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Effect of rice intermittent irrigation on nitrogen cycle and emission in a lysimeter study

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ABSTRACT

Although intermittent irrigation is widely regarded as a saving irrigation water technology in paddy fields, it can cause water and air pollution by changing the nitrogen cycle. A two-year lysimeter experiment was conducted to investigate the effect of intermittent irrigation on the nitrogen cycle. For applying intermittent irrigation, soil drying began about 30 days after transplanting and the alternate wetting and drying was considered weekly. To investigate the nitrogen cycle in the lysimeter, nitrate and ammonium concentrations and acidity were measured periodically at depths of 18, 30, and 70 cm. Results showed that water saving was 23-24%, which varied over two years depending on the weather conditions. The most nitrate and ammonium concentration changes occurred at a depth of 30 cm in 2018 and a depth of 70 cm in 2019. Nitrate concentration after two dried periods at a depth of 30 cm indicated the producing and leaching of nitrate in the soil, which upraised the risk of groundwater contamination. Nitrate concentration in the dried period increased compared to the previously flooded period, although the rate of increase was variable in each alternation. The reduction of ammonium concentration was about 13% in the first alternation at a depth of 30 cm, which was much lower in the following periods. Nitrogen balance in the surface layer showed that 39 and 51% ammonium volatilization and rice uptake occurred, respectively. Denitrification was obtained 0.5 kg N ha^{-1} which could be as an index for the emission of N_2O. Total nitrogen loss based on applied nitrogen fertilizer was 52%, of which 47% is caused by ammonium volatilization. Results showed the importance of the number of alternations in nitrogen changes in paddy fields.

Key words: Ammonium, Denitrification, Rice uptake, Volatilization.
Article type: Research Article.

INTRODUCTION

Rice has great importance in feeding half of the world's population, especially in Asian countries. Global rice production has grown by 1.5% to 170.4 million tons (FAO 2018). Climatic parameters, soil characteristics, plotting, topographic condition, as well as nutrient and fertilizer management are factors that affect the quantitative and qualitative performance of rice production in paddy fields. Continuous flooding of water generally provides the best growth environment for rice. Continuously flooded with water level of 3-10 cm during the grown season is common irrigation in bunded paddy fields in Asia. The water usage in the continuous flooding method is very high due to water loss in terms of canal leakage, deep seepage, low efficiency, open-end basin, evaporation from the water surface, and preparing the field (about 30-50% loss; Borel *et al.* 1997; Tuonge & Bouman 2003; Pascual & Wang 2017). In addition, the creation of revitalization conditions due to lack of ventilation, water and soil pollution, accumulation of toxic substances in the root environment, and plant susceptibility to pests and diseases are some problems in this method (Lin *et al.* 2003). Using intermittent irrigation management reduced water consumption by half and increased rice water productivity by over twice as much as by flood irrigation

