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# Potential of Irrigation and Biochar on Reduction Methane Emission and Leaching Nitrate into Groundwater

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## ABSTRACT

Agricultural by-products such as rice husks are very popular in Vietnam, which are often burned in the fields, causing an increase in dust smoke and greenhouse gas (GHG) emissions. To study the effects of different irrigation methods, quality of irrigation water and additive biochar from rice husk (BFRH) on leaching nitrate from paddy fields into shallow groundwater and methane ($CH_4$) emissions, we investigated a two-season experiment (2021–2023) under two irrigation methods: water-saving irrigation and flood irrigation with 120 kg N/ha. The results illustrated that seasonal $CH_4$ emissions and leaching nitrate were affected by irrigation practices and significantly correlated with the quality of irrigation and the amount of BFRH added. To compare of control, the flood irrigation water increased the leaching of GHG and $NO_3^-$ into shallow groundwater from 27.3–32.4% and 16.4–31.25%, respectively. Meanwhile, the saving water irrigation reduced $CH_4$ and leaching of $NO_3^-$ into shallow groundwater from 13.3–17.8% and 15.63–18.9%, respectively. Applying biochar with controlling fertilizer reduces $CH_4$ and $NO_3^-$ content in surface field water, contributing to the decreased leaching of $NO_3^-$ into groundwater. Reducing 20% fertilizer rate of N (96 kg N/ha) with application biochar of 5% without a change in yield reduces $NO_3^-$ content into shallow groundwater from 13.7–14.3%. We conclude that water-saving irrigation combined with biochar from rice husk incorporation simultaneously mitigates $CH_4$ emissions, improves yield, and reduces leaching nitrate into groundwater, making it a suitable environment-friendly nitrogen management practice for sustainable farming in northern Vietnam.

**Keywords:** nitrogen loss, mitigation nitrogen loss, mitigation greenhouse gas, paddy fields, saving water irrigation, groundwater.

## INTRODUCTION

Climate change caused by the lack of water for agriculture and hydroelectric in the dry season has increased significantly in recent years in Vietnam. In 2023 summer, large hydroelectric reservoirs with deficient water levels were only allowed to conduct electricity for a few days, and some small lakes stopped power conduction. As a result, all regions in the North of Vietnam lack a power shortage in the summer affecting the economy and people‘s activities on hot days of May and June. Rice (*Oryza sativa L.*) is the main staple crop in the world and the foremost important food in Asia and Vietnam. Water is an essential requirement for rice growth, meanwhile, climate change caused 7.24 million ha of paddy soil using the main technique of flood irrigation in Vietnam to become scarcity of water resources in the dry season (Phuong et al., 2020). Furthermore, some irrigation systems without water resources must receive contaminated domestic and livestock wastewater to provide for paddy systems. Many irrigation systems polluted nitrogen (N) with content over standard of 2.48–4.15 times such as Bac Hung Hai, Bac Duong and Cau Bay rivers (Vu et al., 2022). Besides growing rice is a major contributor to human-made greenhouse gases, releasing

6 to 11% of all methane emissions from our activities globally (Smith et al., 2021). This raises serious concerns that ramping up rice production could significantly worsen climate change.

Besides water requirement for rice growth, fertilizer is an important factor in removing growth and yields. However, there is a problem of over-fertilizer applications to promote yield was applied in many regions in the world. For example, East and South Asia (such as China and India and others) with large agricultural areas leading fertilizer N consumption increased several more than in the other regions (Bijay-Singh et al., 2021). In Vietnam, the recommendation of the N fertilizer regime used for rice in the North includes 120 kg N/ha which is applied for paddy in the condition of clean irrigation resources. But so far, in situation of N contaminated water with fertilizer ratio of 120 kg N/ha remains unadjusted.

Reasonable fertilizer utilization of rice is necessary because the plant has specific N nutrition requirements for the growth process. Overuse of chemical fertilizers to increase yield causes excess nitrogen in field surface water which can lead to groundwater pollution through leaching under the main form of nitrate or ammonium. Besides, a large amount of nitrogen fertilizer applied to crops is lost to the environment through denitrification, volatilization, surface runoff and leaching. Once the amount of N nutrition in application is over-demand rice leads to excess N in the surface field causing N loss by greenhouse gas emission, runoff and leaching N into groundwater. The N fertilizer application for paddy as urea or ammonium transforms to $NH_3$ or $N_2O$ by biochemical processes in the surface soil layer that enters the atmosphere causing polluted air (Abdikani et al. 2018). N in the paddy soil can be lost in other ways as enters water bodies, including leaching into groundwater or through surface runoff under the form of $NO_3^-$ or is mineralized to $NH_4^+$ being kept on the surface of soil colloidal (Ju XT. et al., 2017). Nitrate ($NO_3^-$) is a popular contamination form of N in groundwater and surface water with available direct leach into the permeable soil layer before entering groundwater or neighboring areas (Bijay-Singh et al., 2021). $NO_3^-$ moves by water into the soil (infiltration process) before percolation through the soil and leaching into the subsoil layers before entering groundwater due to the soil colloidal particles do not retain $NO_3^-$ form because they have the same negative charge (Frick et al., 2022). The high levels of $NO_3^-$ in surface field water and the leaching process can be the main reason for the accumulation of $NO_3^-$ in-depth soil layers and groundwater. The rate of the leaching process increases when the surface water level on the field is high or in the condition of heavy rain. Furthermore, nitrate contamination in groundwater increases in the condition of integration of fertilizers and contaminated nitrate irrigation water (Ju et al., 2017). When $NO_3^-$ content in groundwater is over standard causing seriously affects drinking water quality. In addition, leaching $NO_3^-$ from shallow groundwater through a permeable soil layer to the river, channel systems is one of main reasons for the eutrophication phenomenon leading to lack of oxygen in the water (Chiwetalu, 2022**)**. The leaching $NO_3^-$ is prevalent in many agricultural regions in the world, leading to $NO_3^-$ with high content detected in groundwater which is over the standard for dring in many regions such as Europe, the USA, Australia, and the UK (Rivett et al., 2011). Moreover, N contamination in groundwater has been reported globally with approximately 60% of cultivated areas in situations of N contamination in groundwater with typical areas using water pollution irrigation (Shukla et al. 2018).

Based on observations over many years, (Zhou M. et al., 2014) showed that the annual leaching $NO_3^-$ concentration can be up to 32.8 kg N/ha according to the surface water layer on the field. The total leaching N was 34.9 and 27.9 kg/ha during the off and main seasons (Abdikani et al., 2018). The factor of irrigation increases the water level of the field surface. In addition, heavy rain also contributes to improving the surface water level, which causes leaching nitrate. Some studies indicated that in just one heavy rain with a rainfall of 211 mm in 36 hours after a drought period leading to 70% of $NO_3^-$ accumulated in the paddy soil was lost (Chen et al., 2020). Another study (Chen et al., 2020) also showed that heavy rainfall causes $NO_3^-$ to move through field surface water to deeper soil layers contributing to the N leaching rate after one crop can be 38–45% compared to the initial amount of N. In addition, N residues from fertilizers also contribute to the leaching of $NO_3^-$ through soil layers. Excessive N input is the cause of nitrate leaching (Zhao-Hui Wang et al., 2019). Using N fertilizer for a long time in crop cultivation increases N accumulation in deep soil layers from 40–100 cm, which is detected in N content going up 73.5 kg/ha, and $NO_3^-$ concentrations over 10 mg/L in the shallow groundwater (Xiyun Jiao et al. 2017). More than ever, more fertilizer application is used for rice to increase yield, contributing to more $NO_3^-$ leaching into the deeper soil layers. Even $NO_3^-$ accumulated content in the 0–300 cm soil layer can be up to 1500 kg/ha after 23 years in the condition of application of 180 kg N /ha (Chen et al., 2020).

Shallow groundwater – the upper layer of the lower qh1 Holocene is often polluted due to the leaching process of pollutants matter from surface water. The groundwater level increases in heavy rain conditions leading to contact with the upper soil layers to contribute to increasing pollution compared to other layers (Preetha et al., 2020). Some chemicals from irrigation water including $NO_3^-$ can through the soil and potentially contaminate groundwater. In recent years, groundwater has been used by about 2 billion people worldwide, with a production of 982 $km^3$ per year, including about 50% for living. Using $NO_3^-$ contaminated groundwater causes some problems in health for children as methemoglobinemia or blue baby syndrome in newborn babies (WHO 2019*)*. The amount of water leaching into groundwater increases by the surface water with thick level causing large leaching. Because soil storage capacity is limited leading to excess N moving into groundwater (Bijay-Singh et al., 2021). The leaching mechanism relates to Darcy‘s Law with $NO_3^-$ follows water moving from higher to lower regions. The leaching of pollutants matter often occurs more strongly on well-drained soils such as paddy soil contributing to entering $NO_3^-$ into the shallow groundwater (Zhao-Hui Wang et al., 2019).

