POTENTIALITY OF ALTERNATIVE IRRIGATION REGIMES TO MITIGATE GREENHOUSE GAS EMISSIONS FROM MALAYSIAN PADDY RICE CULTIVATION

By

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Rice is an important food source and is the third-largest consumed grain worldwide. However, the production of rice under continuous flooding (CF) paddy fields is a primary anthropogenic source of methane (CH_4) gas, one of the major greenhouse gases (GHG) that contributes to global warming. Alternate wetting and drying (AWD) and mid-season drainage (MD) are two alternative irrigation regimes for rice paddies that can potentially reduce CH_4 emissions from rice cultivation. The principle behind these two irrigation regimes is water level in the soil will be lowered, and the soil will be exposed to oxygen, shifting the soil to an aerobic state and hence retarding the production of CH_4 by soil methanogens. However, exposing the soil to oxygen may increase nitrous oxide (N_2O) emissions, another significant GHG more potent than CH_4. The present study was carried out to measure and compare GHG emissions of rice planted under CF, AWD, and MD practices, the soil microbial diversity and abundance of each irrigation practice, and its effect on rice plant physiology and grain yield. Rice (Oryza sativa var. MR297) was transplanted into 15 tanks, assigned equally to the three treatments: AWD, MD, and CF, and arranged in a randomized complete block design. The soil used in this study was taken from a rice field in Pendang, Kedah. Emissions of GHG were measured weekly using static chambers, and the sampled air was analyzed for CH_4 and N_2O concentrations using gas chromatography. Soils were sampled on the 58^{th} and 96^{th} day after transplant (DAT) from each treatment to assess their microbial diversity and abundance using 16S rRNA microbiome sequencing. Rice plant height, leaf area, and greenness were measured weekly, while 1000-grain weight and total plant biomass dry matter were measured after harvest. Leaf photosynthesis rates were measured during the rice plant's reproductive, flowering, and ripening stages to measure plant water stress and water use efficiency. Leaf samples were analyzed for δ13C isotope composition to determine water stress in plants. This study found that rice plants under alternative irrigation regimes do not undergo plant water stress due to water scarcity. The photosynthesis rate shows a similar pattern between the treatments, and the carbon isotope composition shows a negative value under CF, MD, and AWD on the 78th and 96th DAT. The CH_4 emissions from CF, AWD, and MD were 70.24, 30.75, and 15.93 g CH_4 m^{-2} for CF, AWD, and MD, respectively. The methane emissions from MD and AWD were 77.07% and 57.81% lower, respectively, then CH_4 emissions from CF. On the other hand, MD and AWD did not emit N_2O fluxes throughout the planting period. Methanogenic microbes were found abundant in the CF soil samples, while methanotroph microbes were abundant in CF and MD soil samples. CF, MD, and AWD presented 82.74, 86.59, and 67.02 kg m^{-2} of grain yield, with no significant differences between the treatments. Besides, alternative irrigation regimes do not affect rice plant height, leaf area, and greenness index between the treatments. The present study demonstrated that alternative irrigation regimes when applied to Malaysian rice soil planted with Malaysian rice variety did not cause any reduced crop performance and yield, at the same time, were proven to reduce emissions of GHG.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