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(Pourgholam-Amiji *et al.* 2021). Saberi *et al.* (2011) reported that although the reduction of nutrient transfer to the plant and leaf area causes reducing yield in intermittent irrigation, 5, 8, and 11 days intervals have not exhibited a significant effect on rice yield. Roderick *et al.* (2011) reported that deficit irrigation with alternate wetting and drying reduces water consumption of paddy irrigation water by about 38% without reducing the yields and farmer's profits. Nitrogen is an essential element for rice growth and production. Urea (46% N) is the conventional N fertilizer in paddy fields. In flooded paddy fields, root nitrogen uptake is in the form of ammonium, and due to denitrification process, nitrate leaches less. In intermittent irrigation, due to nitrate production in the nitrification process, root nitrogen uptakes are in the forms of ammonium and nitrate that cause higher N use efficiency. However, nitrate leaching and atmospheric pollution with nitrogen gases are more likely under these conditions. Improper management of water and fertilizer, causes serious environmental problems in the rice planting areas. Research has illustrated physical and chemical properties of soil and the water availability in soil influence the migration and the utilizing efficiency of nitrogen under water-saving irrigation methods. Soil type, the application of nutrients, organic matter, water management (irrigation and mid drainage), rice genotype, and climate condition are factors that affect nitrogen utilizing efficiency in paddy fields. Proper management of soil nutrients as nitrogen, requires knowledge of the nitrogen cycle and its behavior in the soil and ecosystem. In flooded paddy fields, rice prefers ammonium to nitrate as a nitrogen source, and rice uptake ammonium faster than nitrate (Li *et al.* 2015). Some of the ammonium ions released into the soil mass are probably oxidized to nitrate in the rhizosphere and absorbed by roots in the form of nitrate (Dobermann & Fairhurst 2000). Nitrification occurs by converting organic nitrogen to nitrite and then converting nitrite to nitrate under aerobic conditions. Denitrification defines as a bacterial process for converting nitrate to nitrite and nitrite to nitrogen gas under anaerobic conditions (Cai 2002). These processes are affected by many factors such as soil temperature, bacterial population and activity, soil acidity, oxygen content, organic matter content, soil texture and structure, gas distribution coefficient, the volume of the anaerobic section, and nitrate concentration in the soil (Sahrawat & Keeney 1986; Conrad 1996). So, alternate wetting and drying increase the complexity of nitrogen transformation in paddy fields compared to continuous flood irrigation. Nitrite and nitrate do not absorb on soil clay particles due to their negative charge and leach to the groundwater aquifer. The rate of leaching depends on the amount of fertilizer and the rate of water seepage, so in soil with a seepage rate of 4.4 mm per day, the rate of leaching losses of 10% of nitrogen fertilizer application and in soil with a seepage rate of 18.3 mm per day, 88% has been reported (Mitsui 1954). Gholami & Booij (2022) reported a mean nitrate concentration of 23.4 mg L^{-1} in the Mazandaran plain, Northern Iran which is a region under rice cultivation. NH_3 emitted from different sources such as fertilizers, human excreta and fossil fuel combustion have contributed significantly to air pollution, water eutrophication, and declining human health (Stokstad 2014). NH_3 volatilization from agricultural lands has been identified as an important source of atmospheric NH_3, accounting for 43.3% of total global NH_3 emissions (Paulot *et al.* 2014). The ammonia volatilization is another way to lose nitrogen in paddy fields that are affected by fertilizer form, the timing of application, soil properties such as high pH, applied depth of fertilizer, temperature, and wind of weather after application. Nitrogen loss through the denitrification process is estimated to be 68% in soils without proper drainage. The relationship between soil pH and denitrification has not been clarified (Zhang *et al.* 2009). It is generally believed that the optimal pH for denitrification is 7 to 8 (Zhang *et al.* 2009). Some studies expressed that the denitrification rate in flooded soils can be regulated by nitrification rate (Zhou *et al.* 2012). The oxygen status and soil pH are critical factors in the nitrification process (Zhang *et al.* 2013). Due to low oxygen concentration in flooded rice soils, nitrification can occur only in the root rhizosphere or oxidized soil layer. Some Studies showed that nitrification rates increase by elevaing soil pH during denitrification (Zhao *et al.* 2007; Qian *et al.* 2019). The nitrogen losses were estimated at 20 to 40% in paddy fields by denitrification in India (Abichandani 1995) and 30-50% in Japan (Mitsui 1954). In general, the nitrification process is most efficient in the optimal environmental condition such as acidity 4-8, air conditioning, proper humidity, and temperature of 30 ℃ (Morkved *et al.* 2007; Qin *et al.* 2010). Castaldi (2002) stated that the highest amount of denitrification occurs at 40 ℃ and stops below 10℃. Williams *et al.* (1995) simulated denitrification by examining the available nitrate parameters, soil temperature, and humidity reporting that anaerobic and suitable conditions for denitrification occur when the soil moisture is 95% of the field capacity or 90% of the soil saturation moisture. Hutson & Wagenet (1991) showed that the rate of denitrification in different soils varies between 0.05-0.2 kg m^{-2}. Cai (2002) investigated nitrogen loss by volatilization and denitrification in paddy fields of China (with soil pH 4 to 8.8) finding that about 30 to 39% of nitrogen fertilizer losses through volatilization. In addition, mixing the nitrogen fertilizer with soil reduces the amount of volatilization and denitrification. Martens & Bremner (1998) studied the effect of soil properties on the volatilization of ammonia on 20 types of soil treated with urea for 10 days at 30 ℃ reporting that the ammonia volatilization in soils amended with urea was from 0 to 65% of applied urea and averaged 14%. In addition, the volatilization had a positive correlation with sand content, equivalent calcium carbonate, and soil pH after incubation with urea. Tan *et al.* (2013) reported that percolation was reduced by 15.3 and 8.3 % in 2007 and 2008 compared to continuously flood irrigation (CFI). However, the cumulative percolation of the first 5 days after irrigation in AWD was significantly larger than CFI. The total NH_4^+–N, NO_3 −N, and TN leaching losses of AWD in the first 3 days after irrigation were higher than CFI. Their results indicated that preferential flow and strengthened nitrification–denitrification nitrogen in alternate wetting and drying increase the NO_3-N loading to the groundwater. Water management practices influence greenhouse gas emissions in paddy fields, particularly those of methane (Oo *et al.* 2020) and nitrous oxide (N_2O; Song *et al.* 2021). The alternate aerobic and anaerobic periods in AWD enhance N_2O emissions via nitrification (aerobic; Dang Hoa *et al.* 2018) and denitrification (anaerobic) processes (Fertitta-Roberts *et al.* 2019). A few studies have reported that global warming potential did not significantly differ between CF and AWD (Singha *et al.* 2019) due to offsetting the reduction in CH_4 emissions by increased N_2O emissions (Ku *et al.* 2017). A study in Italy showed saving irrigation water by 70%, loss yields by 33%, and N_2O emissions more than quadrupled, in AWD (Lagomarsino *et al.* 2016). Qiu *et al.* (2022) reported that alternate wet and dry irrigation had a significant yield-increasing effect (average 2.57% increase) but has a significant effect on increasing N_2O emissions, with an average increase of 67.77%. They also reported that the effect of alternate wet and dry and controlled irrigation on nitrogen leaching reduction was 49.13 and 14.24, respectively. In addition, the effect of controlled irrigation on reduction of ammonia volatilization was significantly higher than that of alternate wet and dry, with an effective value of 20.97%. Due to the scarcity of water resources in the Northern Iran, the need to change irrigation methods from continuous flooding to water saving in rice cultivation, affecting of aerobic conditions and properties of soil, as well as rice variety on the nitrogen cycle, the aim of this study was to investigate the nitrogen cycle under intermittent irrigation management in Guilan paddy fields, Northern Iran. The great significance of the study is assessing the risk of nitrogen loss from paddy fields to achieve fewer environmental problems, promote sustainable agricultural development, and help to recommend the best management in intermittent irrigation.

MATERIALS AND METHODS

A lysimeter experiment was conducted in 2018 and 2019 at Irrigation and Drainage Research Station, University of Guilan, Rasht, Iran. The latitude and longitude of the region are 37°30′33″ N and 49°35′19″ E, respectively, and its height above sea level is 8.6 m. The mean annual precipitation and air temperature in the region are approximately 1337.5 mm and 15.8 ℃, respectively. The lysimeter (300 cm in length, 60 cm in width, and 100 cm in height), was filled with paddy soil that had been dried in air and passed through a 5-mm sieve. Hardpan was formed in the depth of 22 cm by paddy soil that passed through a 2-mm sieve and compacted with about 1.3 g cm^{-3} bulk density. The basic physical and chemical properties of soil are shown in Tables 1 and 2. After saturating the soil in 2018 in early July and 2019 in mid-June, rice transplanting (Hashemi variety) was transferred to lysimeter and cultivated at intervals of 25 × 25 cm. In both years, 11 g of urea fertilizer was applied 19 days after transplanting according to the fertilizer need of rice (90 kg ha^{-1}). Intermittent irrigation was applied with flooding to 5 cm and drying with interval 8 and 7 days in 2018 and 2019, respectively. The dates of irrigation interval along the grown season are given in Table 3 for 2018 and 2019. Due to occurrence precipitation, it was not possible to apply a fixed irrigation interval, but they were mostly 7 and 8 days. The amount of precipitation and air temperature were used from the meteorological station of Rasht Agricultural Meteorological Research Center (Fig. 1).

Table 1. Some physical properties of the soil used in the experiment.