Flood irrigation (FI) method in paddy cultivation with water level from 7–10 cm and over in heavy rain conditions is main reason for consuming large amounts of water required for rice than saving water irrigation (SWI). The FI is traditional farming due to rice is a water-loving crop so flood irrigation is essential for its growth. Thus, the SWI with saving water by 36–50%, improving yield, and reducing greenhouse gas emissions, however, SWI had only been experimented in some areas with a small scale (Phuong et al., 2020). Besides, agricultural by-products were burned popularly on fields causing dust smoke and greenhouse gas emissions (Lan, 2023). Biochar from agricultural by-products with high porosity and good water-holding capacity was widely used to treat N in wastewater and improve soil moisture and nutrition (Diep et al., 2020). Biochar from rice husk with low-cost was produced from the pyrolysis of rice husk under limited or no oxygen (Vu et al., 2022) to evaporate organic substances to keep on the porous surface with components $K^+$, $Na^+$, $Ca^{2+}$, $Mg^{2+}$ carry a positive charge (Konneh et al., 2021). The $NO_3^-$ adsorption process occurs by electrostatic attraction including negatively charged $NO_3^-$ attracted to the surface of biochar (Vo et al., 2021; Gai et al., 2014). Some research has indicated that incorporating rice straw-derived biochar into paddy soils leads to a noteworthy reduction of over 80% in methane ($CH_4$) emissions compared to control conditions. The decline in $CH_4$ emissions is primarily linked to the influence of biochar on the physical and chemical properties of the soil, along with alterations in microbial communities. Specifically, there is a decrease in the abundance and activity of methanogens, which are responsible for $CH_4$ production, and an increase in the abundance and activity of methanotrophs, which aid in $CH_4$ oxidation (Zhao et al., 2014).

The effect of flood irrigation with contaminated water integrated fertilizer on N loss from paddy fields remains unknown. Therefore, this study goal is to: effects of different irrigation methods, quality of irrigation water and additive biochar from rice husk on leaching and runoff nitrate from paddy fields and $CH_4$ emissions. The results can contribute to the schedule of irrigation and fertilizer and technical support for sustainable agriculture management.

## MATERIALS AND METHODS

### Properties of soil and irrigation water

#### *Properties of soil*

The experimental field was planted with rice year round. The depth of the experiment soil from 0–120 cm was investigated, including three layers from 0–35 cm, 35–70 cm, and 70–120 cm. The colour of the 35–70 cm layer is dull reddish brown, and silty clay loam. The layer colour of 70–120 cm is grey, yellow-brown, and clay. The paddy soil is the alluvial soil of the Red River delta with pH $H_2O$ from 6.2–7.1, and $pH_{KCl}$ from 5.4–6.6. OC content is from 1.5–2%, and total N is from 0.18–0.25% in the surface layer at a depth of 2–30 cm and reduced through the depth of soil. Soil base saturation is 80–85%, exchange Ca is 7.1–15.4 meq/100g of soil, exchangeable Mg is 1.8–5.7 meq/100g of soil. Total P is 0.08–0.13% $P_2O_5$, available P is 12.0–15.0 mg $P_2O_5$/100g of soil. Total K is 1.72–2.14% K2O. Available K is 5–25 mg $K_2O$/100g of soil. Clay is 21.5–30.5%, limon is 54.5–57.25%, and is 15.0–21.5% with porosity in the top layer.

*Properties of water*

The contaminated irrigation water from Cau Bay River with $NO_3^-$ is 0.5–2.9 mg/L, $NH_4^+$ content is 1.8–5.1 mg/L, $NO_2^-$ is 0.068–1.092 mg/L, total N is 0,19–1,15 mg/L, pH is 6.8–7.5.

## EXPERIMENTAL DESIGN

*Treatment 1: Potential biochar on reduction of leaching nitrate into groundwater*

Biochar was produced from rice husk, heated under anaerobic conditions at 550 °C for 03 hours, pH of 8.9–9.4, CEC of 57.1 mmol $kg^{-1}$, the porosity of 59.34%, OC < 1%. The treatment aims to reduce nitrate in surface field water, decreasing the leaching nitrate content into subsoil layers. In the treatment, ratios of biochar from rice husk were added, including 1% (Bio1), 2.5% (Bio2.5), and 5% (Bio5), with four ratios of fertilizer applied. The experiments were designed in a pot system in a greenhouse with three crops. Soil samples were air dried before passing through a 2-mm sieve, and about 10 kg of soil was transferred into a pot with a 30 cm diameter and higher of 40 cm with one rice plant/pot. The biochar ratio was chosen from our previous study of biochar application in the paddy field (1, 2.5, 5%, w:w) (Vu et al., 2022) and based on many tests before designing the experiment. The treatment with a biochar under 1% ratio was not significantly changed and a biochar over 5% ratio reduced grain yield. The NPK fertilizer was applied only once after two weeks, and the regime of surface field water was applied with a water level of 7–10 cm (Table 1). The experiments were designed in the greenhouse and the paddy field at Vietnam National University of Agriculture, Trau Quy, Gia Lam district, Hanoi, Vietnam (21°00’00 N – 106°55’54 E) from 6/2021 to 5/2023 with two Spring and Summer season crops. Including three treatments:

*Treatment 2: Effect of contaminated irrigation water on $CH_4$ emission, and leaching nitrate into groundwater, includes three treatments*

- F1: Applied contaminated irrigation water and fertilizer with a ratio of 120 kg N : 90 kg $P_2O_5$ : 90 kg $K_2O$/ha;
- F2: Applied clean irrigation water and fertilizer with a ratio of 120 kg N : 90 kg $P_2O_5$ : 90 kg $K_2O$/ha;
- F3: Applied contaminated irrigation water without fertilizer.

F1, F2, and F3 conducted in field experimental with the area of each treatment is 960 $m^2$. Each treatment was separately irrigated.

*Treatment 3: Effect of irrigation methods on $CH_4$ emission and leaching nitrate into groundwater, including two formulas*

- SWI: the saving water irrigation (SWI) with the surface water level from 3 – 5 cm and drying field after irrigating from 3 – 5 days. The total area of the experimental field is 960 $m^2$ without applying fertilizer.
- FI: the flood irrigation (FI) with the surface water level from 7–10 cm over the crop. The total area of the experimental field is 960 $m^2$ without applying fertilizer.

Each plot was surrounded by brick walls that were 160 cm high (120 cm below the soil

**Table 1**. Treatment 3 used biochar from rice husks and control fertilizer

| Ratio biochar (%w:w) | 100% including 120 kg N: 90 kg $P_2O_5$ : 90 kg $K_2O$/ha | Namely |
|---|---|---|
| 1 | 100 | Bio1-F100 |
|  | 80 | Bio1-F80 |
|  | 50 | Bio1-F50 |
|  | 0 | Bio1-F0 |
| 2.5 | 100 | Bio2.5-F100 |
|  | 80 | Bio2.5-F80 |
|  | 50 | Bio2.5-F50 |
|  | 0 | Bio2.5-F0 |
| 5 | 100 | Bio5-F100 |
|  | 80 | Bio5-F80 |
|  | 50 | Bio5-F50 |
|  | 0 | Bio5-F0 |

**Figure 1.** The soil profile is from 0–120 cm (left) and the SWI and FI irrigation (right)

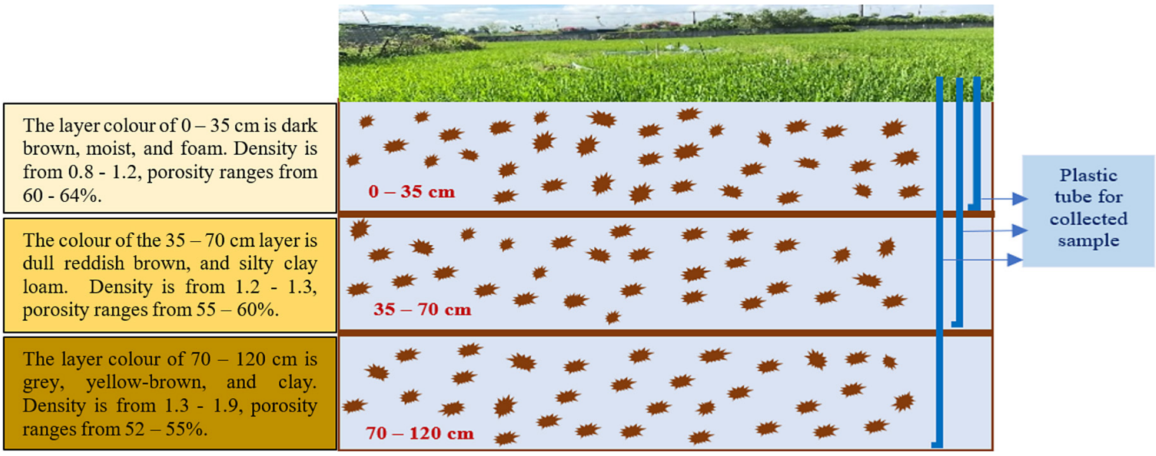
surface and 40 cm above the soil surface) to form a barrier to prevent runoff. Each plot was separately irrigated (Fig. 1).

