MINISTRY OF EDUCATION AND TRAINING

MINISTRY OF AGRICULTURE AND RURAL DEVELOPMENT

VIETNAM ACADEMY FOR WATER RESOURCES

NGUYỄN ĐĂNG HÀ

STUDY THE EFFECTS OF ON-FARM WATER MANAGEMENT ON THE EMISSION OF N_2O IN RICE LANDS IN RED RIVER ALLUVIAL SOIL WHICH ARE NOT ANNUALLY UNDEPOSITED IN HƯNG YÊN PROVINCE

Major: Water resources engineering

Code: 9 58 02 12

SUMMARY OF PH.D. DISSERTATION

Ha Noi, 2022

The study is completed in:

VIETNAM ACADEMY FOR WATER RESOURCES

Supervisors:

Prof. Dr. Đoàn Doãn Tuấn

Prof. Dr. Nguyễn Xuân Hải

Evaluation panel member No. 1: Prof. Dr.. …

Evaluation panel member No. 2: Prof. Dr. …

Evaluation panel member No. 3: Prof. Dr. …

The Dissertation will be defensed before the Evaluation Council of the Vietnam Academy for Water Resources

The evaluation meeting will take place in the headquarter of Vietnam Academy for Water Resources

Address: 171 Tay Son – Dong Da – Ha Noi

At ... h, dd.... mm .... 2022.

The Dissertation can be accessed at:

- Hanoi National Library
- Library of Vietnam Academy for Water Resources.

PRELUDE

1. The necessity of the research

Water shortage and climate change are two major problems both in in Vietnam and globally. Many countries and many scientists are quite interested in these two issues. These two issues are interrelated. Climate change, sea level rise, saltwater intrusion are reducing freshwater resources whereas water demands are increasing. Therefore, ensuring water security is one of high national concerns due to its importance to livelihoods and lives of people as well as to sustainable development of the country.

In Vietnam, agriculture is the largest water user. It is calculated that the annual water consumption of agriculture sector is about 93 billion m^3, of industry sector 17.3 billion m^3, domestic uses 3.09 billion m^3 and service sector 2.0 billion m^3.

According to the IPCC summary (from Denman et al. 2007) [39] arable land emits about 2.8 TgN of N_2O per year, making up for 42% of anthropogenic N_2O or about 16% of the global emissions. However, the emissions from wet rice fields have not been separated from upland crops. Recently, many studies have suggested that wet rice cultivation is a source of CH_4 and N_2O emissions into the atmosphere. N_2O in wet rice fields has been not clearly defined internationally and in Vietnam, in-depth studies on N_2O emissions from rice fields, especially in undeposited alluvial soils in relation with on-farm water management have not been studied. Moreover, among GHG emissions (CH_4 and N_2O), the CH_4 emissions is 25 times and N_2O 298 times greater than the CO_2 generated. Vietnam has about 7.72 million hectares of rice land cultivated every year, the GHG emissions (CH_4 and N_2O) into the environment are not small. According to Nguyen Tung Phong [9], a research to help reduce N_2O emissions in rice cultivation areas in Vietnam is very necessary.

At the UN Conference on Climate Change during November 1-12, 2021 in Glasgow, UK, Prime Minister Pham Minh Chinh pledged that Vietnam made a commitment to net zero emission by 2050 [27].

Stemming from the urgent problems mentioned above such as the increasingly shortage of irrigation water, water saving needs, solutions to reduce GHG emissions from wet rice planting, especially solutions to reduce N_2O emissions, which have not been studied yet in Vietnam and an actual survey has not been conducted in Vietnam. Given the fact, the research on effects of on-farm water management on N_2O emissions in Red River

alluvial soils for rice cultivation which are not deposited annually in Hung Yen province has such scientific and practical significance.

2. Research objectives

- Determine the relationship between Eh, pH and N_2O emissions in wet rice fields in relation to different on-farm water management regimes.

- Determine the effects of on-farm water management regimes on N_2O emissions in different rice crops in alluvial soil of the Red River which will be bases for the proposal of on-farm water management solutions to reduce GHG emissions, save water and maintain rice yields.

3. Scientific and practical significances

- *Scientific significance*: The dissertation shall contribute to the clarification of effects of soil and water environment in fields in Red River undeposited alluvial soil in Hung Yen province on the formation and emission of N_2O.

- *Practical significance*: The dissertation shall prove that due to the strong reducibility of soil, the alternate wetting or drying regime (AWD) does not have different effects on N_2O emissions. Therefore, it is possible to select on-farm irrigation regimes in a way that water will be saved and crop yield is ensured.

4. New contributions

(1) Red River alluvial soils for rice cultivation in Hung Yen province which are not deposited on annual basis have strong reducibility in different on-farm water management regimes and these are favorable conditions for the formation and emission of N_2O.

(2) The total N_2O emissions in different irrigation regimes, including flood irrigation vs AWD is quite low (0.3 ÷ 0.4 ppm) and there is no difference in quantity between the two formulas. The stage from transplanting to tillering producing the largest amount of N_2O emissions is explained by effects of fertilization.

CHAPTER 1. OVERVIEW OF STUDY ISSUES

1.1. Irrigation regimes for rice and scientific basis of water-saving irrigation techniques for rice (WSI)

1.1.1. Water demands and characteristics of rice plants

There are many researches on water demands and characteristics of rice in the tropical regions. Rice is the crop that uses the most water and requires more irrigation water than other crops. According to Smith (Le Thi Nguyen, 2002) [7], the transpiration of rice is 710 mm/crop, wheat 513 mm/crop and corn 368 mm/crop. Although rice is a wet plant needing a lot of water, the growth of rice plants and its roots also heavily depend on oxygen in the soil. Rice plants can absorb O_2 in the air through leaves, stems and roots.

1.1.2. Rice irrigation techniques

Rice irrigation techniques can be analyzed in two: continuous flooding (CF) techniques and water-saving irrigation techniques. CF technique means maintaining a layer of water of 5 ÷ 10 cm in fields during the transplanting process till before the harvest.

Water saving irrigation technique has many different names such as: intermittent (irregular) irrigation technique which has been studied by Tran Viet On (2016) [8]. AWD technique; sallow-wet and dry technique; absolute dry irrigation technique; Moderate dry irrigation technique; water saving and GHG emission mitigation irrigation techniques which have been studied by Le Xuan Quang and others [6], [14], [15], [17], [21].

1.1.3. Scientific and practical significance of rice water saving techniques

The scientific basis of water-saving irrigation techniques is based on three main drivers: saving water, as the name of the technique indicates; effects on the transformation of nutritional elements; effects on the growth of rice plants.

1.2. The formation and emission of N_2O in the soil

1.2.1. Cycle, source and the loss of nitrogen in the soil

The nitrogen cycle in the soil is a complex cycle and has been studied by many authors for a long time. According to Beck T. (1968) [35], the nitrogen cycle in the soil reflecting the formation of N_2 from the soil into the air via the nitrification and NO_3- from the rainfall. Under anaerobic conditions, denitrification occurs. The intermediates will be formed such as: NO_2-, NO, N_2O and the final product is N_2 will fly into the air. In the process, the N_2O can also fly into the air if it is not reduced to N_2.

Fixation of atmospheric nitrogen is done through microorganisms. By nitrogen labelling method, more researches on this issue are conducted. For some bacteria with weak N_2 fixation, it has almost no sense in practice. Through the collected rainwater, nitrogen atoms are separated into

molecules and are combined with Hydrogen into ammonia or being combined with oxygen to form Nitric acid and fall into the ground together with rainwater. Inorganic - organic fertilizer is a very important source of nitrogen for soil to increase crop yield.