Depth of soil (cm)	Soil particle size distribution			Texture of soil	Bulk density (g cm^{-3})
	Sand (%)	Silt (%)	Clay (%)		
0-22	9.84	49.97	40.19	Silt clay	1.25
22-25	9.84	49.97	40.19	Silt clay	1.30
25-90	19.45	63.10	17.45	Silt loam	1.35

Table 2. Some chemical properties of soil solution extract in the experiment.

	2018				2019			
Depth of soil (cm)	**pH**	**EC (μs cm^{-1})**	**NO_3^- (mg L^{-1})**	**NH_4^+ (mg L^{-1})**	**pH**	**EC (μs cm^{-1})**	**NO_3^- (mg L^{-1})**	**NH_4^+ (mg L^{-1})**
0-25	6.84	1082	0.35	0.55	6.49	654	0.20	0.55
25-90	6.99	841.3	0.17	0.59	6.90	695	0.12	0.70

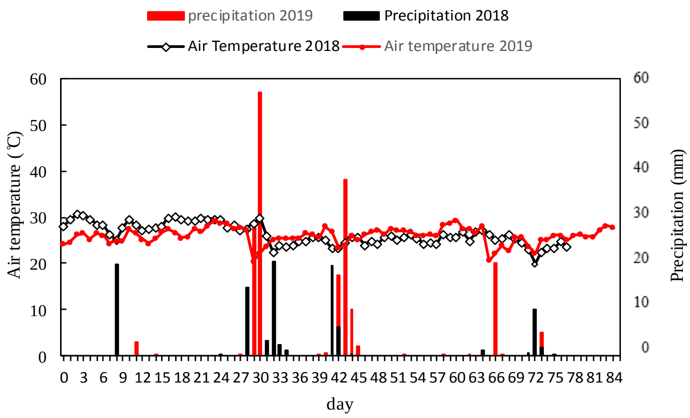

Fig. 1. Average temperature and precipitation during the growing season in 2018 and 2019.

To measure nitrate, nitrite, and ammonium concentration of the soil, ceramic suction cups were installed at the depth of 70 cm (cup numbers 5, 6 and 7), 40 cm (cup numbers 2, 3 and 4), and 18 cm (cup number 1). Fig. 2 shows the layout of the ceramic suction cups in the lysimeter. During the growing season, samples were taken from the soil solution and irrigation water in both flooded and dry conditions of the soil. Ion chromatography was applied to determine nitrite, nitrate, and ammonium anions and, soil pH was measured by a pH meter (Standard Method Examination of Water and Wastewater 2013). In the cutting time of irrigation, due to reduced soil moisture, there was not possible to sample soil solution at a depth of 18 cm. Also, a piezometer was installed at the depth of 70 cm to monitor the water table. To evaluate environmental impact of intermittent irrigation, ammonia volatilization was estimated by equation 1 (Saiki *et al.* 2020).

$$N_{budget} = N_{fer} + N_{irr} + N_{pre} + N_{fix} - (N_{rice} + N_{drain} + N_{sub} + N_{per} + N_{vol} + N_{den} + N_{other}) \qquad \textbf{(1)}$$

where N_{fer}, N_{irri}, N_{pre} and N_{fix} denote the amounts of nitrogen inputs from fertilizer, irrigation, precipitation and biological fixation, respectively; N_{rice}, N_{drain}, N_{sub}, N_{per}, N_{vol}, N_{den} and N_{other} denote the amounts of nitrogen outputs by rice uptake, surface drainage, subsurface drainage, percolation, ammonia volatilization, denitrification and uptake by other plants, respectively. N_{budget} was calculated by comparing soil total N at the beginning and the end of the experiment. N_{irri}, N_{pre}, and N_{per} were calculated by multiplying the daily water flux with the concentration of each form of nitrogen. Mean nitrogen concentration in irrigation water, surface drainage, subsurface drainage and precipitation were 0.39, 0, 0 and 0 mg L^{-1}. Deep percolation was calculated 2.5 mm/d based on piezometer data. Urea has the highest nitrogen content of 46%, so N_{fer} was obtained based on fertilizer application rate and nitrogen ratio in urea. N_{den} was calculated by multiplying the NO_3–N concentrations in ponded water by its depths and denitrification rate constant (0.0001 day^{-1}) that was estimated on the basis of a one-order reaction by Mahmoud Soltani (2019). Antonopoulos (2010) calculated the amount of nitrogen uptake using algae, which resulted in 9.4% of total input NH_4^+–N. Multiple regression between total nitrogen uptake, grain yields, N application rates and applied irrigation water used by equation 2 (Saiki *et al.* 2020).

$$NU = 9.89 + 0.0136Y + 0.471N - 0.0134W \qquad R^2 = 0.94 \qquad \textbf{(2)}$$

where NU is total plant nitrogen uptake in kg ha^{-1}, Y is grain yield in kg ha^{-1}, N is nitrogen application rate in kg ha^{-1} and W is applied irrigation water in mm. Grain yield and applied irrigation water were measured 3080 and 3050 kg ha^{-1} and 2330 and 2630 mm in 2018 and 2019, respectively.

Table 3. Date of alternative irrigation in 2018 and 2019.

2018				2019			
Date	**Days after transplanting**	**Soil moisture condition**	**Depth of irrigation water**	**Date**	**Days after transplanting**	**Soil moisture condition**	**Depth of irrigation water**
2018-7-9	1	Flood	5	2019-6-1	1	Flood	**5**
2018-8-8	30	Dry	0	2019-7-6	35	Dry	**0**
2018-8-18	40	Flood	5	2019-7-14	43	Flood	**5**
2018-8-25	47	Dry	0	2019-7-23	52	Dry	**0**
2018-9-1	54	Flood	5	2019-7-30	59	Flood	**5**
2018-9-9	61	Dry	0	2019-8-6	66	Dry	**0**
2018-9-16	68	Flood	5	2019-8-13	73	Flood	**5**
2018-9-23	75	Dry	0	2019-8-19	79	Dry	**0**