## Sampling

In treatment 1, sampling water on the surface field was collected at stages of transplanting (stage 1), the end of tillering (stage 2), flowering (stage 3), and ripening (stage 4). The yield was calculated in grams/pot. Treatment 2 + 3: Groundwater was collected at three depths of 35 cm, 70 cm, and 120 cm for seven days/time. Sealed bottom plastic pipes (10 cm in diameter, 85 cm, 120 cm, and 170 cm long, respectively) were punched with small holes very near the bottom and were installed vertically at a depth of depths of 35 cm, 70 cm, and 120 cm to collect the daily percolation water of each plot. The pipe orifice was 50 cm above the soil surface, and the upper pipes were covered to close rain. Before sampling water, the percolation water in pipes was sucked away, sampling percolation water for analysis was collected after 24 in pipes by a suction pump. Soil samples were taken at depths of 0–35 cm, 35–70 cm, and 70–120 cm by homemade iron pipes (Figure 3) to collect soil sampling for total N analysis at the harvest. In total, the leaching water was measured 11 times for treatments 2, and 3; the runoff water was measured five times for treatments 2 and 3; and the surface field water was measured 4 times for treatment 3 (Fig. 2).

## Variety, fertilizer, and pesticides

A Bacthom No 7 (BT) rice variety selected and purified by Thai Binh Seed Corporation (Vietnam), widely grown in the northern provinces of Vietnam, was chosen for the crop experiments. The BT variety is a healthy growing variety with the growing time in the spring crop 125–135 days and the winter season 105–110 days. Fertiliser was used in the experiment with a nitrogen/phosphorus/potassium (NPK) ratio of 125 g of compost + 1.25g N + 0.75 g $P_2O_5$ + 0.75 g $K_2O$ per pot. A pesticide, namely Nouvo 3.6EC, was used to prevent disease. For the


The layer colour of 0 – 35 cm is dark brown, moist, and foam. Density is from 0.8 - 1.2, porosity ranges from 60 - 64%.

The colour of the 35 – 70 cm layer is dull reddish brown, and silty clay loam. Density is from 1.2 - 1.3, porosity ranges from 55 – 60%.

The layer colour of 70 – 120 cm is grey, yellow-brown, and clay. Density is from 1.3 - 1.9, porosity ranges from 52 – 55%.

**Figure 2.** Sampling description

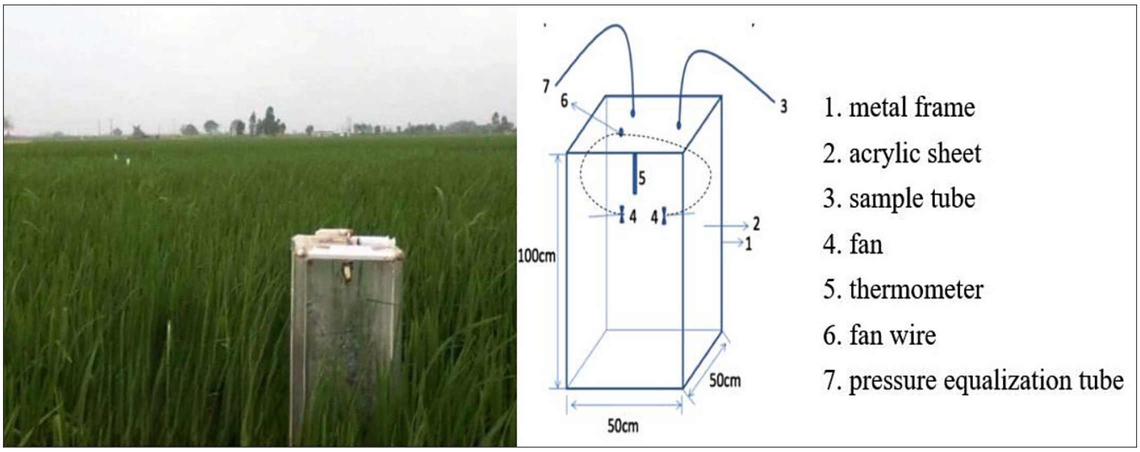


**Figure 3.** $CH_4$ fluxes measure

field experiment, the amount of fertilizer was applied as 10 tons of compost + 120 kg N + 60 kg $P_2O_5$ + 60 kg $K_2O$ per ha.

### Analysis

The water parameters analysis included the following: TN, $NH_4^+$–N, $NO_3^-$–N. Soil parameters analysis that were monitored included TN, $NH_4^+$-N, $NO_3^-$–N. All the analyses were conducted as recommended by the National Technical Regulation on Water and Soil analysis of Vietnam (TCVN). Rice growth, yield attributes, and grain yield measurements of treatments 2 and 3 were measured, including growth traits, plant height, and tiller number on the main stem. The plant height was measured from the ground to the leaf's tip smoothed at the experiment's end. SPAD index using a SPAD meter (Konica-Minolta 502, Japan). Leaf area (dm2 plant-1) was calculated by weighing method. At the end of the experiment, rice plants in each pot were separated from leaf, stem, panicle, and root and were determined after drying samples at 80 °C for three days until constant weight. After harvesting, component yields such as panicles number per plant, number of filled grains per panicle, percentage of filled grains (%), 1000 grain weight (g), and grain yield of each treatment were calculated. The yield was determined after the harvest of treatments 2 and 3 by Vietnam's standard.

#### *$CH_4$ flux measure*

The researchers used a static chamber technique to measure methane ($CH_4$) emissions, as described in Tirol-Padre et al. (2017). They placed three chambers with a diameter of 50 cm and a depth of 10 cm into the soil at each treatment site one day before collecting samples. The chambers were made from plastic pails that were 100 cm tall and had a volume of 250 L. They had sampling tube, thermometers, and fans on the inside. Gas samples were collected at 0, 10, 20, and 30 minutes after the chambers were closed. The samples were analyzed at Environmental engineering lab – Thuyloi University. A gas chromatograph (8610C, SRI Instruments, USA) with a flame ionization detector was used to measure the amount of $CH_4$ in the samples. The column used for the analysis was packed with Porapak Q (50–80 mesh), and nitrogen ($N_2$) was used as the carrier gas (Fig. 3).

### Statistical analysis

All statistical analyses for the result data from the experiment were compiled by Microsoft Excel version 5.5 (Microsoft, USA). Each value represented the average of three replications. The data were subjected to analysis of variance (ANOVA), and significant differences in mean values were determined using Duncan's multiple range test ($P < 0.05$).

## RESULTS AND DISCUSSION

The rainy season is from June to September, the dry season is from October to May of the following year. The rainiest month is August, with an average rainfall of 266–486 mm. The month with the least rain in Hanoi is February with an average rainfall of 12 mm. Therefore for all treatments, the

**Table 2.** Precipitations (mm) in HaNoi from 2021–2022

| 1/2021 | 2/2021 | 3/2021 | 4/2021 | 5/2021 | 6/2021 | 7/2021 | 8/2021 | 9/2021 | 10/2021 | 11/2021 | 12/2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.0 | 66.7 | 38.5 | 129.0 | 123.6 | 313.0 | 246.6 | 266.3 | 384.3 | 368.9 | 13.6 | 0.7 |
| 1/2022 | 2/2022 | 3/2022 | 4/2022 | 5/2022 | 6/2022 | 7/2022 | 8/2022 | 9/2022 | 10/2022 | 11/2022 | 12/2022 |
| 46.8 | 103.7 | 47.2 | 68.7 | 414.9 | 296.9 | 392.5 | 486.3 | 242.0 | 84.4 | 7.8 | 13.7 |

field was irrigated 7 times in the dry season and 3 times in the rainy season (Table 2).