1.2.2. Mechanism of N_2O formation and emission and influencing factors

Denitrification is a process that converts NO_3- into NO_2-, NO, N_2O and finally into N_2, which is released into the air, given denitrification takes place to the final product. Stefanson R.C. (1972) (from Alexander M. 1977) [30] studied the N_2O emission during denitrification with and without the presence of wheat and showed the same results. With the presence of wheat, the emission of nitrogen is large. The author explains that root activity increases microbial activity and increases volatile N_2O and N_2. On the other hand, rice plant roots, during its growth, excrete organic matters (exudation process) which increases the activity of rhizosphere microorganisms, including bacteria involved in the denitrification, increasing the generation and emission of N_2O and N_2.

1.3. Conclusions of Chapter 1

1.3.1. Key literature review results

- Water-saving irrigation for rice has been studied by many domestic and international authors and many important results have been gained, including practical application in rice production in many countries to increase rice yield and reduce GHG emissions.

- The formation and emission of N_2O in different soils and influencing factors have been studied by many scientists around the world for a long time. N_2O is an intermediate product of this process that can be further converted into molecular nitrogen (N_2) or released into the atmosphere, depending on soil environmental conditions, with the most important as the oxidization – reduction potential in the soil.

The water regime, including soil moisture, flooding conditions and oxidation-reduction potential, all affect the formation and emission of N_2O, has also been studied for a long time for some soils. However, many soil types have not been studied, especially in the context of rice soil with changing irrigation regimes.

1.3.2. Issues to be solved

The water-saving irrigation regime for rice such as AWD effecting the formation and emission of CH_4 has been studied by many authors and specific results have been produced. However, in the relation with the formation and emission of N_2O, effects of water-saving irrigation regimes such as Moderate drying, absolute drying and CF as a traditional irrigation method, have not been fully explained. Therefore, studying the effects of on-

farm irrigation regime on oxidation - reduction potential, a soil property closely related to the formation and emission of N_2O, and crop yield, is quite necessary.

1.3.3. Conclusions

1) In order to save water, limit GHG emissions and ensure rice yield, recently, many water-saving irrigation measures have been applied, notably the AWD, shallow wet and dry irrigation technique etc...

2) The formation and emission of N_2O depends on many factors such as: water regime, temperature, fertilization method, ecological characteristics of wet rice fields. The most important is the water regime that affects the oxidation - reduction potential (Eh).

3) There have been many studies on the effects of irrigation techniques on the formation and emission of GHGs such as CH_4, CO_2, rice yield and water saved, including alternating wet and dry irrigation (AWD). However, in the relation with the formation and emission of N_2O, effects of such water-saving irrigation regimes such as Moderate dry, absolute dry irrigation and CF as a traditional irrigation method, have not been fully explained. Recently, some authors have shown that continuous flood irrigation is not a condition that increases N_2O emissions. Aerobic conditions are required for the nitrification to occur to form NO_3-. And the NO_3- is reduced to form N_2O.

Thus, the effects of irrigation regime, Eh and pH on the formation and emission of N_2O, rice yield and water saved are outstanding issues which will be clarified in this research.

CHAPTER 2. METHODOLOGIES

2.1. Field experiment research

2.1.1. Objectives

- Determine the relationship between Eh, pH, Ec and N_2O emissions in wet rice fields corresponding to different water management regimes.
- Determine the effects of irrigation regime on alluvial soil of the Red River on N_2O emissions so that an irrigation regime is proposed to reduce GHG emissions, saving water and ensuring rice yield.
- Select a reasonable irrigation regime for rice in the alluvial soil of the Red River.

2.1.2. Scientific basis of the selected study area

The Red River Delta is one of the two largest rice hubs in Vietnam. In addition, the Red River Delta is the largest political and cultural center of Vietnam with a population accounting for 20% of Vietnam's population. Hung Yen is located in the center of the Northern Delta where less acidic soils are characteristics of alluvial soil in the Red River and Red River Delta.

Fig. 2.1. Location map of the experimental site

2.1.3. On-farm experiments

- The experimental area is located in an area of 50.2 ha in Phu Thinh commune, using the following 3 irrigation formulas: (1) absolute drying irrigation: 9.10 ha. (2) Moderate drying irrigation: 8.11 ha. (3) Traditional irrigation area: 32.79 ha. In each area, 2 plots of fields were selected for case study.
- Irrigation system for the entire cultivation area of Bac Hung Hai irrigation system, i.e. across Tan Giang river. Water is supplied to the experimental area through a 2-pump station of 1,400 m^3/h and 1,000 m^3/h each pump. Currently the pumping station is working well and is being managed and operated by Phu Thinh Agricultural Cooperative.

- The on-farm water regulation works are equipped with 15 sluices.
- Devices to measure on-farm water level, water level in canals, and water level in pumping station tanks are installed and provide automatic measurements of every 10 minutes on average during the experiment. There are also daily manual measurements.
- The measuring devices for Eh, pH are mounted directly in experimental fields and automatic measurements take place every 10 minutes.
- Meteorological measuring device is installed directly in the testing site during the experiment.

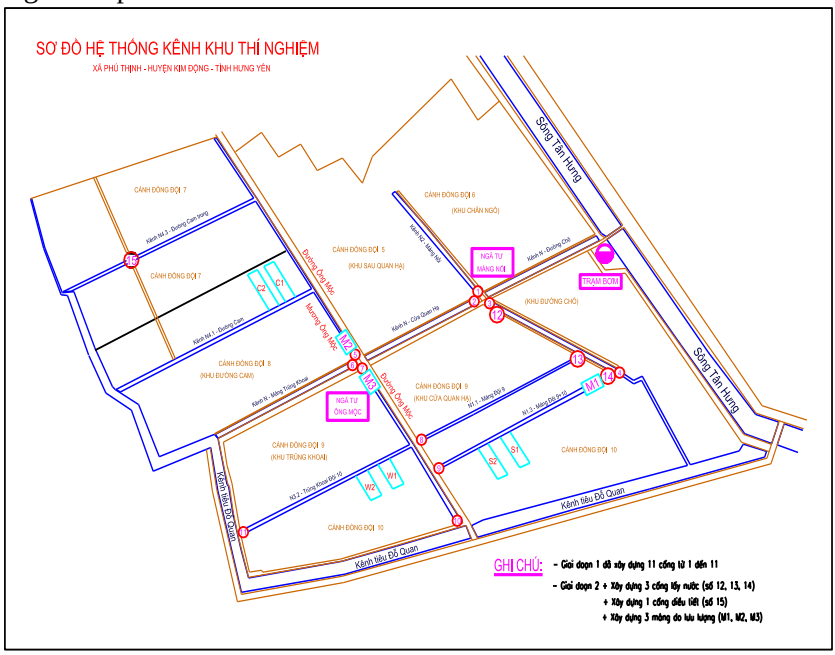


Fig. 2.2. Layout of the experimental site

- Irrigation formula: AWDs =∇H*f(t) (2-1)

Including:

∇H : Water level in fields (cm).

f(t) : Growth time of crops (day).

(1) Absolute dry irrigation: ∇H: -15 ÷ 3 cm. (2) Moderate drying irrigation: ∇H : -5 ÷ 3cm. (3) Traditional irrigation methods: ∇H 0 ÷ 10 cm.

The experimental formulas differed only in terms of irrigation regime whereas other factors such as rice variety, season, cultivation techniques, fertilization and maintenance were performed equally for each crop in the entire experimental area. Experimental follow-up time is 6 crops in 3 years (2015÷2017).

2.2. Methods of analyzing soil properties, N_2O and monitoring rice growth, influencing factors on rice yields and rice yields

2.2.1. Soil property analysis method

The Eh was measured directly using Toledo's handheld ORP/pH electrode which are submerged to a depth of 5, 15, 30 cm in the ground.