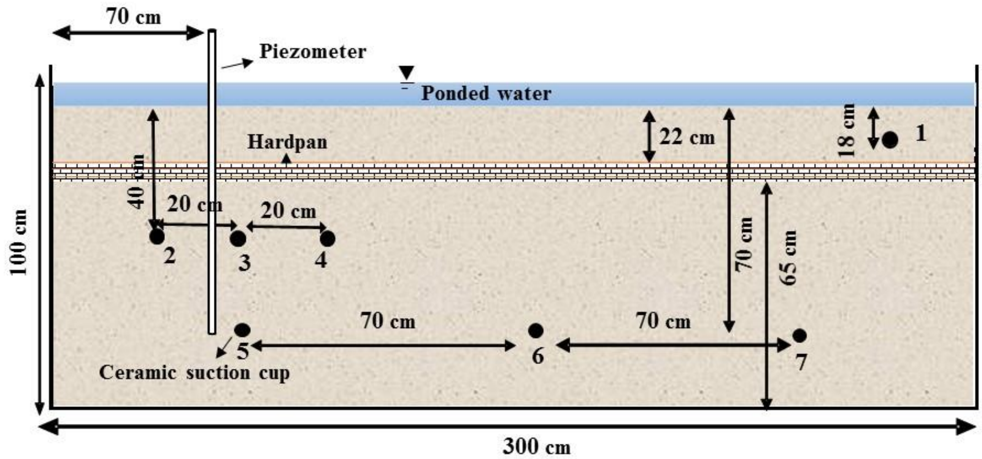

Fig. 2. Lysimeter, ceramic suction cup and piezometer.

RESULTS AND DISCUSSION

The pH changing trend at different depths of soil under intermittent irrigation are shown in Fig. 3. In 2018, the ranges of pH at the depths of 18, 40, and 70 cm were 6-7.7, 5.9-7.6, and 6.2-7.3, respectively. In 2019, pH varied between 6.3-7.1, 6.4-7.1, and 5.8-7.1 at the same depths, respectively. In both years, pH fluctuated between 6-7.5, and this is in line with the results by Kashem & Sing (2001) who reported stabilization of pH between 6.5-7.0 a few weeks after flooding in paddy fields, in most soils. The mean of pH (Fig. 3) at the depth of 18 cm (the layer above hardpan layer) was 6.98 and 6.75 in 2018 and 2019, respectively. Therefore, in the case of pH, there was good potential for nitrification in both years. In addition, at the depth of 40 and 70 cm, the range of pH exhibited optimal value for denitrification and NH_3 volatilization.

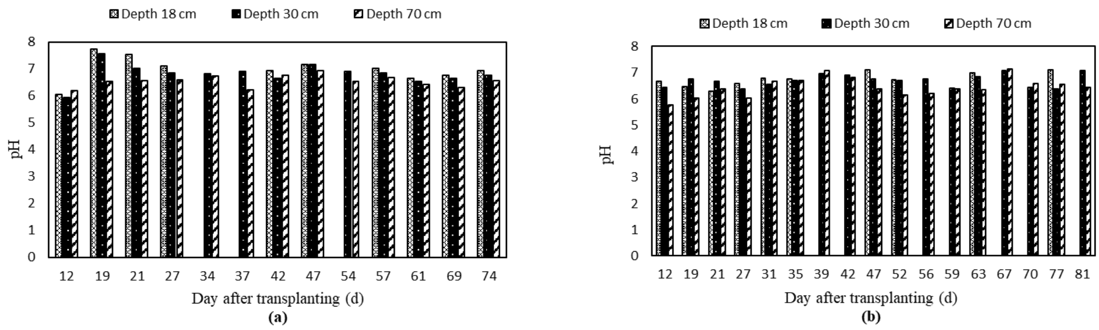

Fig. 3. Soil pH at different depths during the growth season in 2018 (a) and 2019 (b).

Nitrate concentration changes in the flooded and drying alternation

Nitrate concentration changes in the flooded alternation are given in Fig. 4. According to this Fig., in both years, the nitrate concentrations in the first and second flooded alternations at the depth of 18 cm was higher than 30 and 70 cm. In the third and fourth flooded alternations, the nitrate concentration at the depth of 30 cm were obtained higher than 18 and 70 cm. The result indicates nitrate leaching by the passing time. The reduction of nitrate concentration at the depth 70 cm exhibits denitrification. As shown in Fig. 6, in both years, the water table did not decrease more than 35 cm. So, along growth season at this depth anaerobic conditions had been occurred that caused denitrification. According to Fig. 5, in the first dry period, nitrate concentration at the depth of 30 cm was higher than at that of 70 cm, but in the second period, the opposite result was observed. According to the water table changes in 2019 (Fig. 6), in all dry period, the amount of nitrate concentration in the depth of 30 was higher than in 70 cm, which was similar to the results in 2018.

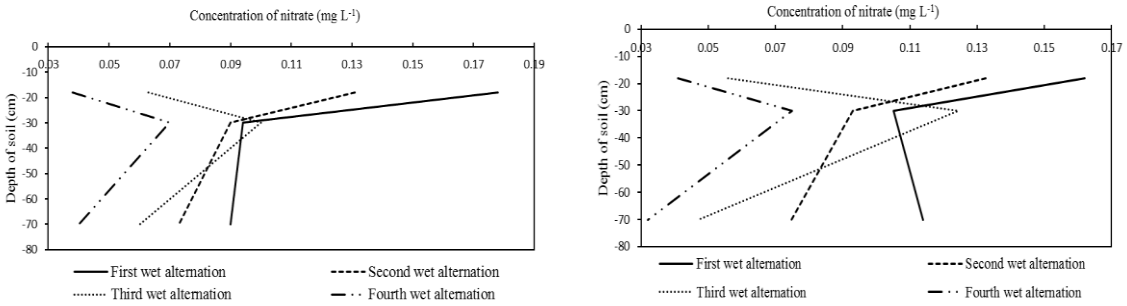

Fig. 4. Nitrate concentration changes at the depths of 18, 30 and 70 cm in flooded alternation in 2018 (left side) and 2019 (right side).