## Effect of contaminated water on leaching nitrate

There were treatments including contaminated water with applicate fertilizer (F1), non-contaminated water with applicate fertilizer (F2), and contaminated water without applicate fertilizer (F3). The results showed that the F2 treatment and the F3 treatment reduced leaching nitrate, however, the effect of the F1 treatment on leaching nitrate was significant. It is noteworthy that the effect of clean water irrigation (F2) on reducing leaching nitrate reached 32.16%, while the effect of contaminated water irrigation and fertilizer (F1) on increasing leaching nitrate reached 33.23%. The amount of leaching nitrate was caused by all three levels of water quality, among which the increasing effect of F1 on the amount of leaching nitrate was significant, and the increasing effect of F1 on the amount of leaching nitrate was 1.2 times higher than non-fertilizer application (F3) and was 2 times higher than clean water (F2). The research results showed that the total N content of the 0–35 cm layer was 0.24–0.26%, the layer of 35–70 cm was 0.14–0.19%, and the layer of 70-120 cm was 0.07–0.12%. It can be seen that there is a gradual decrease in total N content between the soil layers of all the formulas contributing to reduce N leaching from 34–62%, consistent with the results of the soil profile survey. Thus, the N content at different layers, these results are similar to the conclusions of (Zhao B.Z. et al., 2007) about the gradual decrease of leaching N in the lower layers. The results are similar to the conclusion of (Luying Chen et al., 2021), which is vertical leaching N in the soil profile in which $NO_3^-$ loss is the main form (69.94–90.12%). Results of control about irrigation regime and fertilizer leading to the differential accumulation of N content in layers of each treatment. The F2 treatment reduces leaching N in soil layers by about 16.4% at 0–35 cm, 25% at 0–70 cm depth, and 31.25% at 70–120 cm depth compared to the F1. In the F3, contaminated irrigation without fertilizer reduced total N in the soil layer of 0–35 cm to 9.4%, and the soil layer of 0–70 cm to 19.64% compared to the F1 (Fig. 1 and Fig. 4).

The reason for leaching depends partly on the nutrition of the rice plant. Rice plants need to absorb N and other nutrients for the growth process,

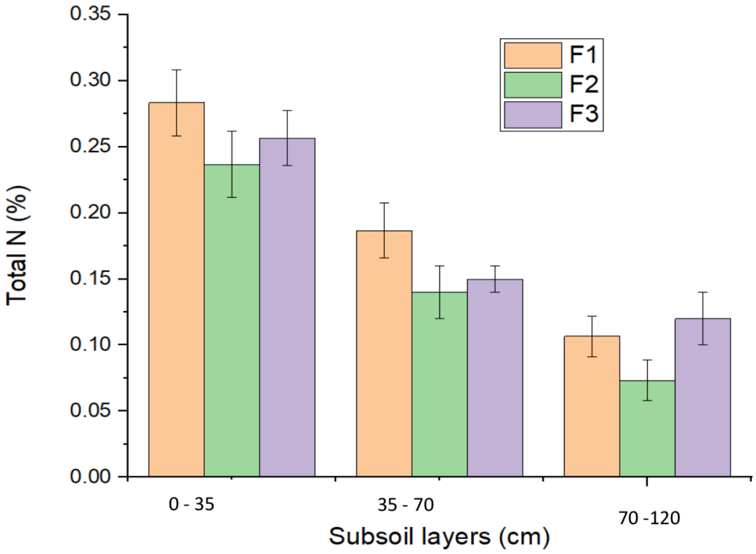


**Figure 4.** Leaching N in soil layers under contaminated water and fertilizer

but the amount absorbed is at most 50% of the fertilizer applied in the field, causing leaching loss. A part of N is lost to the root zone by about 30% (Bijay-Singh et al., 2021), leading to infiltration and accumulation of $NO_3^-$ in deeper layers (Jankowski et al. 2018). Some studies have shown that a large amount of $NO_3^-$ accumulates from fertilizer residues in the vadose (unsaturated zone) area (Zhao B.Z. et al., 2007). Leaching $NO_3^-$ into depth soil layers must pass through the unsaturated zone before entering the groundwater (Fig. 4). The research results are also quite relevant to the conclusions of (Zhou J.Y et al., 2016) that about 70% of nitrate-N from fertilizers for maize, wheat, and vegetables is absorbed into soil deep layers under 1 m due to N content that exceeds nutrition requirements of plant. Due to nitrate has a negative charge like soil colloids, so this characteristic explains why nitrate is more easily leached from the soil than ammonium. Therefore, $NO_3^-$ ions is not held by the soils, but remains as a free ion in soil water to be leached through the soil profile in some soils and under some rainfall conditions (O. Latifah et al., 2027). The amount of $NO_3^-$ under the rice root zone cannot be used for the next crop (Ju et al., 2006; Zhao RF et al., 2006) because rice roots are not able to penetrate to lead to increase leaching $NO_3^-$ during heavy rain or after irrigation (Huang et al., 2017). The results of the main previous study based on 32 studies on maize and wheat from all over the world indicated that there were an average of 22% and 15% of fertilizer N to wheat and maize, which were leached into subsoil layers as a form of $NO_3^-$ (Zhou M. et al., 2014).

Experimental results showed that insignificant difference in $NO_3^-$ content in groundwater between spring and summer crops in rice fields of three treatments (F1, F2, and F3) ($P > 0.05$). When the $NO_3^-$ content in irrigation water increases, the $NO_3^-$ content in the groundwater layers increases accordingly. In the irrigation periods with very high $NO_3^-$ content up to 2.9–3.1 mg/L of the F1, the average $NO_3^-$ content in the aquifers was 2.4–2.9 times higher than in other stages. At the stage of fertilizing, $NO_3^-$ content for all three sampling depths in treatments of F1 increases from 1.9–3.6 times compared to other stages. In addition, integrating fertilizer and contaminated irrigation water in the F1 treatment increases the $NO_3^-$ content in groundwater from 2.1–3.8 times compared to the treatments of F2 and F3. Except for fertilization and contaminated watering, the average $NO_3^-$ content in groundwater ranges from 0.6–1.0 mg/L, 0.1–0.6 mg/L, and 0.4–1.2 mg/L in F1, F2, and F3 treatments, respectively. In the F2 treatment, fertilizing application led to $NO_3^-$ at a depth of 35, 70, and 120 cm increased significantly compared to the time before fertilizing. Specifically, $NO_3^-$ at a depth of 35 cm and 70 cm increased by 1.4–4.2 times and 1.4–2 times compared to before fertilization, respectively. At a depth of 120 cm, it was increased from 1.25 to 2 times compared to before fertilization. Compared with the F1 treatment, $NO_3^-$ decreased average from 1.1–4 times, 1.1–5.3 times, and 1–3 times at a depth of 35 cm, 70 cm, and 120 cm, respectively. Experimental results show that if the quality of irrigation water is improved, it will reduce the

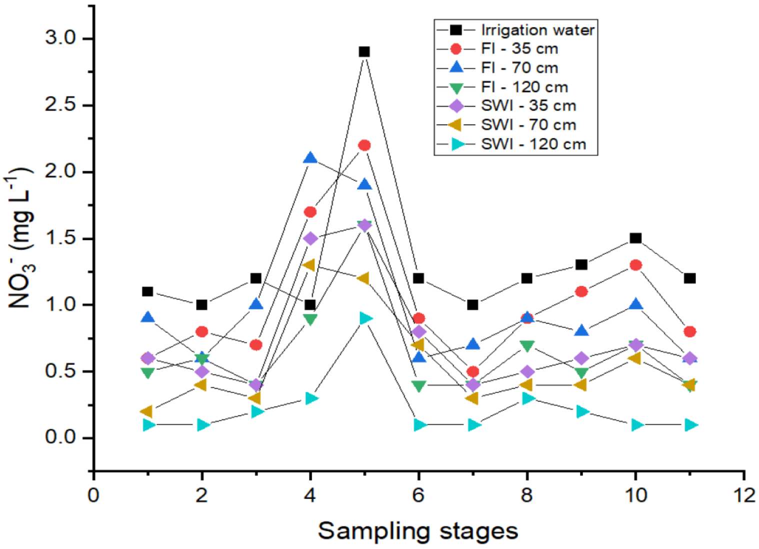


**Figure 5.** $NO_3^-$ content in groundwater in the treatments of F1, F2, and F3

leaching of $NO_3^-$ into the subsoil and groundwater. In the F3 treatment, $NO_3^-$ content in groundwater increased with $NO_3^-$ content in irrigation water. $NO_3^-$ content at a depth of 120 cm decreased 1.9–6 times and 1–3 times compared to a depth of 35 cm and 70 cm, respectively ($P < 0.05$). No significant difference was in $NO_3^-$ content at the depths of 35 cm and 70 cm ($P > 0.05$). $NO_3^-$ content at a depth of 70 cm only decreased by 1.1–2 times compared with a depth of 35 cm. Compared to F2, it indicated that $NO_3^-$ content at depths of 35 and 70 cm was 1.5–4 and 1.1–1.8 times higher, respectively, notably at a depth of 120 cm, higher from 1.2–3.5 times. Thus, in the condition of not fertilizing but continuously watering contaminated water, $NO_3^-$ leeches into the subsoil layers. When irrigation water is controlled, leaching $NO_3^-$ into the subsoil layers is reduced.