The pH (H_2O) was measured using a Horiba Laqua pH meter.

Soil samples were taken from the testing site and are analyzed in laboratories of the Thuyloi University and Kyoto University, Japan.

2.2.2. N_2O measuring, sampling and analyzing methods

The GHGs are sampled once a week with samples taken simultaneously at 6 locations in the 3 experimental sites with samples taken 3 times in each position. Sampling time is 10h, 10h10' and 10h20'. Gas samples are analyzed in the laboratory of Kyoto University - Japan.

2.3. Methods of processing experimental data

Given the large quantity of samples ($n \geq 30$), verification method $H_o : \mu_1 = \mu_2$ is applied, using *z-Test.*

2.4. Conclusions of Chapter 2

The study site is located in Phu Thinh commune, Kim Dong district, Hung Yen province. This area is typical of the Red River Delta with a convenient irrigation system for rice and commune based irrigation supply can be well managed. Rice land here is typical of alluvial soil of the Red River which is not deposited on annual basis.

Field experimental equipment are arranged in an area of 50.2 ha to monitor 6 crops identified correctly rice field factors, including water levels in rice fields, water levels in irrigation canals, water levels in pumping stations, Eh, pH, Ec. ; meteorological factors (precipitation, temperature, air humidity, light intensity, etc.). In addition, such infrastructure as water intakes, regulators on canals, on-farm irrigation canal etc. are well and synchronously developed which supported the effective management of irrigation system using different irrigation formulas.

The N_2O sample data tested in the Laboratory of Kyoto University - Japan have high reliability. Collected data are processed by statistical verification method using Z.test standard.

CHAPTER 3. RESEARCH RESULTS ON EFFECTS OF ON-FARM WATER MANAGEMENT ON N_2O EMISSIONS

3.1. Basic characteristics and changes of Eh values in soils in the study area

3.1.1. Basic characteristics of the soil

The soil in the study area is moderate textured soil and slightly compacted.

Table 3.1: Physical properties of the studied soil

Density (g/cm^3)	**Proportion** (g/cm^3)	**Porosity** (%)	**Gradation (%)**			
			2.0 ÷ 0.2 (mm)	**<0.2 ÷ 0.02** (mm)	**<0.02 ÷0.002** (mm)	**<0.002** (mm)
1.10	2.50	56.0	6.60	45.75	27.75	19.90

The soil has a pH (H_2O) of 6.9. According to Vietnamese standard TCVN 8886:2011 Soil quality – to determine the exchangeable acidity in the barium chloride extract and the rating scale of Pagel H (1981) [68], the pH (H_2O) at 6.2 ÷ 6.9 is evaluated as weak acid soil. From 6.9 ÷ 7.6 is considered Moderate acid soil.

3.1.2. Results of analysis of Eh, pH of soil in the laboratory

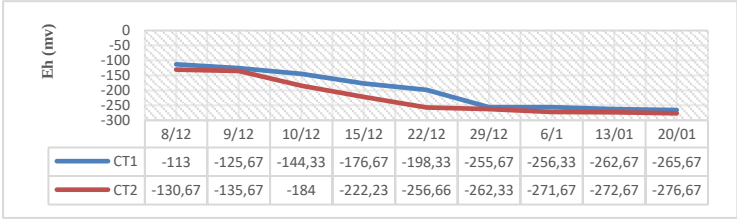


Fig. 3.1. Changes of Eh values of flooded dry soil

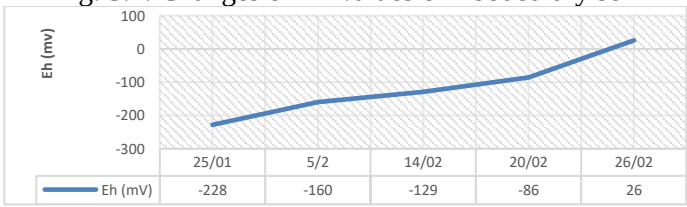


Fig. 3.2. Changes of Eh values in soils after reducing water and drying fields

Ehs of flooded dry soil in both formulas are low, ranging from -113 to ÷ -276.7 mV. When being re-wetted, the Eh of the soil decreases and decreases rapidly during the first days of flooding, from -113 mV to -219 mV; Eh of the soil decreases and reaches a stable value (-195 to -219 mV) in the 5^{th} and 6^{th} week of flooding (March 24 and April 1, 2017). Soil pH when dry soil is flooded is 5.6 ÷ 6.7.

3.2. Rainfall in the experimental area

In 2015, the total rainfall in the winter-spring crop was 244.6 mm and the summer-autumn was 634.8 mm. In 2016, the total rainfall of the winter-spring crop (February 19 - June 15, 2016) was 586.2mm; summer-autumn crop (June 20 ÷ September 25, 2016) is 1192.8mm. It can be seen that the 2016 summer-autumn crop rainfall is larger than that in 2015, because of the storms hitting the Red River Delta in 2016, including storm No. 1 on July 28, 2016 and storm No. 2 on August 19, 2016 which caused widespread rainfall and inundation in many places. In 2017, the total rainfall of the winter-spring crop (February 26 ÷ June 11, 2017) was 397.0 mm; summer-autumn crop (1/6 ÷ 21/9/2017) was 1012.2mm. Winter-spring crop witnessed 48 rainy days with the heaviest rainy day (April 28, 2017) of 103mm. The summer-autumn crop has 73 rainy days and an average of 1.5 days/rain. On July 17, 2017 the largest rainfall of 114mm was measured. Total rainfall in 2017 is more than that in 2015 and less than in 2016.

3.3. Irrigation water quantity and water quality in field experimental formulas

3.3.1 Irrigation water consumed in 2015

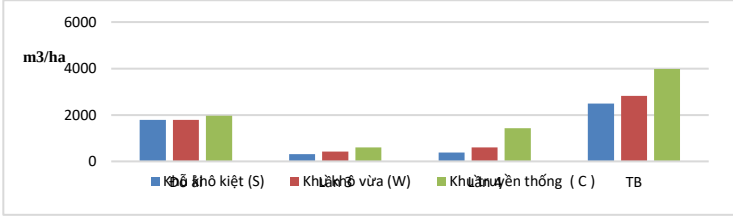


Fig. 3.11. Irrigation water in winter-spring crop 2015

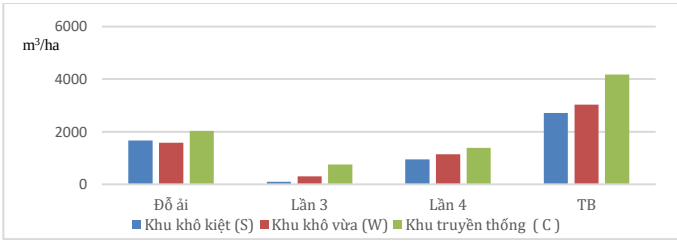


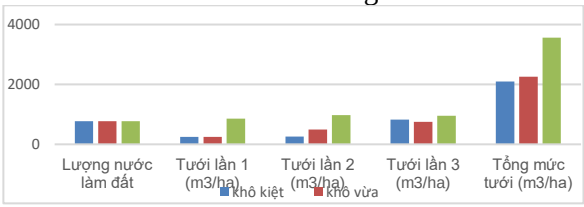
Fig. 3.12. Irrigation water in summer-autumn crop 2015

Total amount of irrigation water in winter-spring crop 2015 (the total amount of water pumped up to on-farm level) is 176,639 m^3. The average amount of water pumped for land preparation in fields and in experimental fields is 1,903 m3/ha. The water used in absolute dry and moderate dry irrigation modes are equal i.e. 1,794 m^3/ha.