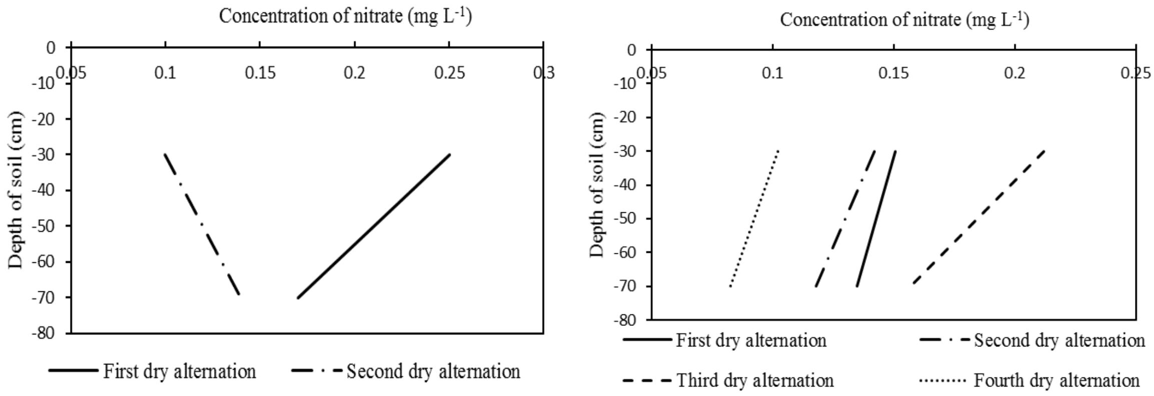

Fig. 5. Nitrate concentration changes at the depths 30 and 70 cm in drying alternation in 2018 (left side) and 2019 (right side)

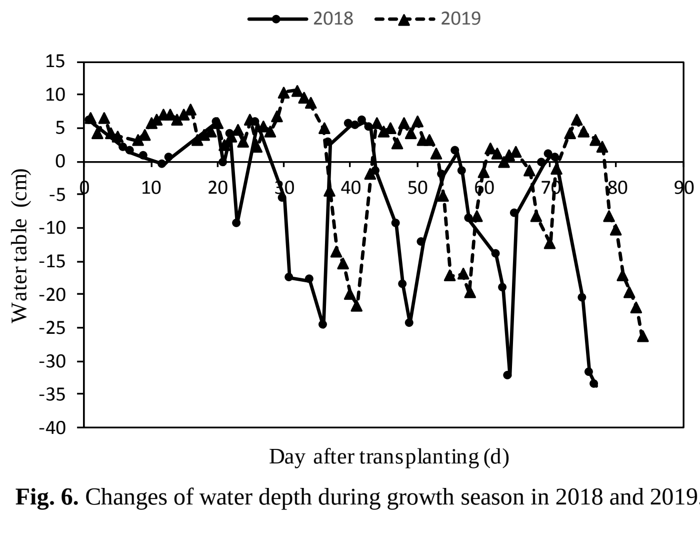

Fig. 6. Changes of water depth during growth season in 2018 and 2019.

In 2018 (Fig. 7a), in the flooded term of alternation at the depths 18, 30, and 70 cm, nitrate concentrations decreased by 79, 26 and 56% compared to the first flooded period, respectively. In 2019 (Fig. 7b), similar to 2018, the rate of decrease in nitrate concentration at 18, 30 and 70 cm depths were 75, 29 and 72%, respectively. So, a decreasing trend occurred for nitrate concentration in all three depths during the growth season. The highest reduction in nitrate concentration was achieved in both years at the depth of 18 cm in the third flooded alternation. So, the number of alternation could be important for nitrate changes in nitrogen cycle. At the depth of 30 cm was observed an increase of 10 and 25% in the third alternation, which indicates leaching of nitrate in 2018 and 2019. More precipitation in 2019, probably caused elevation of nitrate leaching than in 2018. Investigating the nitrate concentration at different dry periods in 2018 (Fig. 8a), showed decreasing by 60 and 18% compared to the first dry alternation during the growth season at the depths of 30 and 70 cm, respectively. In 2019, these values were 32 and 39% at the depths of 30 and 70 cm (Fig. 8b), respectively. The acceleration in dropping nitrate at the 30 cm was higher in 2018 than in 2019, which may be due to the higher concentration of nitrate in 2018. Similar to flooded alternation, the nitrate concentration upraised in the third alternation in the both depths, exhibiting higher occurrence of nitrification after the two alternations (about 50 days after transplanting). At the depth of 70 cm, the decreased nitrate concentration was not significant, which may be due to the lack of root nitrate uptake and low rate of nitrification.

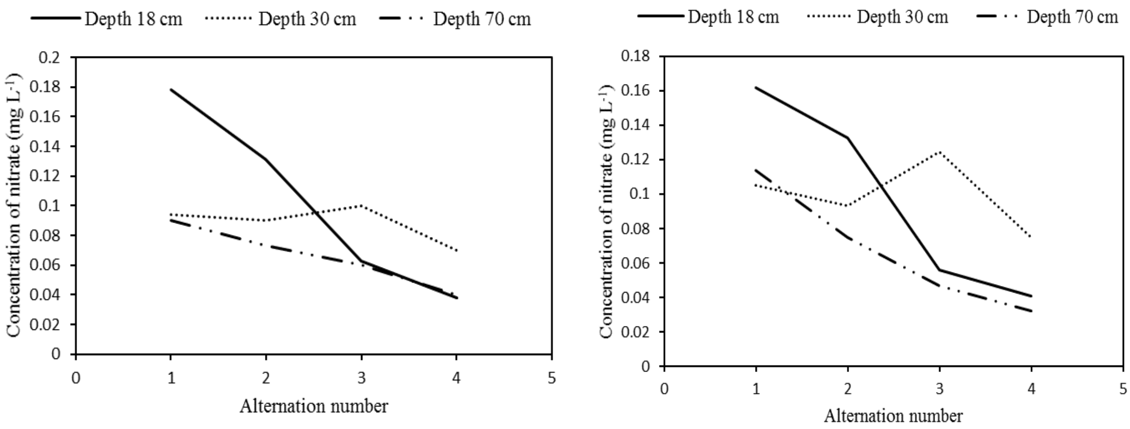

Fig. 7. Nitrate concentration changes at the depths of 18, 30 and 70 cm in the flooded alternation in 2018 (left side) and 2019 (right side).