The results showed no significant difference in $NO_3^-$ content at depth layers of 35 cm and 70 cm ($P > 0.05$). However, there is a difference in $NO_3^-$ content of the depth layer between 35 cm and 120 cm ($P < 0.05$), so nitrate contamination generally decreases with increasing depth to groundwater. In which, $NO_3^-$ the content of the depth layer of 120 cm is lower than the depth layer of 35 cm from 1.2–2.2 times. The results are suitable soil profile properties, the 70–120 cm layer with the main ingredient as clay. High clay concentration helps to keep $NO_3^-$ in the soil to reduce the leaching of $NO_3^-$ into subsoil layers (Daniel Said-Pullicino et al. 2014). Compared to the QCVN 09:2023/BTNMT (The standard about the groundwater quality of Vietnam), they have indicated that $NO_3^-$ content is lower than the standard. However, the experiment showed a phenomenon of leaching $NO_3^-$ into the subsoil layers and groundwater when the surface field water was affected by contaminated water and fertilizer (Fig. 5).

85% of N was leaching loss in the $NO_3^-$ form because rice roots are short $NO_3^-$ nutrition can be absorbed in a depth of 0–40 cm, and a large quantity of $NO_3^-$ accumulation under the root zone will quickly through the water transit into the subsoil (Abdikani et al., 2018). The experiment results are consistent with the studies of (Jankowski et al., 2018) when $NO_3^-$ content which is over leading to rice plants cannot wholly absorb, contributing to the phenomenon of nitrate pollution in groundwater. This phenomenon is also demonstrated in other studies as only 22% of N-applied fertilizer to wheat is absorbed as $NO_3^-$ form, and the remaining amount is lost to the environment or into groundwater with an average amount of 29 kg N/ha (Zhou et al., 2014). Flood irrigation makes paddy soil always in a state of water saturation, leading to the soil reaching a point where it cannot hold any more water. As a result, the soil air spaces become filled with water causing water to move down through the subsoil layers.

## Effect of irrigation methods leaching nitrate

The FI treatments had the following leaching losses: $NO_3^-$ 0.69–0.93 $kg \cdot ha^{-1}$, TN 3.9–5.3 $kg \cdot ha^{-1}$. Compared with the FI treatments, the

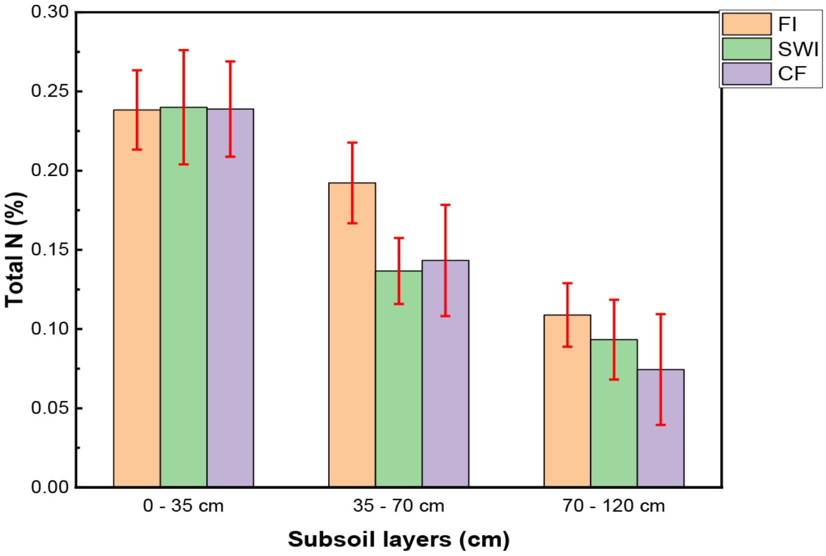


**Figure 6.** Leaching N in the soil layer under the FI and the SWI

leaching losses of $NO_3^-$–N, and TN were 36 – 52%, 38–55% significantly smaller in the SWI treatments, respectively. The results showed that FI increases the accumulation of total N in the subsoil layers compared to saving water irrigation due to the leaching $NO_3^-$ under the effect of surface water level (Fig. 6). The result can be explained by the FI with contaminated water leading the field surface water with high level increasing to leaching available. The leaching of water which brings $NO_3^-$ contributes to a large amount of $NO_3^-$ accumulating in vadose in many agricultural areas (Zhao B.Z. et al., 2007). $NO_3^-$ from agricultural soils is popular leaching into deeper soil layers than others due to the effects of excess fertilizers and irrigation levels. For example, there is 70% of $NO_3^-$ from applied fertilizers corn, wheat, and vegetables were leached into depth soil under 1 m due to N content in the soil which is over the nutritional requirements of plants (Zhou J.Y. et al., 2016).

The results trend is similar to previous studies with total leaching N content through the depth of soil layers of the layer of 120 cm reduced by about 63.5% compared to the layer of 35 cm, while the total N content in the layer of 70 cm was reduced by only about 36.3% compared to the layer of 35 cm. The results are suitable for the soil profile with properties of surface porosity. The porosity gradually decreases from 0–70 cm and 70–120 cm with the non-porous soil. The porosity of the soil gradually decreases, or the density of the soil increases with depth to reduce leaching, leading to decreased N content in subsoil layers (Zhao B.Z. et al., 2007) (Fig. 7). Results showed that the SWI reduces the percolated N compared to the FI. Percolated total N content in soil layers of 0–35 cm, 35–70 cm, and 70–120 cm of the SWI was lower than 15.63%, 18.9%, and 14.29% compared to the FI, respectively. Meanwhile, the layer of 0–35 cm of the FI with total percolated N increases by 16.01%, the layer of 0–70 cm increases by 25.43%, and the layer of 70–120 cm increases by 31.63% compared to the CF. The results are relevant to studies of (Abdikani et al., 2018) about N transportation in the paddy system with applied flood irrigation. About 48–50.3% of percolated N was accumulated in the top 40 cm soil layer, and the leaching N from 49.7% to 52% was lost in 40–100 cm soil layers, respectively. The results are consistent with the study of (Shufeng Chen et al., 2017) about water management irrigation significantly reduced nitrate leaching with 58.8% in the treatment of fertilizer control and 85.2% in fertilizer and irrigation control. Irrigation based on soil water content monitoring can be the best management practice for saving water and preventing nitrate leaching (Fig. 7). The FI. Under the condition of the FI, the average surface water level was from 7 – 10 cm and over in heavy rain stages which can leach into the subsoil. Besides, the results showed that $NO_3^-$ content in groundwater increases levels of contaminated irrigation water. In the time of high $NO_3^-$ content in irrigation water is over 2.4–2.9 times compared to the other contributes to $NO_3^-$ in three of the sample depths to increase from 2.1 to 3.8 times. Details, $NO_3^-$ content in the depth of 35 cm, 70 cm, and 120 cm were 1.7–2.2 mg/L, 1.9–2.1 mg/L, and 0.9–1.6 mg/L, respectively. Except for fertilizing and contaminated irrigation water, $NO_3^-$ content in groundwater was from 0.6–1.0 mg/L. In contrast, under controlling surface field water of the SWI reduced significantly $NO_3^-$ content in groundwater compared to the FI from 1.4–2.84 times. Details, the depth of 35 cm with reduced $NO_3^-$ content from 1.13–1.86 times, the depth of 70 cm with significantly reduced $NO_3^-$ content from 1.5–3.33 times, dramatically reduced content of $NO_3^-$ the depth of 120 cm from 1.78–7 times compared to the FI. So, the results showed that the SWI reduced $NO_3^-$ content in groundwater from

**Figure 7.** The saving water irrigation (SWI) and flood irrigation (FI)

28.69–64.79% compared to the FI. The high surface field water of the FI with high $NO_3^-$ content in the irrigation water increased $NO_3^-$ concentration in groundwater, indicating that the results are suitable of previous studies (Ju et al., 2017, Zhou M. et al., 2014, Chen et al., 2020). The results showed that there is a phenomenon of leaching $NO_3^-$ into groundwater when surface field water with high levels and contamination (Fig. 6). Leaching N in some paddy systems in Vietnam as Tam Duong district in the RRD on high-rainfall and flood irrigation conditions with applied fertilizer, leads to over-crop N demand contributing to leaching about 50 kg N·ha$^{-1}$ (Mai, et al., 2010).