Total amount of irrigation water consumed in summer-autumn crop in 2015 is 186,712 m^3; given 1,000 m^3/h pumping capacity and 102 pumping hours; for pumping capacity of 1,400 m^3/h, the pumping hours is 76 and the average pumping efficiency is 75% compared to the designed capacity.

3.3.2 Irrigation water consumed in 2016

Amounts of irrigation water consumed in winter-spring crop 2016 (Appendix - Table P3.3) for periods showed that: soil preparation before transplanting requires irrigation (phase 1) for 3 days from 25 ÷ 27 January 2016 with the total water volume of 38,666 m^3. The total irrigation water during land preparation accounts for 25% of the total irrigation amount in the entire crop.



The total amount of irrigation water consumed in summer-autumn 2016 in the entire area is 193,128 m^3; including water irrigated to the traditional irrigation fields 4,239 m^3/ha; to moderate dry fields: 3,368 m^3/ha and to absolute dry fields: 2,899 m^3/ha.

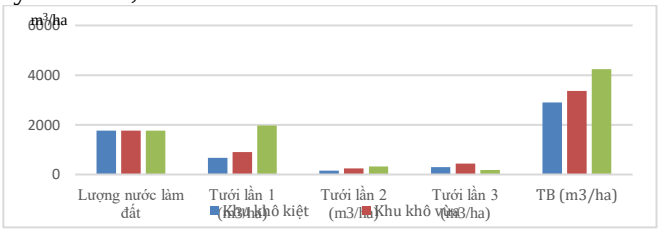


Fig. 3.14. Irrigation water consumed in summer-autumn crop 2016

3.3.3 Irrigation water consumed in 2017

The total amount of irrigation water in winter-spring crop 2017 in the entire area is 123,034 m^3, including water irrigated to the traditional irrigation field 2,795 m^3/ha; to moderate dry fields 2,045 m^3/ha and to absolute dry fields 1,605 m^3/ha. The total amount of irrigation water used in summer-autumn crop 2017 is 74,020 m^3or an average of 1,480 m^3/ha.

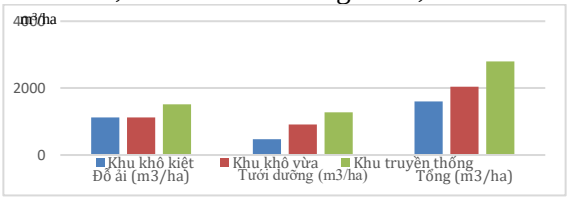


Fig. 3.15. Irrigation water in winter-spring crop 2017

3.3.4 Total irrigation water consumed in 3 years (2015 ÷ 2017)

The amounts of irrigation water consumed in 3 years depend on the rainfall and on the raining time. See results in Table 3.3.

Table 3.3: Total irrigation water volume consumed in 3 years (2015 ÷ 2017)

Experimental area	2015		2016		2017	
	Winter-spring crop (m^3/ha)	**Summer-autumn crop** (m^3/ha)	**Winter-spring crop** (m^3/ha)	**Summer-autumn crop** (m^3/ha)	**Winter-spring crop** (m^3/ha)	**Summer-autumn crop** (m^3/ha)
Absolute dry	2496	2713	2098	2899	1605	1480
Moderate dry	2825	3037	2260	3368	2045	1480
Traditional irrigation	3985	4178	3559	4239	2795	1480

3.3.5 Irrigation water quality

Monitoring parameters to assess water quality in the studied area are compared with Vietnamese standards QCVN 08-MT-2015/BTNMT - Surface water quality for irrigation. The analysis results showed that monitoring parameters such as pH is 6.1÷6.84 and NO_3- is 0.01÷1.4 mg/l which are within the allowable limit of QCVN 08-MT-2015/BTNMT. There are some indicators such as NH_4^+: 0.22 ÷ 10.81 mg/l. and PO_4^{3-} from 0.04mg/l ÷ 0.76mg/l which exceeded the allowable limit. Other nutritional parameters such as total nitrogen: 5.71 mg/l ÷ 41,552 mg/l, total phosphorus: 0.18 mg/l ÷ 1.04 mg/l, EC is not regulated relating to permissible limits. However, based on similar research results, these criteria are within the limit and water quality for irrigation thus is ensured.

3.4. Effects of irrigation regimes on rice yield

3.4.1. Winter-spring crop 2015

Winter-spring crop 2015 was transplanted with Bac Thom rice variety. The transplanting density is still high, i.e. 35 to 38 stands/m^2. The moderate dry irrigation area saw the largest number of grains per panicle which is 113 grains per panicle; the highest yield in the moderate dry irrigation area is 4.61 tons/ha; in the absolute dry irrigation area 4.25 tons/ha; the lowest is found in the traditional irrigation area i.e. 3.7 tons/ha.

3.4.2. Summer-autumn crop 2015

The 2015 crop was transplanted with Thien Uu 8 variety. The transplanting density is 36 to 40 stands/m^2. The number of high quality grains is probably higher than that of the winter-spring crop, reaching 149 grain/panicle; the highest yield in the moderate dry irrigation areas is 6.6 tons/ha, which is 30% higher than thanks to more favorable weather and irrigation conditions. The rainfall in summer-autumn crop 2015 is 634.8mm, while only 244.6mm is measured in winter-spring crop. Tan Giang river (supplying irrigation water for Phu Thinh commune) facilitated the irrigation in winter-spring crop whereas the summer-autumn crop is dry so summer-autumn crop 2015 does not have high yield.

3.4.3. Winter-spring crop 2016

The rice variety TBR 225 was tested in the winter-spring crop 2016. The results showed that the irrigation regime after tillering effected the growth, development and yield of rice variety TBR225. The water saving irrigation mode (moderate dry) is the irrigation method that result in highest rice yield i.e. 5.7 tons/ha.

3.4.4. Summer-autumn crop 2016

The rice variety N25 was introduced into the 2016 crop trial, the yield study results showed that the moderate irrigation dry (W) formula produces the highest rice yield of 4.22 tons/ha which is followed by the absolute dry irrigation formula. (S) 4.19 tons/ha and the final control formula (traditional irrigation) (C) with the lowest rice yield of 4.14 tons/ha.

3.4.5. Winter-spring crop 2017

The 2017 winter-spring crop was planted with Thien uu 8 rice variety and the transplanting density is 36 stands/m2. The number of high quality grains from 185 to 202 grains/panicle, the highest number of grains is recorded in the moderate dry irrigation area (202 grains). Winter-spring crop 2017 has the highest yield, from 6.4 tons/ha to 7.26 tons/ha; the highest yield is recorded in the moderate dry irrigation area.

3.4.6. Summer-autumn crop 2017

The 2017 winter-spring crop was planted with Thien uu 8 rice variety and the transplanting density is (31÷40) stands/m2. The number of high quality grains from 170 to 183 grains/panicle, the highest number of grains is recorded in the moderate dry irrigation area (183 grains). Summer-autumn crop 2017 yield is from 4.45 tons/ha to 5.59 tons/ha; the highest yield is recorded in the moderate dry irrigation area.

3.4.7. Rice yields in 6 crops in *3* years (2015-2017)

On-farm water regime has also affected rice yield significantly. Irrigation and drainage in winter-spring crops in 2015 and 2017 are affected by drought (winter-spring crop 2015), heavy rain (winter-spring crop 2017).

Table 3.10: Actual yield in the experimental area adopting different irrigation regimes during 2015÷2017

Experimental area/seed variety	2015		2016		2017	
	Winter-spring	Summer-autumn	Winter-spring	Summer-autumn	Winter-spring	Summer-autumn
Seed variety	Bắc thơm	Thiên ưu 8	TBR225	N25	Thiên ưu 8	Thiên ưu 8
Absolute dry (S)	3.7	5.5	5.2	4.14	6.40	5.13
Moderate dry (W)	4.61	6.6	5.7	4.22	7.26	5.59
Traditional irrigation ©	4.25	5.9	5.0	4.19	5.86	4.45

3.5. Water level in experimental plots

In the winter-spring crop, the water layer in fields is over 5cm from rooting to the end of tillering stages. From the end of tillering to the panicle initiation,

we have data on on-farm water level and water level in canals which are irrigated 3 – 5 times, except for plot S_2 where only two irrigations are carried.

