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SciVerse ScienceDirect
Energy Procedia 16 (2012) 907 – 914
Energy Procedia

2012 International Conference on Future Energy, Environment, and Materials

Effects of Controlled and Mid-gathering Irrigation Mode of Paddy Rice on the Pollutants Emission and Reduction

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Abstract

The experiment was carried out in Nanjing Vegetables (Flowers) Scientific Institute with 4 kinds of irrigation and drainage treatments, rice field discharge, nitrogen concentration and total nitrogen emissions in drainage water were studied during the rice growth period. The results showed that discharge in controlled and mid-gathering irrigation reduced by 23.8% -27.7% compared with the other three treatments, It also showed that the total emissions of pollutants in drainage discharge reduced significantly, of which the reduction of NH_4^+-N reached by 29.1-33.3% and NO_3^--N reached by 34.3% -51.3% compared with the other three treatments. The results indicated that controlled and mid-gathering irrigation had good environmental effects through accumulating rainfall, achieving the effect of water and fertilizer conservation and reducing pollutant emissions .

Key words: controlled and mid-gathering irrigation; drainage discharge; NH_4^+-N; NO_3^--N

1. Introduction

Rice is one of the major food crops in southern China, but also consumes more nitrogen and losses more nitrogen in drainage of paddy rice field [1], which resulted in serious pollution on nearby water bodies, and increased the load of surrounding environment. The farmland nitrogen loss was one source of growing non-point source pollution. The deterioration of water environment is largely due to agricultural

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1876-6102 © 2011 Published by Elsevier B.V. Selection and/or peer-review under responsibility of International Materials Science Society.
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non-point source pollutants such as nitrogen nutrition [2-5]. As the main rice growing period synchronized with the rainy season, the discharge caused by irrigation and drainage, including underground drainage and surface drainage happened more frequently than dry crops. According to studies from Zhang Yu-fang, Li Rong-gang, Hide [6, 7], due to soil adsorption and filtration, the role of rice fields lost through leaching of nitrate nitrogen is mainly soluble and ammonia nitrogen, accounting for a low percentage of the total fertilizer amount, only about 3% and 7% under the water saving irrigation and conventional flooding irrigation modes, while the nitrogen through leaching loss is almost negligible [8]. Therefore, the nitrogen loss is mainly through the surface runoff of rice fields.

Studies have shown that reducing nitrogen and phosphorus losses of rice field in controlled drainage have two main ways: one is to reduce rice field discharge [6, 9], while the other is to reduce nitrogen and phosphorus concentrations in drainage discharge [10, 11]. Reducing nitrogen and phosphorus concentration in drainage under controlled drainage mainly through crop uptake and nitrification, denitrification [12] and sediment deposition [13~15]. Besides, crop absorption of nitrogen and phosphorus is also a major reason for reducing nitrogen and phosphorus concentration [16]. By controlling the drainage, soil moisture can be reasonable regulated and dry crops can make more efficient use of groundwater, playing a similar role as underground irrigation, making the crop growth and yield significantly increased, and increase in the nitrogen and phosphorus absorption and utilization [10]. In controlled drainage conditions, the water table elevated, soil moisture increased, anaerobic soil conditions enhanced, which was more conducive to microbial denitrification [17].

In controlled and mid-gathering irrigation, the field surface maintained a water layer of 5~25 mm to keep rice seedlings alive in returning green stage. Depending on different growth stages of paddy rice , the upper control limit of soil moisture was the saturated water content during irrigation, while the lower limit was 60%~80% of saturated water content, with no water layer after returning green stage. If it rained, the upper limit of rain ceiling storage was set 70~100 mm according to different growth stages, which was about half of the maximum submergence-enduring depth, meaning “mid-gathering”, to maximize the effective utilization of rainfall.

This model have achieved the effect of saving water, besides, it can make more effective use of rainfall, thus reducing pollutant emissions caused by rainfall drainage. In this paper, the amount of rice field drainage and changes in the concentration of pollutants in the whole growth period of rice in controlled and mid-gathering irrigation mode were studied, to provide a reference to development of more scientific and rational rice irrigation and drainage modes.

2. Materials and Methods

2.1. Experimental Site

The experiments were carried out in the farmland at Vegetables (Flowers) Scientific Institute. (latitude30°38′N ～ 32°13′N, longitude 118°31′E ～ 119°04′E), Hengxi County of Nanjing, Jiangsu province in China. The experimental site was located at subtropical humid region, with average annual rainfall of approximately 1106.5 mm, concentrated in the rainy season from the end of June to the middle of September，accounting for about 70% of the whole year rainfall. Average yearly evaporation was around 1472.5 mm, with around 2017.2 sunshine hours and average annual temperature of about 15.7℃. The maximum average humidity was 81%, with maximum wind speed was 19.8m/s.

