mg · L ⁻¹	0.710	1.02
Total organic carbon	mg · L ⁻¹	1.4	5.6
Total nitrogen	mg · L ⁻¹	1.00	5.18

2.2 Experimental Design

The experiment started in the water conservancy test hall in College of Water Resources and Civil Engineering, China Agricultural University from July 29, 2013. The soil tank area was 1.2m × 1.2m, 1.5m high. The irrigation method was surface flood irrigation. There were six treatments which were: CK, CK-APSU, RW-APSU, RW-U, RW-APS, RW-SPC (Table 3).

According to efficient water-saving irrigation system of Beijing Plain area for summer maize flat water years, the irrigation quota was 600m³/hm², simulating summer maize irrigation. Irrigation was conducted three times in the experiment. The first irrigation amount was 40L, the second and the third irrigation amount was 20L for each treatment. Nitrogen fertilizer (300 kg/hm²) was applied with water at the first irrigation. Test used urea with 46% nitrogen content, ammonium sulfate nitrogen content of 21% and slow-release fertilizer nitrogen content of 46%.

Table 3. Fertilization treatments

Treatments	Urea (g/m ²)	Ammonium sulfate (g/m ²)	Slow-release fertilizer (g/m ²)
Clean water (CK)			
Clean water with ammonium sulfate and urea (CK-APSU)	32.61	71.43	
Reclaimed water with ammonium sulfate and urea (RW-APSU)	32.61	71.43	
Reclaimed water with urea (RW-U)	65.22		
Reclaimed water with ammonium sulfate (RW-APS)		142.86	
Reclaimed water with slow-release fertilizer (RW-SPC)			65.22

2.3 Experimental Methods

The basic principle of sampling static chamber ^[9] is to use the sealed bottomless boxes (made from a chemically stable material) to cover up the surface to be measured for a certain period of time and extract the gas inside. Determine trace gas concentration using chromatograph machine and then calculate the gas exchange rate of surface quilt-trace gases between ground and atmosphere according to the changing time rate of gas concentration.

Temperature and soil moisture are all important factors affecting trace gases. Therefore, in the determination of fluxes of greenhouse gas emissions, it is also

necessary to measure the temperature and soil moisture in observation point. This experiment used TRIME tube which had been laid in the soil already, measuring water content in different soil depths (0-10cm, 10-20cm, 20-40cm, 60-80cm, 80-100cm, 100-120cm) for each treatment. Domestic JM624 portable digital thermometer was used for measuring air temperature and soil temperature in observation points.

Gas sampling is generally collected at 9:00-11:00 am, for soil temperature during this period is closest to average daily temperature. Before covering the box, the tank was filled with 1/2 water. After covering the boxes, we extracted gas in 0,10,20,30 min with 40mL polypropylene medical syringes which have three-way valve. Sample collection was tested by Chinese Academy of Agricultural Sciences Institute of Agricultural Environment and Sustainable Development Analysis Test Center and the analysis is completed within 24h. After the initial time and the last sample extraction were completed, the temperature value would record. After the gas samples was collected, using TRIME tube to measure water content in different soil depths (0-10, 10-20, 20-40, 60-80, 80-100, 100-120 cm) of different treatments. Samples were collected before irrigation and at 1 d, 2 d, 5 d, 10 d, 18 d after irrigation.

2.4 The data processing principle

Flux refers to the amount of substance of unit area per unit time ^[10]. According to the calculation formula of sampling static chamber:

$$F = \frac{M}{V_0} \frac{P}{P_0} \frac{T_0}{T} H \frac{dc}{dt} \quad (1)$$

For the specific target compounds, the type M is the molar mass, P₀ and T₀ are ideal gas pressure and temperature (1013.25 hpa and 273.15 K) under standard conditions, V₀ is the target compound molar volume in the standard state, i.e. 22.4L • mol⁻¹, H is the sampling box chamber top space height, P and T is the actual sampling gas pressure and temperature, dc/dt is regression curve slope of the time changing target gas concentration.

The parameters required in calculation are the actual height of sampling box H, the sampling pressure P, sampling temperature T in the box, and regression curve slope of the time changing target gas concentration dc/dt.

2.4.1 The determination of actual height of sampling box (H)

The vertical distance from the bottom depth of the soil surface is defined from the water at the bottom of the base when measuring, then

$$\text{The actual height} = \text{sampling box height} - \text{bottom depth} \quad (2)$$

In this experiment, the sampling box height is 50cm, the water depth is -3cm, the actual height of sample box is 53cm, namely H=0.53m.

2.4.2 The determination of pressure (P)

Pressure of ideal gas under standard state is 101.3 kPa. The testing area pressure all year round maintains a stable value with small changes. Take a stable pressure value 100.5 kPa as the pressure sampling value P₀.