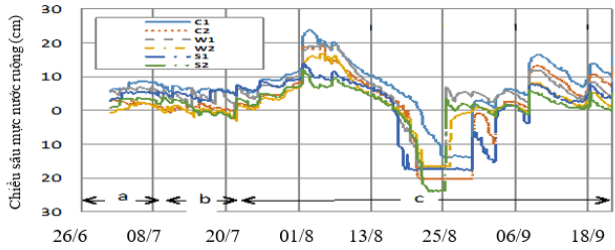


Fig. 3.17. Water level in experimental plots in winter-spring crop 2015

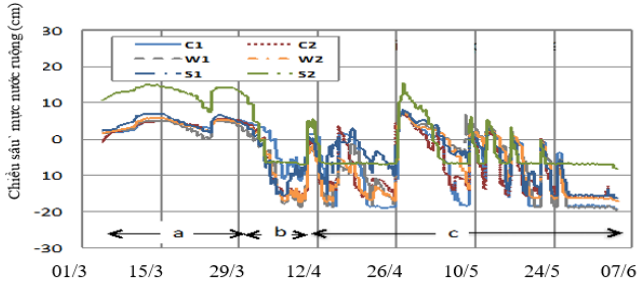


Fig. 3.18. Water level in experimental plots in summer-autumn crop 2015

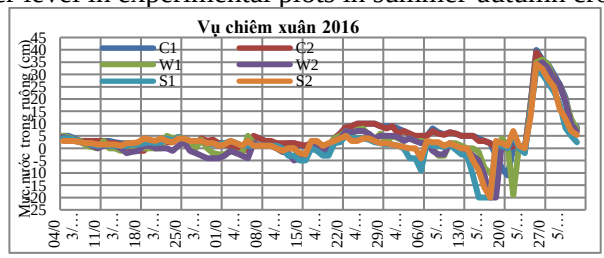


Fig. 3.19. Water level in experimental plots in winter-spring crop 2016

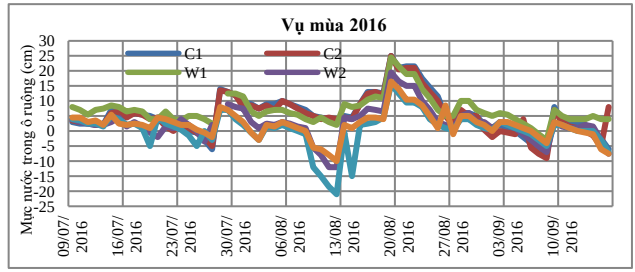


Fig. 3.20. Water level in experimental plots in summer-autumn crop 2016

In the winter-spring crop 2016, water level in fields is always high due to more rainfall in 2015. The lowest water level in fields is recorded on May 20, 2016 in absolute dry plots 01: water level dropped to -20 cm in the entire winter-spring crop. And water reduction in fields is carried out 4 times.

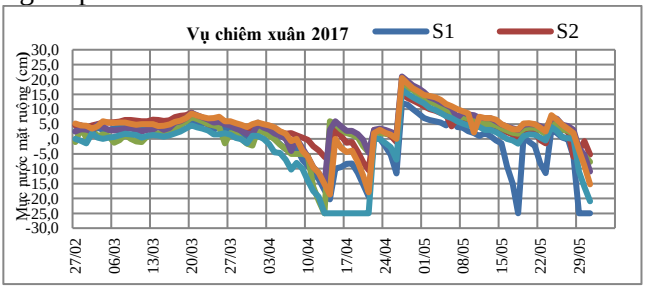


Fig. 3.21. Water level in experimental plots in winter-spring crop 2017

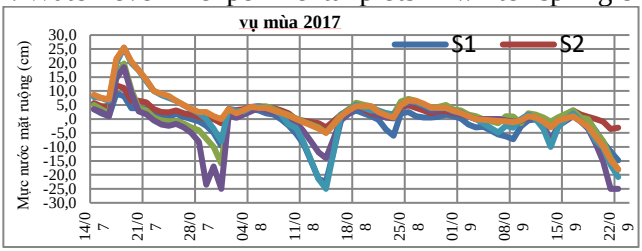


Fig. 3.22. Water level in experimental plots in summer-autumn crop 2017

Year 2017 has relatively heavy and evenly distributed rainfall; winter-spring crop saw 48 rainy days or an average of 2.29 days/rain; summer-autumn crop saw 73 rainy days, or an average of 1.3 days/rain. The heavy and evenly distributed rain significantly affected on-farm water management.

3.6. Effect of irrigation regimes on N_2O emissions in the 3-year experiment

3.6.1. Winter-spring crop 2015

Relating to the N_2O emissions in formulas applied in winter-spring crop 2015, in most of calculations, the emissions ranged from 0.3 to 0.4 ppm. The difference in N_2O emissions between various formulas in winter-spring crop 2015 is quite low and not significant. The sample values also did not differ much in different calculations, depending on growth time of rice, and following this order W>C>S.

The intensity of N_2O emission is quite low i.e. 0.000014 mg/m^2.-min to 0.0133 mg/m^2-min, and there is quite a big difference between the largest and the smallest value. When the water level in fields fluctuated between -17 ÷ +7 cm, the emission intensity was not correlated in all 3 experimental areas.

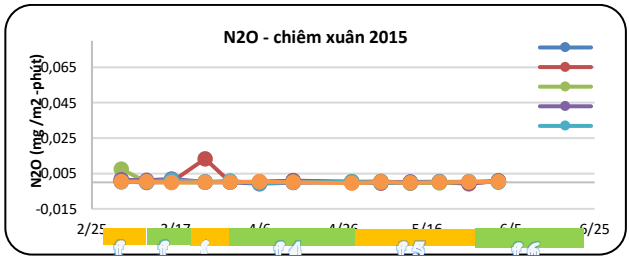


Fig. 3.26. N_2O emission intensity in winter-spring crop irrigation formulas in 2015

3.6.2. Summer-autumn crop 2015

N_2O emissions of the traditional formulas (C), moderate dry formula (W) and absolute dry formula (S) in the summer-autumn crop 2015 in most of calculations fluctuated mainly in the range of 0.3 to 0.4 ppm. Sample values also did not differ much in different calculations, depending on growth time of rice and following this order C > W > S.

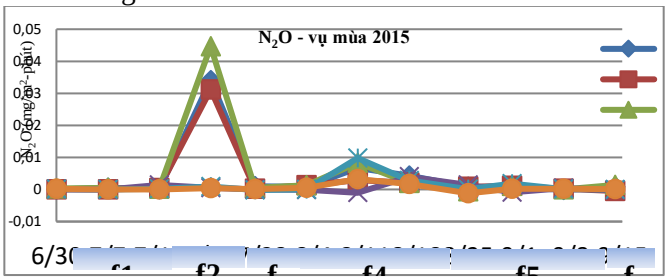


Fig. 3.30. N_2O emission intensity in summer-autumn crop in 2015

The intensity of N_2O emissions in 2015 showed that N_2O is quite small, averaging from 0.0000011 mg/m^2-min to 0.044 mg/m^2-min. The average gas emission intensity in summer-autumn crop (0.0026 mg/m^2-min). In all 3 irrigation formulas, the intensity of N_2O emissions in the absolute dry area was the lowest, i.e. equal to 34% of that of the moderate dry area and 27% of that of the traditional irrigation area.