From measurements in the 0-60 cm soil layer obtained from the experimental sites during this study, the soil type in this area was yellow brown, with heavy clay texture and organic matter content in the range of 0.96~1.48%. Averaged data of some important physical and chemical properties of soil in different treatments are shown in Table 1.

Table 1 Some Soil Properties of the 0-60 cm Layer

pH	Bulk Density (g/cm3)	Field Capacity (%)	Organic Matter (g/kg)	Available Potassium (g/kg)	Available Nitrogen (g/kg)	Available Phosphorus (g/kg)
5.87	1.35	28	21.7	195.3~236.6	83.9~103.9	15.4~35.2

2.2. Experimental Design

Based on the same technical measures of paddy rice（Kaohsiung, Taiwan 139 varieties）seedlings, transplanting, density, plant protection, fertilizer and the same soil fertility conditions, the experiment was designed with 4 different irrigation modes, respectively conventional irrigation(T1), shallow wetting irrigation(T2), controlled irrigation(T3), controlled and mid-gathering irrigation(T4). Each treatment was designed using the method of random blocks in three replications. With a total of 12 experimental plots, each was 80 m^2, and water pumps were installed, while each plot was irrigated and drained alone, and water meter, lysimeter, rain gauge and other facilities were set separately. Controlling targets of soil moisture in each irrigation modes was shown in Table 2.

Besides, a separated terrier was put up and impervious plastic film was buried as isolation layer to prevent lateral seepage around the test area.

Table 2 Controlling Targets of Soil Moisture during Paddy Rice Growth Stages under different Irrigation Modes

Treatment	Returning green	Tillering			Jointing-Booting		Heading-Flowering	Milking
		Early	Mid-term	Late	Early	Late		
T1	5-25	0-30-50	15-30-50	60%-0	30-50-70	30-50-70	30-50-70	15-30-50
T2	5-25	0-10	0-10-30	60%-0	10-30-50	10-30-50	10-30-50	0-30-50
T3	5-25	70%-0-50	70%-0-50	60%-0	80%-0-50	80%-0-50	80%-0-50	70%-0-20
T4	30-50	70%-0-70	65%-0-100	60%-0	80%-0-100	80%-0-100	80%-0-100	65%-0-70

Remarks：(1) The soil moisture was controlled by two indicators, lower limit of water layer depth (mm) and upper limit of water layer depth (mm). The third indicator was the storage depth of surface water (mm) if rained. (2) The water layer (mm) in returning green stage was the depth of field water. Water content listed in the table meant volumetric water content (%), average soil moisture in observation depth.

Rice was fertilized by using compound fertilizer, the total fertilizer nutrients in which were more than 45%, with the proportion of three elements of N: P_2O_5: K_2O = 15:15:15. There were two dressing in the entire growth period, and tillering and base fertilizer were the same with compound fertilizer, while panicle was urea. Fertilization amount were 750kg/hm^2,225kg/hm^2 and 105kg/hm^2 respectively.

2.3. Indicators and Measurements

According to the specific observation targets, the sampling was required when rainfall drainage happened, and water meter readings were recorded. The water samples indicators observed included: total nitrogen, NH_4^+-N, NO_3^--N. In accordance with "Water and wastewater monitoring and analysis methods" [18], alkaline persulfate digestion and Nessler's reagent colorimetric phenol disulfonic acid spectrophotometric were used to analysis total nitrogen in water test (TN), ammonia (NH_4^+-N) and nitrate (NO_3^--N) content.

3. Results and Analysis

3.1. Analysis of drainage in controlled and mid-gathering irrigation

Paddy rice drainage is the main way of pollutants output to the environment, while the discharge and pollutant concentration in drainage constitutes the total amount of pollutants discharge. Rainfall and field drying drainage are the main reason of paddy field drainage. Rainfall in this experiment focused on the rice growth period from June to August, with a total of three time larger intensive rainfall, respectively, in mid-June, late June and July mid. From Table 3 we can know the three intensive rainfalls were respectively 168mm, 180mm, 180.7mm, leading to the test area drained during this time. When in late July coming to late tillering stage of rice, the rice fields was in the field drying drainage period, the tested experimental plot was also part of the drainage, drainage time and discharge were shown in Table 5. Table 4 showed that although different irrigation modes drained on the same time, discharge was quite different, with the smallest discharge in controlled and mid-gathering irrigation of 232.7mm, while the other three treatments were respectively 322.1mm, 305.3mm, 310.8mm. The drainage in controlled and mid-gathering irrigation decreased 23.8% -27.7%. Controlled and mid-gathering irrigation showed a significant emission reduction effect, reducing the pollutants from the source output.