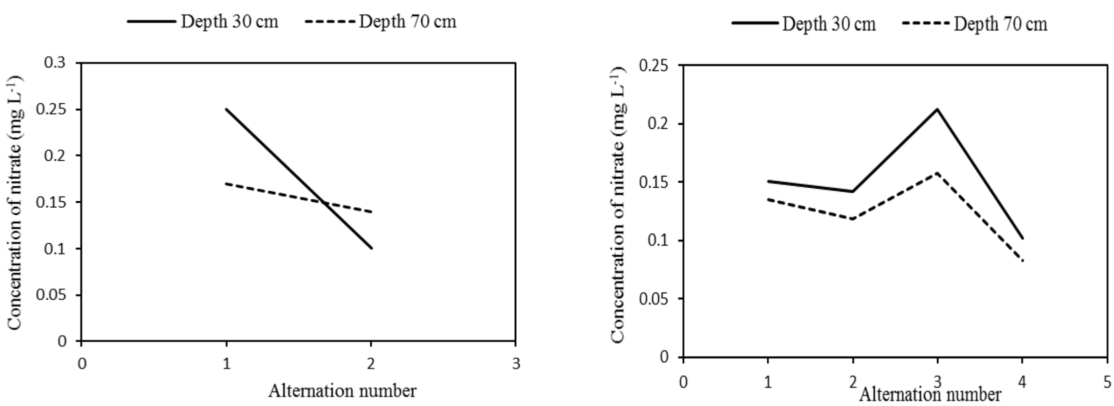

Fig. 8. Nitrate concentration changes at the depths of 18, 30 and 70 cm in the drying alternation in 2018 (left side) and 2019 (right side).

Table 4 shows the nitrate changes in dry period compared to the previously-flooded one at two depths of 30 and 70 cm. According to the results, the nitrate concentration in dry period upraised compared to previously flood period, although the rate of elevation decreased at the depth of 30 cm by repeating the dry period.

Table 4. Comparison of nitrate changes in drying and flooded alternation at depths of 30 and 70 cm.

Alternation		2018		2019		Average	
		Depth 30	Depth 70	Depth 30	Depth 70	Depth 30	Depth 70
First flood	First dry	62	47	30	16	46	31
Second flood	Second dry	10	48	35	37	22	42
Third flood	Third dry	-	-	41	70	-	-
Fourth flood	Fourth dry	-	-	26	61	-	-

Ammonium concentration changes in flooded and drying alternation

The ammonium concentrations in flooded alternation at the depths of 18, 30, and 70 cm during 2018 are given in Fig. 9-a. In the first and second alternations, ammonium concentration at 18 cm was greater than at 30 and 70 cm.

Since ammonium absorbs on the surface soil, less leaching has happened and stabilized at upper depths. In the third and fourth alternations, the ammonium concentration at 18 cm was slightly lower than at 30 and 70 cm, displaying lower potential of ammonium leaching. In 2019, the ammonium concentration in all alternations at the depth of 18 cm was higher than at 30 and 70 cm (Fig. 9b). The difference between ammonium concentrations of 30 and 70 cm in 2018 compared to 2019 can be related by the state of the water table in dry period. As shown in Fig. 6, in 2018, the water table in dry period was higher than 32 cm, so the aerobic condition and change of ammonium to nitrate occurred at this depth, while in 2019, the maximum of water table was about 22 cm. Also, the difference in the ammonium concentration at the depth of 70 cm may be due to the difference in pH, in 2018 and 2019.

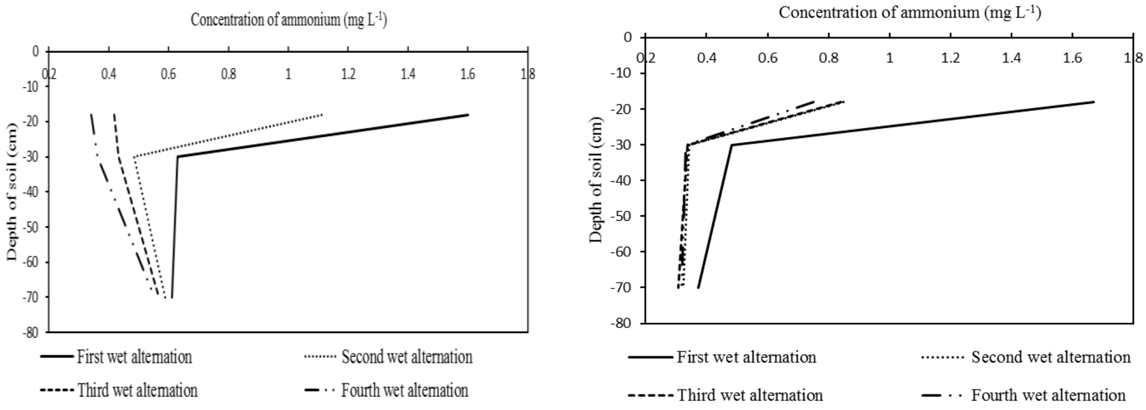

Fig. 9. Ammonium changes at the depths of 18, 30 and 70 cm in flooded alternation in 2018 (left side) and 2019 (right side).

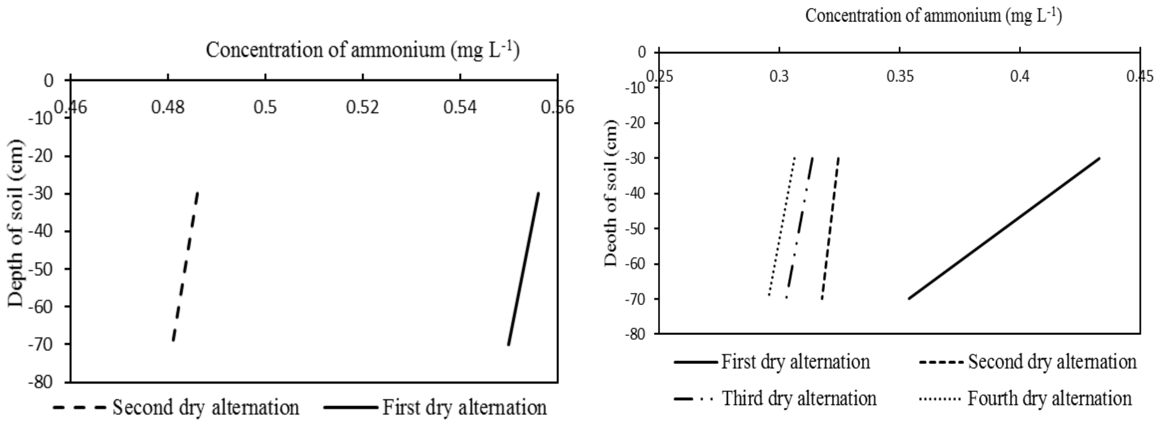

Fig. 10. Ammonium changes at the depths of 30 and 70 cm in drying alternation in 2018 (left side) and 2019 (right side).