2.4.3 The determination of temperature (T)

The temperature T_0 is 273.15K under standard conditions. The temperature value is the average temperature of the sampling process. Then use the formula $T=t+273.15$ to convert Celsius temperature into thermodynamic temperature.

2.4.4 The determination of regression curve slope of the time changing target gas concentration dc/dt .

Detect the collected target gas concentrations, combine with the time recorded in the sampling process, and use excel to analyze regression curve slope of the time changing target gas concentration dc/dt . The dc/dt of CO_2 and N_2O can be calculated. Data were analyzed using SPSS 17.0 software.

3 Results and Discussion

3.1 Effects of different nitrogen fertilizers with reclaimed water irrigation on soil CO_2 emissions

Figure 1 showed CO_2 emission flux over time under the conditions of clean water irrigation, reclaimed water irrigation with urea, reclaimed water irrigation with ammonium sulfate and reclaimed water irrigation with slow release fertilizer. Irrigation and drainage was applied at August 7th, September 8th, September 27th. As shown in Figure 1, treatments of CK, RW-U, RW-APS had consistent gas emissions trend. Obtained from the test results, CO_2 emissions increased gradually to peak at 2-5 days after each irrigation, but treatment of slow-release fertilizer peaked emission flux in the first tenth day after irrigation, later than the other three treatments. Thus, compared to CK water treatment, reclaimed water with urea, ammonium sulfate treatment and slow-release fertilizer had relatively higher total CO_2 fluxes. However, CO_2 flux emissions had a certain relationship with the soil moisture. Figure 2 showed CO_2 emission flux changes with time after the clean water and reclaimed water irrigation with both ammonium sulfate and urea. In the two treatment conditions, the law of CO_2 emissions was close, but RW-APSU CO_2 emission flux was slightly higher than that of CK-APSU. Emission flux peaked on the second day after the first irrigation. CO_2 emissions and soil moisture are clearly related. Emission peak occurred after irrigation and the first emission peak was higher than the second and third irrigation.

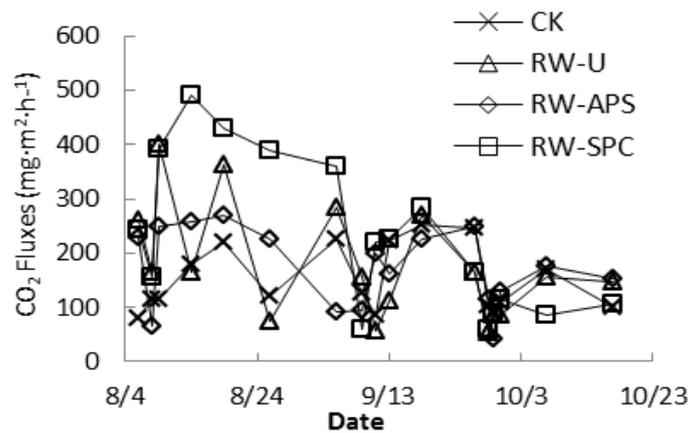


Fig. 1. Greenhouse gas emission fluxes of CO₂ with the date change curve of CK, RW-U, RW-APS, RW-SPC

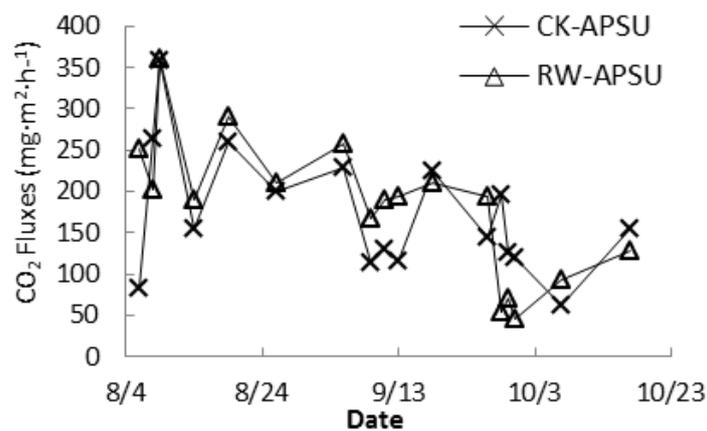


Fig. 2. Greenhouse gas emission fluxes of CO₂ with the date change curve of CK-APSU, RW-APSU