POTENSI SISTEM PENGAIRAN ALTERNATIF BAGI MENGURANGKAN PELEPASAN GAS RUMAH HIJAU DARI PENANAMAN PADI DI MALAYSIA

Oleh

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Padi merupakan sumber makanan yang penting dan merupakan bijirin ketiga terbesar dari segi penggunaannya di seluruh dunia. Walau bagaimanapun, penanaman padi sawah secara terendam (CF) merupakan antara punca penghasilan gas metana (CH_4) dari aktiviti pertanian. Metana merupakan salah satu gas rumah hijau (GHG) yang menyumbang kepada pemanasan global. Pengairan dan pengeringan secara berganti (AWD) dan pengeringan pertengahan musim (MD) adalah dua sistem pengairan alternatif sawah padi yang berpotensi untuk mengurangkan pelepasan CH_4 dari aktiviti penanaman padi. Prinsip di sebalik kedua-dua rejim pengairan ini ialah paras air dalam tanah akan diturunkan, meningkatkan pengudaraan tanah dan menjadikan tanah berada dalam keadaan aerobik seterusnya merencat penghasilan CH_4 oleh mikrob metanogen dalam tanah. Walau bagaimanapun, pengudaraan tanah juga berpotensi meningkat pelepasan gas nitrous oksida (N_2O), yang merupakan satu lagi GHG yang lebih kuat kesannya terhadap pemanasan global berbanding CH_4. Kajian ini dijalankan untuk mengukur dan membandingkan pelepasan GHG dari penanaman padi dengan kaedah pengairan CF, AWD dan MD, kepelbagaian dan kelimpahan mikrob tanah, kesan sistem pengairan yang dinyatakan terhadap fisiologi tanaman padi dan hasil padi. Semaian anak pokok padi (*Oryza sativa* var. MR297) telah dipindahkan ke dalam 15 tangki yang dibahagi sama rata kepada tiga jenis tiga rawatan: AWD, MD dan CF dan disusun secara reka bentuk blok rawak yang lengkap. Tanah yang digunakan diambil dari sawah padi di Pendang, Kedah. Pelepasan GHG diukur setiap minggu menggunakan kebuk statik dan sampel udara dianalisis untuk mengukur kepekatan CH_4 dan N_2O menggunakan kromatografi gas. Sampel tanah telah diambil pada hari ke-58 dan ke-96 selepas pemindahan anak pokok (DAT) dari setiap rawatan bagi penentuan kepelbagaian dan kelimpahan mikrob menggunakan susunan mikrobiom 16S rRNA. Ketinggian pokok padi, luas daun dan kehijauan daun diukur mingguan manakala berat 1000-butir, dan berat kering biojisim tumbuhan diukur selepas penuaian. Kadar fotosintesis daun diukur semasa pokok padi berada pada peringkat pembiakan, pembungaan dan matang untuk mengukur tegasan air tumbuhan dan kecekapan penggunaan air. Sampel daun juga dianalisis untuk menentukan komposisi isotop δ13C untuk menentukan tegasan air dalam tumbuhan. Kajian ini mendapati pokok padi di bawah sistem pengairan alternatif tidak mengalami tekanan air kerana kekurangan air. Kadar fotosintesis menunjukkan corak yang sama antara rawatan, dan komposisi isotop karbon menunjukkan nilai negatif di bawah CF, MD, dan AWD hari ke-78 dan ke-96 DAT. Jumlah pelepasan CH_4 daripada CF, AWD, dan MD ialah 70.24, 30.75, dan 15.93 g CH_4 m^{-2} untuk CF, AWD dan MD, masing-masing dimana, MD dan AWD adalah 77.07% dan 57.81% lebih rendah daripada pelepasan CH_4 daripada CF. Sebaliknya, MD dan AWD tidak mengeluarkan fluks N_2O sepanjang tempoh penanaman. Mikrob metanogenik didapati banyak dalam sampel tanah CF, manakala mikrob metanotrof banyak terdapat dalam sampel tanah CF dan MD. CF, MD, dan AWD mendapati 82.74, 86.59, dan 67.02 kg m^{-2} hasil tanaman, tanpa perbezaan yang ketara antara rawatan. Selain itu, rejim pengairan alternatif tidak menjejaskan ketinggian pokok padi, luas daun, dan indeks kehijauan antara rawatan. Kajian ini menunjukkan bahawa rejim pengairan alternatif apabila digunakan pada tanah padi Malaysia yang ditanam dengan varieti padi Malaysia tidak menyebabkan prestasi tanaman berkurangan dan hasil, pada masa yang sama, terbukti dapat mengurangkan pelepasan GHG.

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LIST OF ABBREVIATIONS

GHG	Greenhouse Gasses
DAT	Day After Transplant
AWD	Alternate Wetting-Drying
MD	Mid-season Drainage
CF	Continuous Flooding
CH_4	Methane
CO_2	Carbon dioxide
O_2	Oxygen
N_2O	Nitrous Oxide
δ13C	Carbon-13
MDP	Data Profiling Module
OUT	Operational Taxonomic Unit
DNA	Deoxyribonucleic Acid
LefSe	Linear Discriminal Analysis Effect Size
NGS	Next Generation Sequencing
PCR	Polymerase Chain Reaction
°C	Celsius
SPAD	Soil Plant Development
MARDI	Malaysian Agricultural Research and Development Institute

CHAPTER 1

INTRODUCTION

1.1 Background of the study

1.1.1 Introduction

Rice (*Oryza sativa*) is one of the most important crops in the world. More than half of the world's population consume rice daily, leading to a global consumption of about 486.62 Mt between 2018 to 2019 (FAO, 2008). To fulfil the high demand for rice, as of 2017, there are 167.25 million ha of rice paddy fields currently under production worldwide, most of which are located in the Asia Pacific region (FAO, 2008).

Asia's population is growing and is expected to reach the peak of its population density before declining towards the end of this century (UN DESA, 2022). Since rice is the staple food for Asians, the demand for rice in this continent will continue to rise along with the growing population (Figure 1.1).