3.6.3. Winter-spring crop 2016

N_2O emissions of the traditional formulas (C), moderate dry formula (W) and absolute dry formula (S) in the winter-spring crop 2016 in most of calculations fluctuated mainly in the range of 0.3 to 0.4 ppm. Sample values also did not differ much in different calculations, depending on growth time of rice and following this order S > W > C.

The intensity of N_2O emission is quite low i.e. 0.0000316 mg/m^2-min to 0.0710 mg/m^2-min, and there is quite a big difference between the largest and the smallest value. When the water level in fields fluctuated between -13 ÷ +10 cm, the emission intensity was not correlated in all 3 experimental areas.

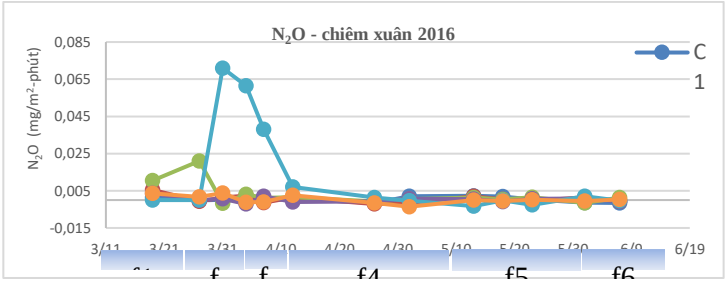


Fig. 3.34. N_2O emission intensity in winter-spring crop in 2016

In Figure 3.34, N_2O emission intensity in 2016 showed the average gas emission intensity in winter-spring crop (0.003 mg/m^2-min). The intensity of N_2O emission in the traditional irrigation area is as low as 23% of that of the moderate dry area and 8% of that of the absolute dry area. During the sampling and analysis, at the time of inorganic fertilizer application (urea), N_2O emission data are exceptionally high.

3.6.4. Summer-autumn crop 2016

N_2O emissions of the traditional formulas (C), moderate dry formula (W) and absolute dry formula (S) in the summer-autumn crop 2016 in most of calculations fluctuated mainly in the range of 0.3 to 0.4 ppm. Sample values also did not differ much in different calculations, depending on growth time of rice and following this order S > W > C.

N_2O emission intensity in summer-autumn crop 2016 is average (0.0011 mg/m^2-min). In 3 irrigation formulas, the intensity of N_2O emission in the traditional irrigation area is as low as 23% of that of the moderate dry area and 8% of that of the absolute dry area. During the sampling and analysis, at the time of inorganic fertilizer application (urea), N_2O emission data are exceptionally high.

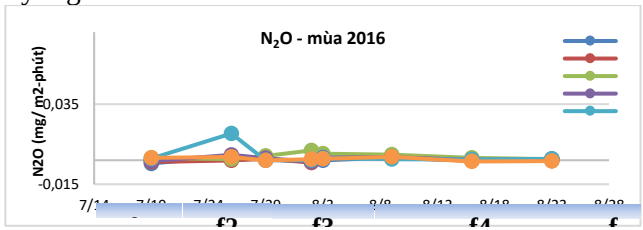


Fig. 3.35. N_2O emission intensity in summer-autumn crop in 2016

3.6.5. Winter-spring crop 2017

N_2O emissions of the traditional formulas (C), moderate dry formula (W) and absolute dry formula (S) in the winter-spring crop 2017 in most of calculations fluctuated mainly in the range of 0.3 to 0.4 ppm. Sample values

also did not differ much in different calculations, depending on growth time of rice and following this order S > W > C.

The intensity of N_2O emission in winter-spring crop 2017 in absolute dry plot is 0.00149mg/m^2-min; in the moderate dry plot: 0.00166 mg/m^2-min; traditional irrigation plot: 0.00129 mg/m^2-min.

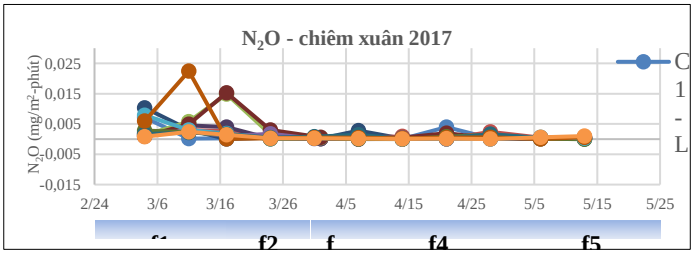


Fig. 3.42. N_2O emission intensity in winter-spring crop in 2017

3.6.6. Summer-autumn crop 2017

N_2O emissions of the traditional formulas (C), moderate dry formula (W) and absolute dry formula (S) in the summer-autumn crop 2017 in most of calculations fluctuated mainly in the range of 0.3 to 0.4 ppm. Sample values also did not differ much in different calculations, depending on growth time of rice and following this order S > W > C.

The intensity of N_2O emission in summer-autumn crop 2017 in absolute dry plot is 0.002758 mg/m^2-min; in the moderate dry plot of winter-spring crop: 0.002649 mg/m^2-min; traditional irrigation plot: 0.002157mg/m^2-min.

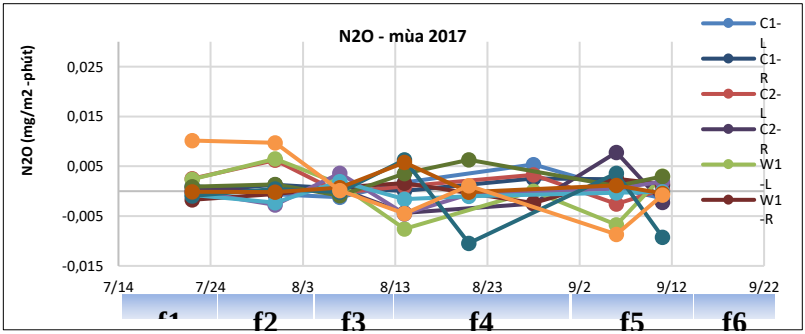


Fig. 3.46. N_2O emission intensity in summer-autumn crop in 2017

3.6.7. Assessment of effects of irrigation regimes on N_2O emissions in the 3 – year experiment

The sample mean values of formulas applied in experimental crops only fluctuated within 0.3 ÷ 0.4 ppm. Given very small amount and differences, it can be concluded that: The N_2O emissions in different formulas between

winter-spring crop and summer-autumn crop in 3 experimental years showed small variations or even insignificant difference.

N_2O emissions over the past 3 years (2015 ÷ 2017) tend to be significant from the transplanting stage to the tillering stage and the lowest emission is recorded from grain maturity till harvesting time.

While the evolution of N_2O emissions is different from year to year, the N_2O converted emission level tends to decrease gradually in moderate dry and absolute dry areas in 2015 and gradually increase from absolute dry and moderate dry areas and the largest value is measured in the traditional irrigation area. In 2017 there was a clear change in the total converted N_2O level, with the highest value is measured in moderate dry area (0.63g/m^2-day), although there was not a big difference between fields, S fields: 0.5g/m^2-day; C fields: 0.43g/m^2-day.

3.6.8. Reducibility and oxidation potential and N_2O emissions

3.6.8.1. Winter-spring 2015

The relationship between N_2O emissions and Eh, pH at a depth of 5cm in the winter-spring crop 2015 showed that the largest emissions are measured when the pH reaches 5.5÷8; Eh concentrated between -50 ÷ -200 mV; N_2O emission intensity is mainly in the range of 0 ÷ 0.002 mg/m^2-min. The suitable temperature for N_2O emission ranges from 20 ÷ 35°C.