Changes in ammonium concentration in the different flooded periods are shown in Fig. 11a. In 2018, the ammonium concentration decreased during the growth season by 79, 43 and 10% at the depths 18, 30 and 70 cm, respectively. According to Fig. 11b, in 2019, the trend was similar to the previous year, however, the reduction was about 55, 31, and 15%, respectively. The ammonium concentration in dry periods decreased compared to previously flooded periods (Table 5) at both depths of 30 and 70 cm. The reduction of ammonium concentration was higher at the depth of 30 than at 70 cm. The ammonium, nitrite, and nitrate concentrations at the depths of 18, 30, and 70 cm are given in Fig. 13 over time. At the depth of 18 cm, all three parameters fluctuated a lot, while in the other two depths, ammonium and nitrite concentrations did not change much. So, intermittent irrigation exhibited higher effect on the nitrogen cycle in the surface layer of soil.

Table 5. Comparison of ammonium changes in drying and flooded alternation at the depths of 30 and 70 cm.

Alternation		2018		2019		Average	
		Depth 30	Depth 70	Depth 30	Depth 70	Depth 30	Depth 70
First flood	First dry	-13	-11	-12	-5	-12.5	-8
Second flood	Second dry	-0.5	-22	-6	-1	-3	-11.5
Third flood	Third dry	-	-	-7	-1	-	-
Fourth flood	Fourth dry	-	-	-8	-7	-	-

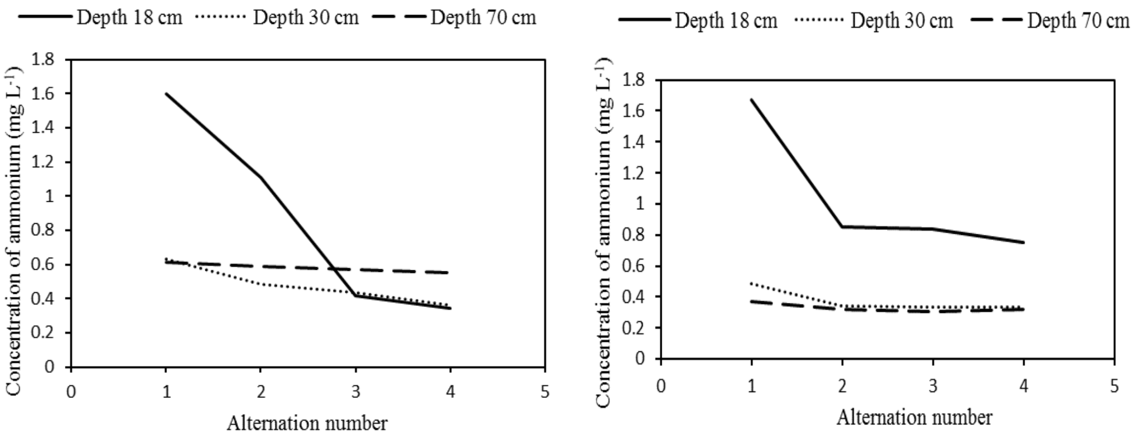

Fig. 11. Changes in ammonium concentration at the depths of 18, 30 and 70 cm in the flooded alternation in 2018 (left side) and 2019 (right side).

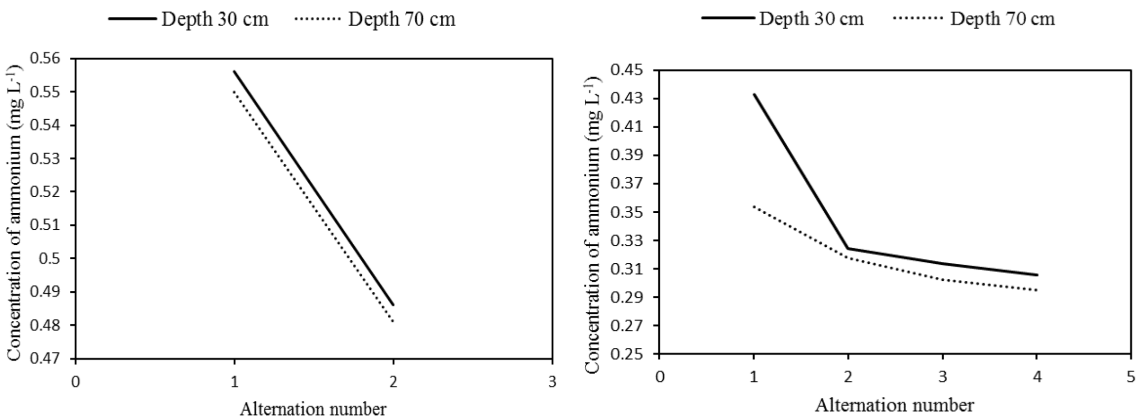

Fig. 12. Changes in ammonium concentration at the depths 30 and 70 cm in the drying alternation in 2018 (left side) and 2019 (right side).