Table 3 Rainfall Statistics in Paddy Rice Growth Period

Rainfall Time	June/Ten days		July/ Ten days			August/ Ten days		
	Middle	Late	Early	Middle	Late	Early	Middle	Late
Rainfall/mm	168	180	0	180.7	79.2	24.8	29.1	49.4

Table 4 Drainage Statistics in Paddy Rice Growth Period

T1		T2		T3		T4	
Drainage Time	Discharge （mm）	Drainage Time	Discharge （mm）	Drainage Time	Discharge （mm）	Drainage Time	Discharge （mm）
6.19	96.0	6.19	79.0	6.19	95.7	6.19	64.1
6.26	108.0	6.26	114.2	6.26	110.3	6.26	64.0
7.21	101.1	7.21	92.1	7.21	86.8	7.21	82.6
7.27	17.0	7.27	20.0	7.27	18.0	7.27	22.0
Total/mm	322.1		305.3		310.8		232.7

3.2. Analysis of drainage concentration in controlled and mid-gathering irrigation

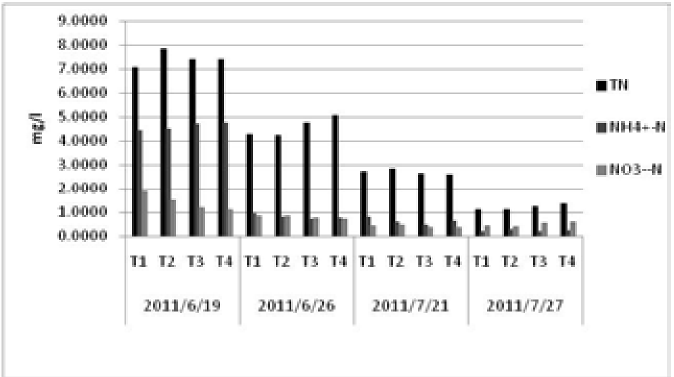

Fig.1 Nitrogen concentration changes of field drainage in different irrigation modes

Fig.1 showed the nitrogen concentration changes of field drainage in different irrigation modes from the time perspective. It can be seen clearly from the figure that N concentration in 4 times was quite different. The N concentration in June 19 drainage was higher, with total averaged nitrogen reaching 7.4421 mg / l, averaged NH_4^+-N reaching 4.6075 mg / l, and averaged NO_3^--N reaching 1.4227 mg / l, while the N concentration in July 27 drainage was lower, with total averaged nitrogen reaching 1.2934 mg / l, averaged NH_4^+-N reaching 0.2388 mg / l, and averaged NO_3^--N reaching 0.3741 mg / l. There was little difference in N concentration between June 26 and July 21, Concentration of each indicator decreased significantly, compared with that in June 19, which was due drainage in June 19, the third day after fertilization, while drainage in June 26 and July 21 was respectively 10 days and 11 days after fertilization. Moat fertilizer dissolved in field surface water in June 19, resulting in a greater concentration of nitrogen in drainage. July 27 was 17 days after fertilization, and nitrogen from field surface water to the soil migration and crop absorption was much more. The field surface water concentration tended to a lower stability of the value, making the lower nitrogen concentration in the drainage. Therefore, the pollution from drainage output to the environment after fertilization should be avoided.

As nitrogen concentration changes in June 19 (3 days after fertilization) and July 27 (17 days after fertilization) under different irrigation modes in paddy rice field for example. It can be seen from the figure, the nitrogen concentration changed little 3 days after fertilization in all irrigation treatments, mainly NH_4^+-N, while NO_3^--N concentration was lower, which was due turning green stage of rice in June 19, and water level in each treatment changed little, leading to little difference in nitrogen concentration in drainage. 17 days after fertilization, the NO_3^--N concentration in rice field drainage was slightly higher than the NH_4^+-N concentration, but all remained in a smaller range of values, of which NH_4^+-N concentration in controlled and mid-gathering irrigation was slightly higher, compared to conventional irrigation, while the NO_3^--N concentration was slightly lower. This was due to no water level controlling in controlled and mid-gathering irrigation mode, so that paddy field was in the state of no oxidation most of the time, and soil nitrification was enhanced, while in the other hand, residence time in the paddy soil was extended during controlled drainage, so that the time of transformation from NO_3^--N to NH_4^+-N in the soil increased. Overall, the concentration of pollutants in the drainage process changed little, while taking into account the discharge difference in each treatment, the emissions of pollutants significantly reduced in controlled and mid-gathering irrigation.