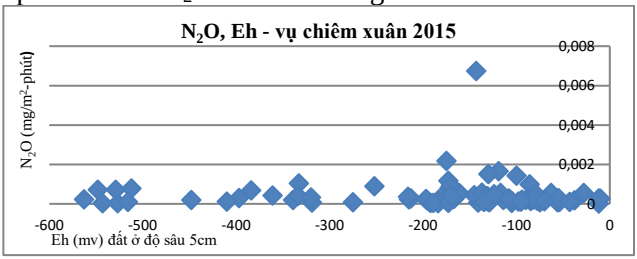


Fig. 3.47. Correlation of N_2O and Eh of the soil at a depth of 5cm in the winter-spring crop 2015

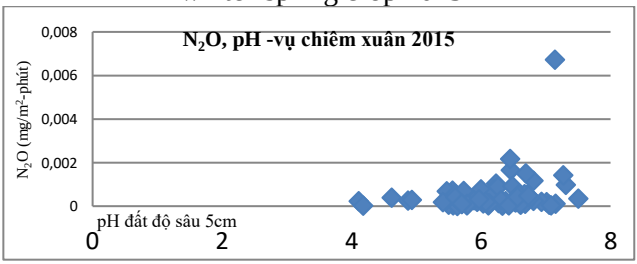


Fig. 3.48. Correlation of N_2O and pH of the soil at a depth of 5cm in the winter-spring crop 2015

3.6.8.2. Summer-autumn crop 2015

Figure 3.49 and Figure 3.50 showed the relationship between N_2O emissions and Eh, pH at a depth of 5cm in the summer-autumn crop 2015; the largest emissions are measured when the pH reaches 6÷8; Eh concentrated between -50 ÷ -200 mV; N_2O emission intensity is mainly in the range of 0 ÷ 0.005 mg/m^2-min. The suitable temperature for N_2O emission ranges from 20 ÷ 35^{o}C.

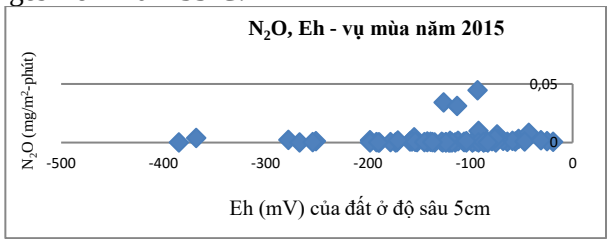


Fig. 3.49. Correlation of N_2O and Eh of the soil at a depth of 5cm in the summer-autumn crop 2015

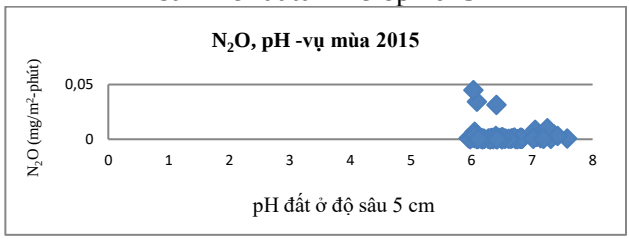


Fig. 3.50. Correlation of N_2O and pH of the soil at a depth of 5cm in the summer-autumn crop 2015

3.6.8.3. Winter-spring crop 2016

Figure 3.51 and Figure 3.502 showed the relationship between N_2O emissions and Eh, pH at a depth of 5cm in the winter-spring crop 2016; the largest emissions are measured when the pH reaches 6÷7.5; Eh concentrated between -50 ÷ -130mV; N_2O emission intensity is mainly in the range of 0 ÷ 0.01 mg/m^2-min. The suitable temperature for N_2O emission ranges from 20 ÷ 35^{o}C.

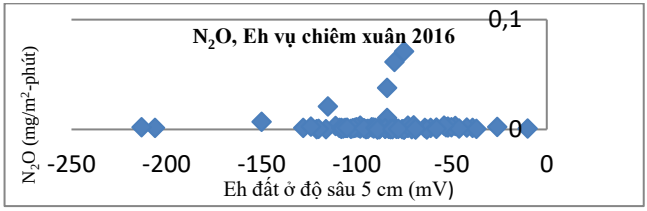


Fig. 3.51. Correlation of N_2O and Eh of the soil at a depth of 5cm in the winter-spring crop 2016

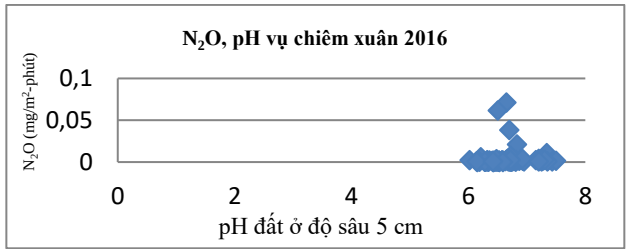


Fig. 3.52. Correlation of N_2O and pH of the soil at a depth of 5cm in the winter-spring crop 2016

Figure 3.53 and Figure 3.54 showed the relationship between N_2O emissions and Eh, pH at a depth of 5cm in the summer-autumn crop 2016; the largest emissions are measured when the pH reaches 5.8÷6.8; Eh concentrated between -80 ÷ -150 mV; N_2O emission intensity is mainly in the range of 0 ÷ 0.004 mg/m^2-min.

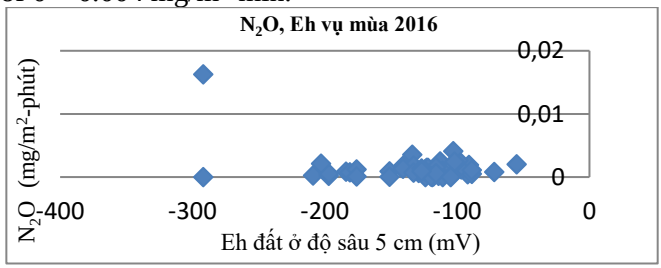


Fig. 3.53. Correlation of N_2O and Eh of the soil at a depth of 5cm in the summer-autumn crop 2016

By comparing winter-spring crop and summer-autumn crop, the N_2O emission intensity in the summer-autumn crop is less variable while in the winter-spring crop, the emission intensity fluctuates to the level of 0.07 mg/m^2-min.

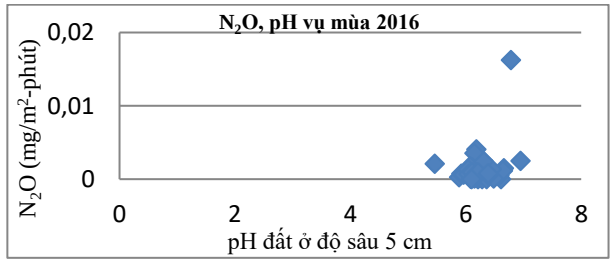


Fig. 3.54. Correlation of N_2O and pH of the soil at a depth of 5cm in the summer-autumn crop 2016

Figure 3.55 and Figure 3.56 showed the relationship between N_2O emissions and Eh, pH at a depth of 5cm in the winter-spring crop 2017; the largest emissions are measured when the pH reaches 5.5÷7.0; Eh

concentrated between -50 ÷ -200 mV; N_2O emission intensity is mainly in the range of 0 ÷ 0.004 mg/m^2-min. The suitable temperature for N_2O emission ranges from 20 ÷ 31^oC.