Due to soil properties with porous surface from 0–70 cm by the survey of the soil profile, this result is suitable with $NO_3^-$ content in both depths of 35 cm and 70 cm, which was no significant difference ($P > 0.05$). However, there was a significant difference in $NO_3^-$ content from a depth of 70–120 cm compared to a depth of 0–70 cm ($P < 0.05$) with $NO_3^-$ content lower than 1.7 times. Thus, the results are consistent with the soil profile: at a depth of 70–120 cm, the main component is clay with sticky and compact properties. The compacted clay layer is a semipermeable membrane that retard or restricts the flow of dissolved chemical species in water. Subsurface water flowing through a geological membrane is lower in TDS than in the surface field water because of the solution on the above soil layer. In addition, the clay layer can absorb $NO_3^-$ and keep $NO_3^-$ in that surface soil layer reducing $NO_3^-$ into subsoil layers. As a result, $NO_3^-$ content decreased gradually with the depth of the layers. Thus, the experiment results showed that $NO_3^-$ content in the surface field water that is over the nutritional requirements of rice plant leads to accumulation of $NO_3^-$ in subsoil and soil solution in the depth of 0–70 cm, which is similar to the study results of (Zhou J. et al., 2016). However, high rainfall or continuous flood irrigation increases the level of surface field water, leading to rising leaching $NO_3^-$ (Chen et al., 2020). $NO_3^-$ content in groundwater is closely related to rainfall and the level of surface field water. In contrast, slight rainfall or low levels of surface field water limit the leaching of $NO_3^-$ into the subsoil layer, causing $NO_3^-$ accumulation in the upper soil layer. Such as rainfall from 220–288 mm does not observe the leaching $NO_3^-$. However, rainfall up to 346 mm causes a large amount of $NO_3^-$ to leach into the subsoil layer of 100 cm (Zhou M. et al., 2014*)*. Thus, flood irrigation contributes to surface field water to keep a level of 7–10 cm, which is equivalent to rainfall of 700–1000 mm that causes leaching of $NO_3^-$ into groundwater (Fig. 8).

The SWI. In the exact condition of the fertilizer regime and irrigation water, the experiment results indicated that the level of surface field water affects available leaching. The difference of 4–5 cm in water level in the field of the SWI compared to the FI reduces leaching $NO_3^-$ at a depth of 120 cm, about 64.79% ($P < 0.05$). The stage of the drying field of the SWI leads to the water level in the field from 0–2 cm (Phuong et al., 2020) to cause $NO_3^-$ content at a depth of 120 cm from 0.1–0.2 mg/L, so the result showed that the SWI control the leaching $NO_3^-$ into the subsoil. Thus, the leaching water amount is proportional to the water level in the field. The thinner water layer leads to less water leaching, consistent with the research results (Ju et al., 2017). The process of leaching nitrate could be decreased significantly by applying saving water management compared to traditional flood methods (Shufeng Chen et al., 2017).

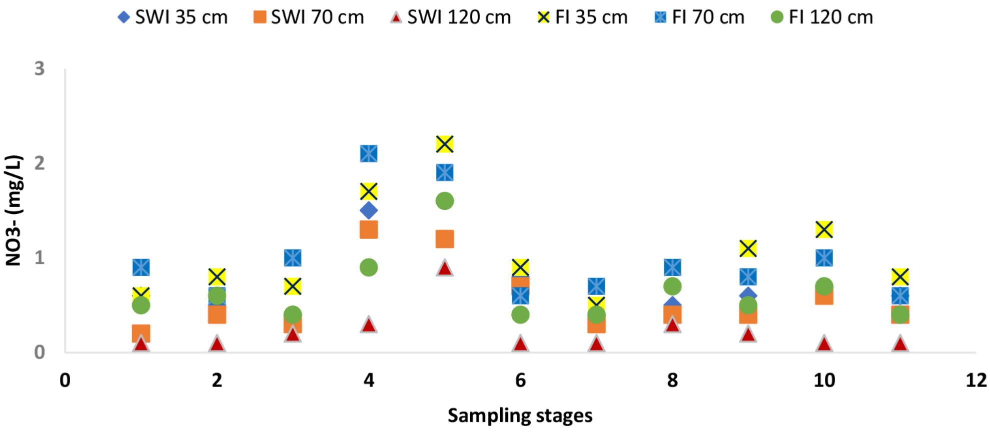


**Figure 8.** $NO_3^-$ content in groundwater in treatments of the IF and SWI

**Table 3.** Total quality of CH4 emission in each crops

| Treatment | $CH_4$ emission flux (kg/ha/crop) | | | |
|---|---|---|---|---|
| | Spring 2021 | Summer 2021 | Spring 2022 | Summer 2022 |
| F1 | 156.78 ±10.4 | 237.3 ± 18.4 | 125.6 ± 13.4 | 274.2 ± 23.1 |
| F2 | 123.63 ± 14.5 | 204.5 ± 12.6 | 103.2 ± 12.5 | 243.3 ± 12.5 |
| F3 | 101.4 ± 9.5 | 175.3 ± 10.6 | 94.6 ± 21.4 | 203.1 ± 17.2 |
| SWI | 91.2 ± 7.3 | 134.7 ± 13.5 | 84.2 ± 21 9.2 | 122.4 ± 23.1 |
| FI | 128.4 ± 9.5 | 175.3 ± 10.6 | 124.6 ± 21.4 | 163.1 ± 17.2 |

### *$CH_4$ emission in each treatment*

Total amount of $CH_4$ emitted in each crop according to each experimental formula discovered in Table 3. In two years 2021–2022, the total amount of methane ($CH_4$) emitted during the spring seasons for different treatments (F1–F3) was from 94.6 to 156.78 kg/ha/crop, and for the summer seasons were up to 274.2 kg/ha/crop. The F1 formula (polluted irrigation water +fertilizer) emitted 156.78 and 125.6 kg/ha/crop during the spring seasons, and 237.3 and 274.2 kg/ha/crop during the summer seasons. The F2 formula (non-polluted irrigation water + fertiklizer) emitted 123.63 and 103.2 kg/ha/crop during the spring seasons, and 204.5 and 243.3 kg/ha/crop during the summer seasons. As well as at F3 (cleaned irrigation water), spring crop $CH_4$ flux were 101.4 and 94.6 kg/ha/crop. The crop emitted 175.3 and 203.1 kg/ha/crop.

Fertilizer and polluted irrigation water play a crucial role in influencing methane ($CH_4$) emissions from rice paddy fields. Generally, F1 treatment actively boosted soil $CH_4$ emissions and resulting in a notable 35.32%, 24.68% at spring seasons 2021, 2022 and 26.12%, 25.9% at summer seasons 2021, 2022 increase compared to scenarios without fertilizer application (F3). Soil $CH_4$ emissions from rice paddies are heavily influenced by fertilizers, both organic and chemical. This influence can be attributed to two main factors: (1) increased substrate availability: fertilizers, especially organic ones like straw and manure, provide readily available carbon sources for methanogen bacteria, the microbes responsible for $CH_4$ production. This boost in food supply directly fuels their activity and increases emissions. (2) altered soil environment: certain fertilizers, particularly nitrogen-rich ones, can lower the soil's redox potential, creating a more anaerobic environment favorable for methanogens to thrive. This shift in conditions further amplifies $CH_4$ production (Li et al., 2018).