3.3. Estimation on total amount of emissions in controlled and mid-gathering irrigation

Table 5 Total amount of NH_4^+-N emissions in each irrigation-drain mode (kg/hm2)

Treatment	June 19	June 26	July 21	July 27	Total Emissions
T1	4.2690	1.0344	0.7979	0.0367	6.1380
T2	3.5616	0.9202	0.5564	0.0600	5.0982
T3	4.5159	0.7944	0.4278	0.0390	5.7770
T4	3.0487	0.4776	0.5179	0.0491	4.0932

Table 6 Total amount of NO_3^--N emissions in each irrigation-drain mode (kg/hm2)

Treatment	June 19	June 26	July 21	July 27	Total Emissions
T1	1.8177	0.9228	0.4283	0.0740	3.2428
T2	1.1880	0.9790	0.4603	0.0806	2.7079
T3	1.1386	0.8397	0.3197	0.1023	2.4004
T4	0.7076	0.4578	0.2827	0.1298	1.5779

Table 5 and Table 6 showed the total amount of two pollutants emissions in different irrigation treatments. From the overall trend, the main nitrogen-based pollutants in drainage were NH_4^+-N, with the amount of NH_4^+-N emissions almost 2 times the NO_3^--N emissions. During the whole growth period, the largest emissions was in June 19, with the averaged NH_4^+-N and NO_3^--N concentration reaching respectively 3.8488kg/hm2 and 1.2130kg/hm2, which was much larger than the other three, that may because June 19 was the third day after fertilization , and fertilizer dissolved in water in the soil surface reached a peak, then suddenly encountered a continuous greater rainfall, resulting in too much water of field area, and rice water beyond the upper limit had to be drained. By a separate analysis of the emissions of NH_4^+-N and NO_3^--N, it can be seen that, the nitrogen emissions in controlled and mid-gathering irrigation was the lowest, of which NH_4^+-N emission was 3.0487 kg/hm2, while emissions from the other three treatments were respectively 4.2690 kg/hm2, 3.5615 kg/hm2, 4.5159 kg/hm2, with emissions increasing by 28.6%, 14.4%, 32.5%. NO_3^--N emission was 0.7076 kg/hm2, while emissions from the other three treatments were 1.8177 kg/hm2, 1.1880 kg/hm2, 1.1386 kg/hm2 , emissions increasing by 61.1%, 40.4%, 37.9%. In this drainage, nitrogen emissions increased less significantly in controlled and mid-gathering irrigation. Taking into account the drainage was at the time after fertilization, which was a special time, the nitrogen emissions in each treatment in the whole growth period was analyzed. It can be seen from the table that, the nitrogen emissions in controlled and mid-gathering irrigation in the whole growth period was still the lowest, of which NH_4^+-N emissions reaching to 4.0932 kg/hm2 and NO_3^--N reaching to 1.5779 kg/hm2. NH_4^+-N emissions reduced 33.3%, 19.7%, 29.1%, compared with the other three treatments, while NO_3^--N emissions reduced 51.3%, 41.7%, 34.3%, which was a significant reduction in emission reduction. As we can see, there were significant effects of controlled and mid-gathering irrigation on agricultural non-point source pollution to the environment brought by drainage in the rice field, which showed greater potential, and it was a water-saving irrigation mode which was suitable for China's southern irrigation district.

4. Conclusions

This paper analyzed field discharge, nitrogen concentration and total nitrogen emissions in drainage in the whole growth period of paddy rice under 4 kinds of rice irrigation modes (conventional irrigation, shallow-wetting irrigation, controlled irrigation, controlled and mid-gathering irrigation). The following conclusions were drawn:

(1) There were a total of 4 drainage in the processing of rice growth period, of which discharge in controlled and mid-gathering irrigation mode was the least, and drainage density was low. Total emissions of nitrogen showed a clear decreasing trend, due to development of indicators in controlled and mid-gathering irrigation, which accumulated as much rain in rice field, in order to achieve water and fertilizer conservation while the same time reducing the effect of pollutant emissions, showing good environmental effects.

(2) In the four drainage, the maximum concentrations of pollutants happened 3 days after fertilization, while nitrogen emissions reached the largest amount. The results showed the drainage after the occurrence of fertilization should be avoided, and there was still more large room for improvement of controlled and mid-gathering irrigation mode.

(3) Research on rice yield and soil environmental impact was still much less. Based on this research, further studies should be conducted on rice physiological growth and yield model in controlled and mid-gathering irrigation, to improve the various effects of this irrigation mode.

Acknowledgements

This work was funded partly by the Research Project of Special Scientific Funds in Public Service Sectors (Water Conservancy) (grant number 201001040)，partly by Water Science and Technology Project of Jiangsu Province (2010, No.28) and partly by the Priority Academic Program Development of Jiangsu Higher Education Institutions（PAPD）

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