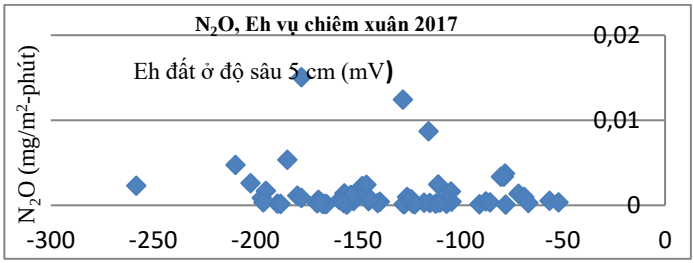


Fig. 3.55. Correlation of N_2O and Eh of the soil at a depth of 5cm in the winter-spring crop 2017

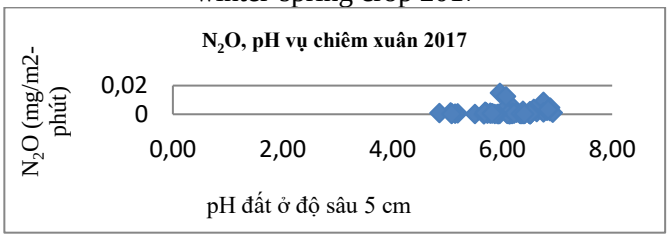


Fig. 3.56. Correlation of N_2O and pH of the soil at a depth of 5cm in the winter-spring crop 2017

Figure 3.57 and Figure 3.58 showed the relationship between N_2O emissions and Eh, pH at a depth of 5cm in the winter-spring crop 2017; the largest emissions are measured when the pH reaches 5.6÷7.5; Eh concentrated between -80 ÷ -200 mV; N_2O emission intensity is mainly in the range of 0 ÷ 0.006 mg/m^2-min. The soil temperature during the sampling time is 26.2 ÷ 40.8^oC.

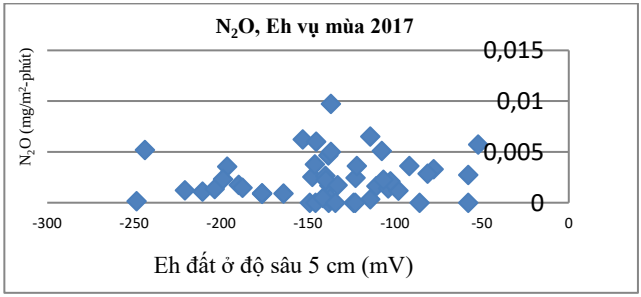


Fig. 3.57. Correlation of N_2O and Eh of the soil at a depth of 5cm in the summer-autumn crop 2017

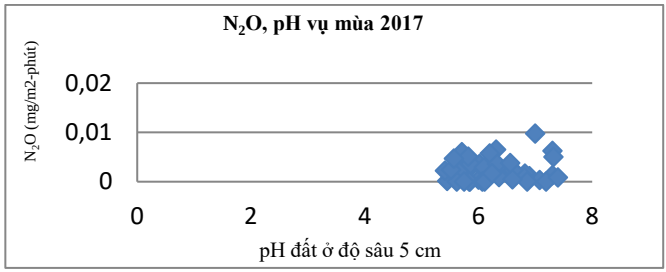


Fig. 3.58. Correlation of N_2O and pH of the soil at a depth of 5cm in the summer-autumn crop 2017

3.7. Conclusion of Chapter 3

3.7.1. Effects of irrigation regimes on N_2O emissions in the 3 – year experiment

The average N_2O emission of traditional absolute dry and moderate-dry irrigation formulas in 6 experimental crops (3 years) was quite low and fluctuated in the range of 0.3 ÷ 0.4 ppm. The difference in N_2O emissions in different formulas, between different crops in the year, is in the range of 0.1 ppm which means that the difference between formulas and between crops is quite small, or even insignificant.

Between crops, N_2O emissions tend to be large from the transplanting stage to the tillering stage and the lowest emission is recorded at the time of grain maturity and going to be harvested.

This result is also explained by above mentioned reasons. Thus, in the study land, weather factors (rainfall) does not affect the N_2O amount emitted.

3.7.2. Effects of irrigation regimes on growths and yields of rice

The amount of irrigation water and crop yield in 3 experimental areas showed that: in 2015, irrigation water consumption of the absolute dry area was the largest, yet the rice yield of the moderate dry irrigation area is the highest in all 3 experimental formulas.

In 2016 the amount of irrigation water consumed in winter-spring crop 2016 in the absolute dry areas is the lowest, yet the rice yield is the highest; the 2016 summer-autumn crop in the moderate dry area gained the highest yield, while the irrigation water is not the largest.

In 2017, the amount of irrigation water consumed in winter-spring crop 2017 in the moderate dry areas brought in the highest rice yield.

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

1) Research experimental site is in Phu Thinh commune, Kim Dong district, Hung Yen province. This is a typical area for the Red River Delta, with a convenient irrigation system for rice. Local officials and people have good educational level and have good awareness of scientific and technological advances in agriculture. Rice land here is typical for alluvial soil of the Red River delta which is not deposited on annual basis.

2) Undeposited alluvial soil in the Red River for rice cultivation in Hung Yen province has Eh ranging from -10 ÷ -350 mV and a pH from 6 ÷8 which is favorable for the denitrification process to form an intermediate product of N_2O (not favorable for the nitrification into NO_3-).

3) The sample mean values of N_2O emissions in different formulas of traditional irrigation, absolute dry and moderate dry in 6 crops in 3 experimental years are quite low, only fluctuating between 0.3 ÷ 0.4 ppm. The difference of N_2O emissions in different formulas and in different crops is quite small or even insignificant (not having statistical implication).

4) During growth and development stages of rice, the largest amount of N_2O emission is measured during transplanting to the end of tillering stage, as fields are flooded during this time (low Eh) and heavily fertilized with urea; N_2O emissions are lowest during grain maturity and going to be harvested due to the lowering of water levels in fields.

5) Research results over 3 years (2015 ÷ 2017): the total N_2O emissions in absolute dry irrigation formula is 0.0003 ÷ 0.0064 tons/ha-crop, or 0.1 ÷ 1.9 tons/ha-crop (CO_2e equivalent); moderate dry irrigation formula 0.0003 ÷ 0.0047 (ton/ha-crop), or 0.1 ÷ 1.4 ton/ha-crop (CO_2e equivalent); traditional irrigation formula: 0.0009 ÷ 0.0064 tons/ha-crop, or 0.3 ÷ 1.9 tons/ha-crop (CO_2e equivalent).

6) Moderate dry irrigation formula brought in best effect with highest rice yield and saved the most irrigation water i.e. 20.5 ÷ 36.5%, the N_2O emissions is not much different compared to other irrigation formulas, however, total GHG emissions (CH_4 and N_2O) decreased from 20.5 ÷ 29.1%.

2. Recommendations

1) Moderate dry irrigation method should be applied in rice cultivation on a large scale for rice soil having Eh value lower than -10 mV and a pH around 6÷8.

2) There should be more studies on effects of different irrigation regimes on N_2O emissions in rice fields for soils with higher Eh values.

LIST OF STUDIES OF THE AUTHOR RELATING TO THE DESERTATION

1. Nguyen Dang Ha, Le Xuan Quang, Tran Hung, Pham Dinh Kien, Le The Hieu, Nguyen Van Tinh, Fukuda Shinji, Hesagawa Kiyoshi, Ono Yumiko, Hirata Junya, Komatsu Hirotaka, Nakamura Kimihito, (2019), "Proposaland practice of eco-friendly water and materials mangement which is compatible with improvement of rice yield and quality in paddy fields in Vietnam". *Proceeding of the International conference on Science and Technology for Water security disaster reduction and climate change adaptation, Hanoi, November 05th, 2019*. ISSN 978-604-67-1637-2.

2. Nguyễn Đăng Hà, (2021), Nghiên cứu ảnh hưởng của quản lý nước mặt ruộng đến phát thải khí N_2O trên đất phù sa sông Hồng không được bồi hàng năm trồng lúa ở tỉnh Hưng Yên. *Tạp chí Khoa học và Công nghệ thủy lợi* số 69.

3. Nguyễn Đăng Hà, (2022), Cơ chế Fig. thành và phát thải khí N_2O trên đất trồng lúa. *Tạp chí tài nguyên nước số 1 năm 2022.*