However, the impact of different fertilizer types and application methods varies significantly. Organic fertilizers, while boosting yield, generally lead to higher emissions than chemical fertilizers. Yet, within organic fertilizers, timing and processing matter. Applying straw before rice transplanting, unlike before winter, significantly increases emissions. Similarly, using fermented manure instead of fresh manure reduces emissions without sacrificing yield. Therefore, mitigating $CH_4$ emissions from rice paddies requires a nuanced approach that considers both fertilizer type and application strategy. Effective water management practices are widely acknowledged as a key strategy for reducing methane ($CH_4$) emissions from rice paddy (Gu et al., 2022).

In general, when compared to traditional long-term flood irrigation (FI), water-saving irrigation (SWI) has proven highly effective, resulting in a highest 39.7% reduction in soil $CH_4$ emissions (Table 2). Conversely, SWI at spring crop 2022 showed the lowest emission reduction rate, registering only 84.2 kg/ha/crop. It is crucial to underscore that proper irrigation practices should meet the water requirements during the various growth and development stages of rice. This not only mitigates $CH_4$ emissions but also ensures optimal rice yield.

The soil methane ($CH_4$) flux results from the interplay between $CH_4$ production and oxidation processes, governed by methanogens and methanotrophs, respectively. Consequently, reducing the activity and abundance of methanogens can inhibit soil $CH_4$ production, while increasing the activity and abundance of methanotrophs can promote soil $CH_4$ oxidation, leading to decreased $CH_4$ emissions (Xu et al., 2017). Numerous studies have identified environmental factors such as physical and chemical attributes, temperature, nitrogen, and metal content as key drivers controlling the activities of methanogens and methanotrophs. However, the intricate relationships between methanogens, methanotrophs, and environmental factors, including complex biological components like the structure of microbial communities' nutrient food webs, remain understudied. Soil methanogens and methanotrophs play essential roles in channeling energy and biomass to higher trophic levels. Some bacteria obtain necessary nitrogen sources for growth by infecting methanogens, and certain anaerobic ciliates extract nutrients from methanogens to support their own growth. The activities of these soil organisms significantly impact the soil methanogenic community, consequently influencing soil $CH_4$ fluxes. Additionally, methanotrophs act as natural filters by consuming $CH_4$, leading to a reduction of approximately 90% in atmospheric $CH_4$ release (Arjen et al., 2016). Recent findings suggest that soil organisms, including amoeba and flagellates, may prey on methanogens and methanotrophs, and the predation pressure regulates the community structure of these soil microorganisms. However, research on predator–prey relationships in the rice field ecosystem is limited. Therefore, utilizing a model of predator–prey interactions and considering micro-predators in the soil microbial community is recommended to assess the significance of predation or grazing as a biological factor affecting $CH_4$ consumption. Understanding the impact of water and fertilizer practices on soil $CH_4$ emissions in paddy fields is pivotal for addressing future global warming. A comprehensive analysis of an extensive database indicates that water-saving irrigation substantially reduces soil $CH_4$ emissions while simultaneously increasing rice yield. Conversely, fertilization enhances both $CH_4$ emissions and rice yields. To establish a mutually beneficial field management strategy that reduces soil $CH_4$ emissions and enhances rice yields, future research should focus on unraveling the interactions among fertilizers, intermittent irrigation, and the associated microbial mechanisms. This involves developing comprehensive models to advance our understanding and facilitate sustainable development in agricultural ecosystems (Gu et al., 2022).

### *Effect of biochar on nitrate removal*

Leaching N in crop systems dues high-rainfall and flood irrigation conditions with applied fertilizer, leading to over-crop nutrient N demand (Mai et al., 2010). In addition, the removal of groundwater $NO_3^-$ pollution is not possible through the process of biological denitrification without additional denitrifiers (Qin et al., 2014). In addition, applicating biochar to some soils reduced leaching $NO_3^-$ by up to 26% (Liu Q et al., 2018). For these reasons, we conducted experiments with biochar from rice husk with low-cost and reduced fertilizer ratio.  Due to experimental

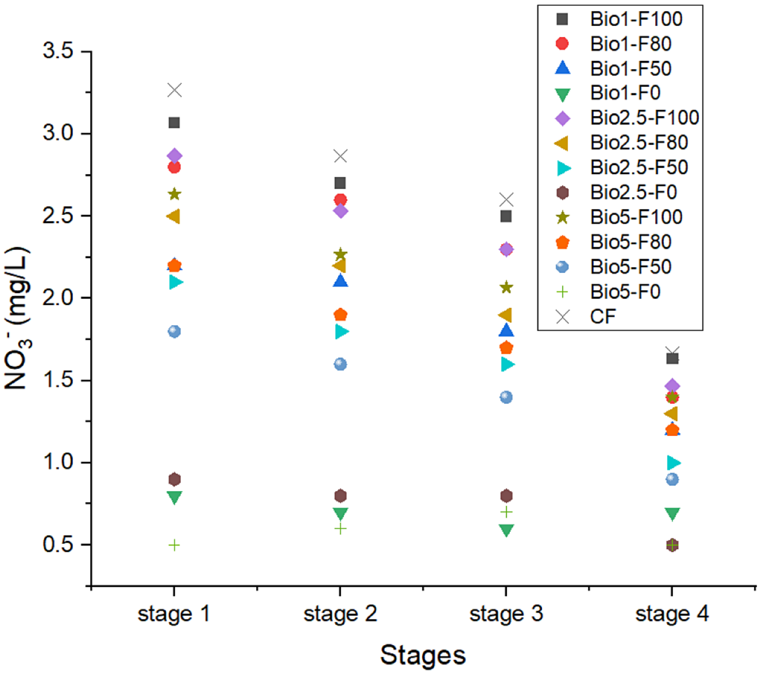


**Figure 9.** $NO_3^-$ content in surface field water

conditions with potted biochar, the quantification of $NO_3^-$ in groundwater may give different results than in the field. So we only determine the nitrate content in the field surface water because reducing nitrate content in surface water will reduce nitrate infiltration into groundwater. The experiment results of applying biochar indicated a slight change in $NO_3^-$ content (2.2–19.8%) of treatments compared to the CF. A biochar ratio of 1% reduced $NO_3^-$ content in the surface field water from 2.2 –6.1% compared to the CF. The biochar 2.5% treatment reduces $NO_3^-$ in the surface field water from 11.5– 12.2% compared to the CF. The significant changes occur in the biochar 5% reducing from 13.8–15.4% $NO_3^-$ in the surface field water compared to the biochar 1% treatment and reducing from 16–20.9% compared to the CF. The results are suitable with the study of (Vo et al. 2021) about $NO_3^-$ absorption ability of biochar being lower than others.

However, $NO_3^-$ content in surface field water has a reducing trend in the controlling N fertilizer. In the treatments of bio1, reducing $NO_3^-$ content in surface field water from 3.7–14.3%, 22.2–28.3% in the bio1-F80 and bio1-F50, respectively. Especially in contaminated water irrigation without fertilizer, reduced $NO_3^-$ content in surface field water from 57.1–76% compared to the bio-F100. In the treatments of bio2.5, the $NO_3^-$ content in surface field water reduced by about 11.4–17.4% in the bio2.5-F80 and significantly reduced from 26.7–31% in the bio2.5-F50. The treatment without bio2.5-F0 $NO_3^-$ fertilizer reduced surface field water content from 65.2–68.6% compared to the bio2.5-F100. Thus, the bio2.5-F80 has a $NO_3^-$ content in surface field water higher than the bio1-F80 from 2.9–7.7%. There is no significant change of $NO_3^-$ content in surface field water between the treatments of bio2.5-F50 and bio1-F50 ($p > 0.05$), and that is the same for treatments of bio2.5-F100 and bio1-F100 (Fig. 9).

There is a significant difference between the treatments of bio5 and bio1. The bio5-N80 reduced $NO_3^-$ content in surface field water from 1–4.4 times compared to bio1-F80. However, there is no significant difference between the treatments of bio5-F50 and bio1-F80, bio1-F100 và bio5-F100 ($P > 0.05$). The result is suitable with the study of (Wang et al., 2019) that showed N leaching reduction when N input was reduced in agricultural production systems. Results of (Liu et al., 2018) also indicated that reducing the fertilizer N ratio by 20% contributed to a reduction of 50% in the day number on which nitrate concentration was over 50 mg/L. The amounts of nitrate input play a significant role in decreasing nitrate concentrations in the subsoil and groundwater, so reducing the N fertilization ratio should be considered in crop cultivation. The optimized N fertilization control could reduce the subsoil's nitrate content, preventing nitrate leaching (Shufeng Chen et al., 2017, Tirol-Padre et al., 2017).