3.2 Effects of different nitrogen fertilizers with reclaimed water irrigation on soil N₂O emissions

Figure 3 was N₂O emission flux over time under the conditions of clean water irrigation, reclaimed water irrigation with urea, reclaimed water irrigation with ammonium sulfate and reclaimed water irrigation with slow release fertilizer. The overall curve trend of four treatments in N₂O emissions flux variation with time was consistent. August 7th, September 8th, September 27th was the three irrigating dates. As shown in fig.3, N₂O emission increased gradually after irrigation. At the beginning of the experiment, the N₂O had a high emission flux mainly because the

basic fertilizer was brought into a lot of nitrogen, promoting the production of N_2O . As the time went, nitrogen fertilizer consumed gradually, N_2O emissions had a promotion after 1 to 3 days irrigation. Along with the time advanced, because the basic fertilizer decreased and no new nitrogen added, greenhouse gas emissions flux was obviously reduced and the late emissions were near zero. Flux peak in the RW-U, RW-APS treatments appeared on the second day after first irrigation, and the peak of RW-SPC appeared on the tenth day after irrigation. There was no significant difference between N_2O emission rules of urea and ammonium sulfate treatment, because urea and ammonium in the soil are decomposed into ammonium ions by promoting nitrification and denitrification. Since urea is highly volatile, it will cause some degree of volatile nitrogen loss in the fertilization process, while the hydrolysis process in the soil will cause part of the nitrogen loss, therefore, pre-emission flux of urea was high. Under different circumstances of different types of nitrogen fertilizer with water and reclaimed water, N_2O emissions of reclaimed water treatment had increased to some extent, while reclaimed water contains large amounts of ammonium nitrogen, which is conducive for soil nitrification. A lot of ammonium nitrogen brought into the soil with reclaimed water irrigation would have a certain role in promoting soil N_2O emissions.

Figure 4 showed N_2O flux variations with time of the clean water and recycled water irrigation with ammonium sulfate and urea. Under both treatment conditions, the law of N_2O emissions was nearly the same, fluxes of the reclaimed water was slightly higher than clean water, emission flux peak appeared on the second day after first irrigation. The figure showed that N_2O emissions had significant relationships with nitrogen fertilizer applied. And reclaimed water had complex ingredient, it interacted with nitrogen leading to a slight increase in N_2O Daily emission flux.

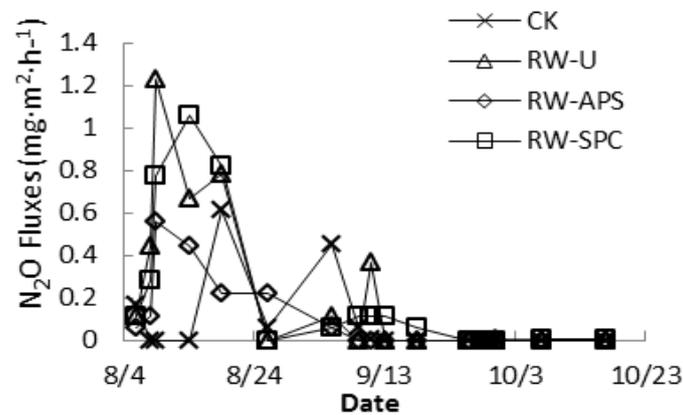


Fig. 3. Greenhouse gas emission fluxes of N_2O with the date change curve of CK, RW-U, RW-APS, RW-SPC

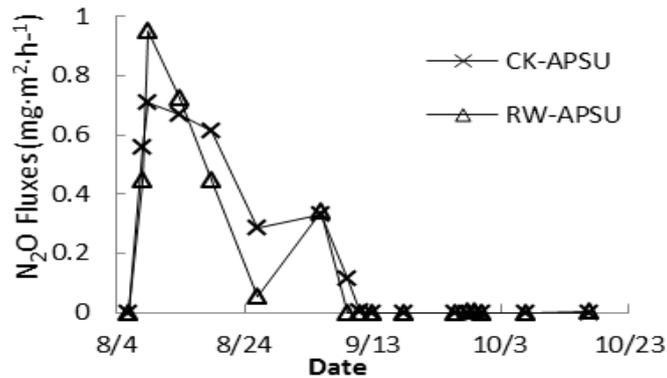


Fig. 4. Greenhouse gas emission fluxes of N_2O with the date change curve of CK-APSU, RW-APSU

5 Conclusions

Soil greenhouse gas emissions caused by reclaimed water had a small increase compared with clean water, but the increase was not significant. Therefore the reclaimed water irrigation had no significant effect on greenhouse gas emissions.

Different nitrogen fertilizer had no significant effect on soil CO_2 emissions but there was some relation with soil water content.

Soil greenhouse gases fluxes of N_2O has a significant correlation with the nitrogen fertilizer applied or not, the nitrogen fertilizer application promoted soil N_2O emissions. Compared with no fertilization, fertilization had significant influence on N_2O emissions from agricultural soil. When using applied nitrogen fertilizer after irrigation, the soil N_2O emission flux increased significantly, reaching the peak at 2-5 days after irrigation. Data were analyzed using SPSS 17.0 software, and significance level was selected at 0.05.

The use of nitrogen fertilizer increases the N_2O emissions, therefore reasonable field management measures must be taken. We can reduce the usage of nitrogen fertilizer if there is no effect on the crop yield. It will have a significant effect on reducing greenhouse gas emissions of N_2O and can effectively mitigate global warming intensifies.

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