The amount of nitrite concentration as a mid-chain of nitrification process was significant in all three depths, its reduction in sometimes occurred acceptable nitrification rate under the aerobic condition in 7-8 days drying period. Nitrogen balance within the paddy field is summarized in Table 6. Rice uptake was a major contributor to total nitrogen outputs, although some previous reports have been shown adverse result in flowing and stagnant irrigation (Sugimoto *et al.* 2008; Zhao *et al.* 2012). So, intermittent irrigation using 51.43% of total input nitrogen, caused better nitrogen utilizing efficiency. Ammonia volatilization (39.36%) was higher than some studies such as Saiki *et al.* (2020) who reported up to 26% in the stagnant irrigation regime, as well as He *et al.* (2014) reporting 18% under drainage condition and Watanabe *et al.* (2009) reporting 30% for flooded irrigation. Higher NH_3 volatilization (39%) than flooded irrigation (30%) exhibits more potential for intermittent irrigation to damage the environment and pollute the air. The overall N use efficiency (NUE) of rice was as low as 30% (Zhu & Chen 2002). However, by the nitrification in the rhizosphere, ∼40% of total N taken up by rice is in the form of nitrate (Zhang & Chu 2019). Zhao *et al.* (2009) and Liang *et al.* (2007) reported 0.2-3.9 kg N ha^{-1} for denitrification when total input nitrogen was 90-100 kg urea ha^{-1} in flooded irrigation. However, in the present study we obtained about 0.5 kg N ha^{-1}. It seems that alternation in using irrigation water has a significant effect on the reduction of the denitrification rate.

Table 6. Estimated nitrogen balance during growing season of rice cultivation (kg N ha^{-1}).

	Inputs			**Outputs**			
	N_{fert}	N_{irri}	N_{fix}	N_{uptake}	N_{per}	N_{deniti}	N_{vol}
2018	41.4	7.57	1.68	23.26	1.61	0.56	22.58
2019	41.4	6.00	1.24	27.71	1.57	0.44	16.61
Mean	41.4	6.79	1.46	25.48	1.58	0.50	19.59
% (per total inputs)	-	-	-	51.43	3.21	1.00	39.36

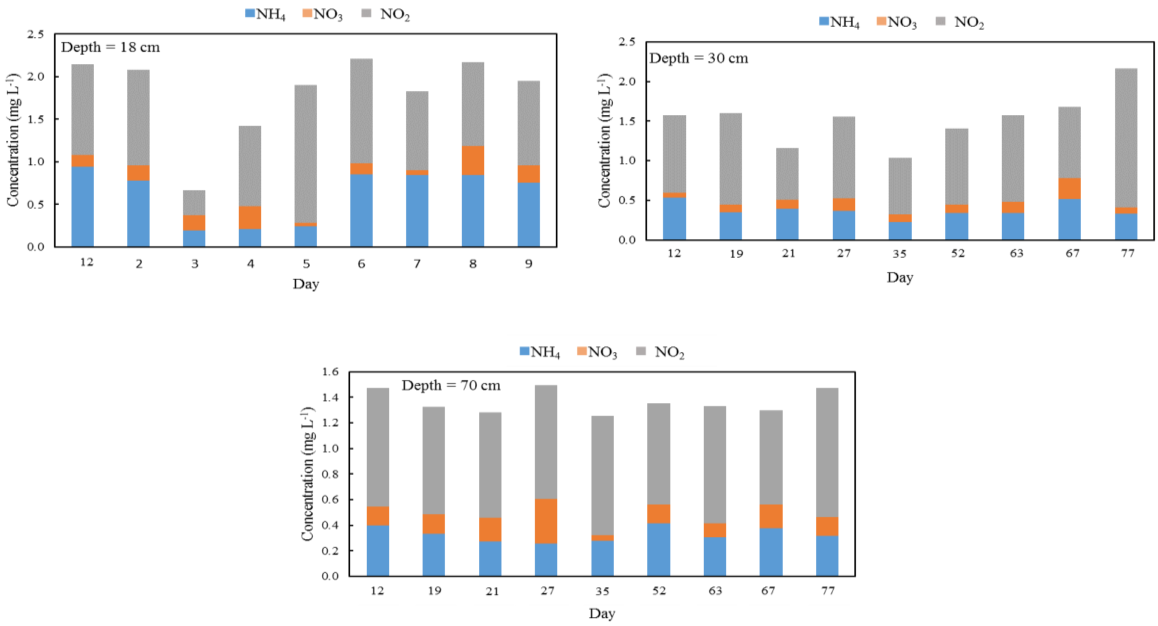

Fig. 13. Changes in ammonium, nitrite and nitrate concentrations during 2018.

CONCLUSION

Water resource pollution, gas emissions, and improving nitrogen use efficiency by rice are reasons for studying the nitrogen cycle in paddy fields. The effect of intermittent irrigation on the nitrogen cycle has been reported, especially in volatilization and rice uptake terms. Nitrogen use efficiency in intermittent irrigation is higher than flooded irrigation due to the possibility of nitrogen uptake in ammonium and nitrate forms. This research found higher nitrogen use efficiency (about 51%) exhibiting a better method for the application of N fertilizer and irrigation water. However, the amount of NH_3 volatilization is higher in this method, which may not be environmentally friendly. Nitrogen loss was obtained about 52.38%, which is in the range of nitrogen loss (Generally, 50–70% of applied fertilizer-N) reported by Coskun *et al.* (2017). The nitrification rate was significant after two alternations in the surface layer of soil. The intensity of nitrification rate decreased by elevating the number of alternations, displaying the effectiveness of ammonium concentration. Although intermittent irrigation could save 15-23% in irrigation water, the application of optimal intermittent irrigation requires further studies on nitrogen. These studies should focus more on the number of cycles, the depth of irrigation water during flooding, the behavior of nitrogen in aerobic and anaerobic layers, and ammonium volatilization rate than flooded irrigation. The results showed that nitrate concentration was increased at a depth of 30 cm due to the nitrification that occurred at higher soil depths. Nitrate contamination in groundwater can be affected by the amount of leaching and nitrate concentration. In paddy fields, depending on the amount and type of clay, soil experience more and deeper seams and cracks during drying that cause an elevation in permeability during irrigation, so a load of pollution entering the groundwater will rise. Lysimeter studies help to understand the nitrogen cycle processes and the affecting factors on it in the soil. Since the paddy fields are not controlled environments and are affected by various environmental and side factors from the neighboring lands, the lysimeter studies can use to understand and analyze the happenings in the soil. The results also clearly showed details of the lysimeter which were not the same in the two investigated years due to the different weather conditions as well as the changes in structure and some chemical properties of the soil. Future studies need express more comprehensive results by measuring different components of nitrogen balance under intermittent irrigation management in paddy fields.

Statements and Declarations

We declare that [the/all other] data supporting the findings of this study are available within the article.

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