The addition of biochar from rice husk simproved temporary retention of against the downward movement of water through soil profile of nitrate. Beside, the treatment indicated that benefit effects of rice husk in controlling leaching of N from adsorption mechanism relates to electrostatic attraction between and the positively charged surfaces of biochar with nitrate.

## Growth and grain yield

Different irrigation methods affect the height of rice plants. Treatment SWI gave the highest plant height and significantly differed from the CF and FI treatments. The results showed that different irrigation methods did not affect the number of tillers per plant. However, SWI treatment still gave the highest number of tillers per plant. The SPAD index reflects the photosynthetic capacity of rice plants, the results indicated that different irrigation methods did not affect the SPAD

**Table 4.** The effects of irrigation techniques on the growth parameters of rice

| Treatments | Plant height (cm) | Number of tillers per plant | SPAD | | | Leaf area (dm²·plant⁻¹) |
|---|---|---|---|---|---|---|
| | | | Tillering stage | Heading stage | Milk stage | |
| CF | $101.44^b$ | $12.33^a$ | $40.00^a$ | $41.39^a$ | $40.99^a$ | $10.86^b$ |
| SWI | $105.78^a$ | $13.22^a$ | $41.37^a$ | $41.89^a$ | $40.69^a$ | $11.49^a$ |
| FI | $100.44^b$ | $12.67^a$ | $40.78^a$ | $40.79^a$ | $40.32^a$ | $10.32^b$ |
| LSD 5% | 3.20 | 1.11 | 2.08 | 1.39 | 1.11 | 1.65 |
| CV% | 1.06 | 4.40 | 2.60 | 1.70 | 1.40 | 7.60 |

**Note:** Mean values with different alphabet letters are significantly different at 0.05 probability and vice-versa.

index. However, the SPAD index was highest in SWI treatment at all three measurement stages (at the tillering stage, heading stage, and milk stage). The highest leaf area in the SWI treatment was significantly different from the other treatments. Treatment SWI had suitable growth parameters compared to other treatments, which could predict high grain yield in this treatment (Table 4).

Different irrigation methods affect the height of rice plants with treatment SWI which gave the highest plant height and significantly differed from the CF and FI. However, different irrigation methods did not affect the number of tillers per plant. SWI treatment still gave the highest number of tillers per plant. Different irrigation methods did not affect the SPAD index. The SPAD index was highest in SWI treatment at all three measurement stages. The highest leaf area in the SWI treatment was significantly different from the other treatments. Treatment SWI had suitable growth parameters compared to other treatments, which could predict high grain yield in this treatment. In FI treatment, there was a significant increase in the panicle number per plant compared to the CF. However, the number of filled grains per panicle increased significantly compared to the CF and SWI treatment, with the highest number of filled grains per panicle compared to the other two treatments. The results showed no significant difference between the weight of 1000 seeds of the three treatments ($P > 0.05$). The 1000-grain weight of the SWI and the FI was higher than the CF. Factors of stable effective panicles and increased grains per panicle were the causes for improving grain yield. Thus, the grain yield of the SWI was the highest, followed by the FI. This result is relevant, with the rice yield from the SWI field being significantly higher than the FI field by 15.56% (Phuong D.T.L. et al., 2020). All the grain yield of SWI and FI was higher at 11.61% and 8.38% than the CF, respectively. Paddy is a water-needing plant, so flooded irrigation gives the highest efficiency in branches, panicles, and filled grains per panicle. However, compared with the FI, the SWI increases the redox potential (the Eh) in the paddy soil, augmenting aerobic capacity and

**Table 5.** Yield components and grain yield of rice of treatment 2

| Treatment | Leaf dry weight (g·plant$^{-1}$) | Stem dry weight (g \·plant$^{-1}$) | Root dry weight (g·plant$^{-1}$) | Panicles number plant$^{-1}$ | Number of filled grains panicle$^{-1}$ | 1000 grain weight (g) | Filled grains (%) | Grain yield (g·plant$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| CF | 11.20$^{a}$ | 46.10$^{a}$ | 22.67$^{a}$ | 8.60$^{c}$ | 1018.60$^{c}$ | 19.70$^{a}$ | 92.30 | 43.05$^{c}$ |
| SWI | 12.35$^{a}$ | 52.43$^{a}$ | 23.06$^{a}$ | 10.00$^{b}$ | 1387.20$^{a}$ | 21.08$^{a}$ | 94.40 | 48.05$^{a}$ |
| FI | 11.96$^{a}$ | 55.94$^{a}$ | 25.17$^{a}$ | 11.60$^{a}$ | 1309.00$^{b}$ | 20.86$^{a}$ | 90.30 | 46.66$^{b}$ |
| LSD5% | 6.07 | 21.43 | 4.17 | 0.59 | 93.14 | 2.54 | | 1.02 |
| CV% | 5.70 | 6.80 | 8.80 | 1.93 | 3.00 | 6.80 | | 3.80 |

**Note:** Mean values with different alphabet letters are significantly different at 0.05 probability and vice versa.

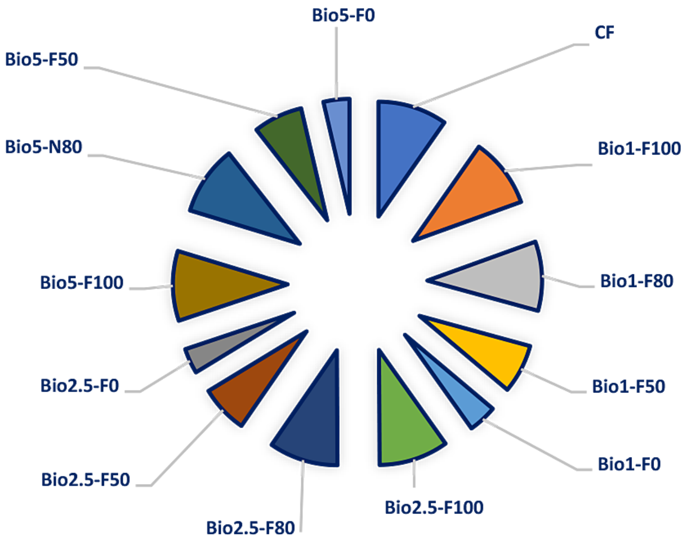


**Figure 10.** Grain yield of treatment 3

improving nutrient forms to promote the yield (Phuong et al., 2020) (Table 5, Fig. 10). Treatment 3 yield is calculated in grams/post (Fig. 10). There was no significant difference in the yield of treatments of CF, bio1-F100, bio1-F80, bio2.5-F100, bio2.5-F80, bio5-F100, and bio5-F80 ($p > 0.05$) with yield ranges of treatments were from 23.7–23.9 g/post. Thus, contaminated irrigation water with a reducing fertilizer ratio of 20% did not affect grain yield. However, the yield tended to reduce significantly in treatment groups, including bio-F50 and bio-F0. Details, treatments of bio1-F50, bio2.5-F50, and bio5-F50 had yield reduced from 28.7–31.2% compared to the CF. Treatments of bio-F0 with yield reduced from 58.8–63.7%. Based on yield and $NO_3^-$ content in contaminated irrigation can provide the conclusion that experiment conditions with contaminated water with $NO_3^-$ content from 0.5–2.9 mg/L, $NH_4^+$ content from 1.8–5.1 mg/L, $NO_2^-$ content from 0.068–1.092 mg/L reducing 20% fertilizer of recommended fertilizer rate no change about yield and help to reduce $NO_3^-$ content in surface field water from 3.7–14.3% compared to the CF. The results are similar to the studies of (Cerro et al., 2014) reduced fertilizer N application by 20% for cultivation activities to limit nitrate pollution in the Alegria watershed in northern Spain.

## CONCLUSIONS

The results showed that the treatment of clean irrigation water (F2) and contaminated irrigation without fertilizer (F3) reduced total N in soil layers compared to the contaminated irrigation water (F1). Under controlling surface field water, the SWI reduced the leaching N compared to the FI. The growth parameters of rice in the SWI treatment, including yield, were higher than others. The total methane emitted during the spring seasons for treatments (F1-F3) is lower than in the summer seasons. The formulas (F1-F3) mitigated yield during the spring seasons more than in summer. The biochar treatments with reducing fertilizer indicated that reducing 20% fertilizer of the recommended fertilizer rate caused no change in yield and helped reduce $NO_3^-$ content in surface field water from 3.7–14.3% compared to the CF.

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