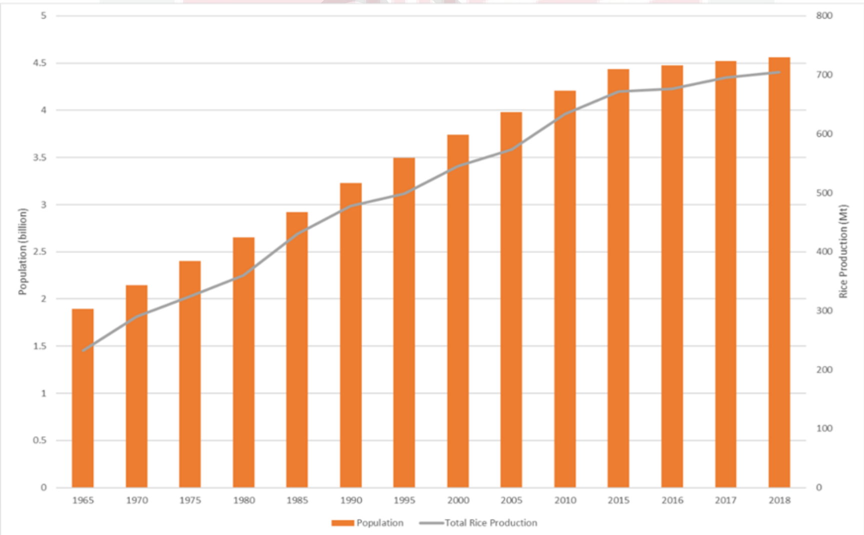

Figure 1.1: Asia's population and rice production from 1965 to 2018.

Rice paddy is unique in its field practice, where the rice fields are irrigated by flooding the field. Paddy rice can flourish in a flooded field due to the presence of a tissue named aerenchyma (Yamauchi et al., 2013). Aerenchyma is the gas space that is formed by inducing dead cells inside of the roots. It transports oxygen from leaves to roots, making it crucial tissue to ensure the crop's survivability in flooded conditions. Since rice paddy is able to withstand flooded conditions, it helps farmers in controlling non-aquatic weeds (MARDI, 2008). It reduces the competition between weeds and rice for nutrient supply.

The commercial water management practice in the paddy field is continuous flooding up to 7-10 days before harvest (IRRI, 2020). After transplanting of seedlings, paddy fields were flooded at 5 cm, then gradually increased to 10 cm depending on plant height (IRRI, 2020).

Malaysia is one of the countries that practices flooded rice cultivation for lowland rice fields. The main paddy production areas in Malaysia are granary areas (Figure 1.2) (DOA, 2022).

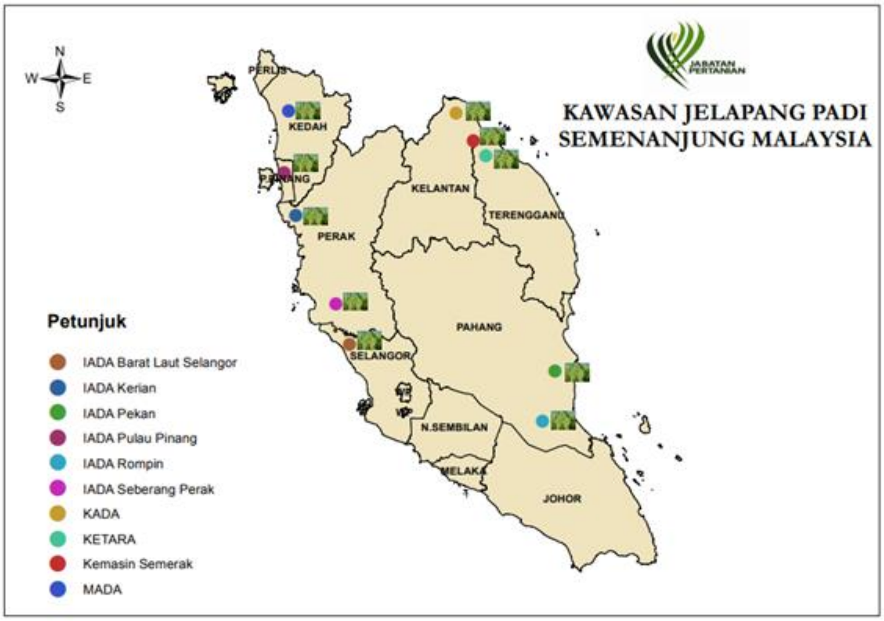

Figure 1.2: Granary area in Peninsular Malaysia
(Source: Soil Management Division, Department of Agriculture Malaysia, 2022)

Rice production in 2021 was 2,428,893 Mt from 647,859 ha of planted area (Figure 1.3). This production has increased by 3.1% compared to 2020. However, Malaysia still depends on imported rice as annual rice production is unable to supply the demand for rice to all people. National Agrofood Policy 2.0 (DAN 2.0) stated that the national food system needs to be strengthened, especially to deal with the global crisis.

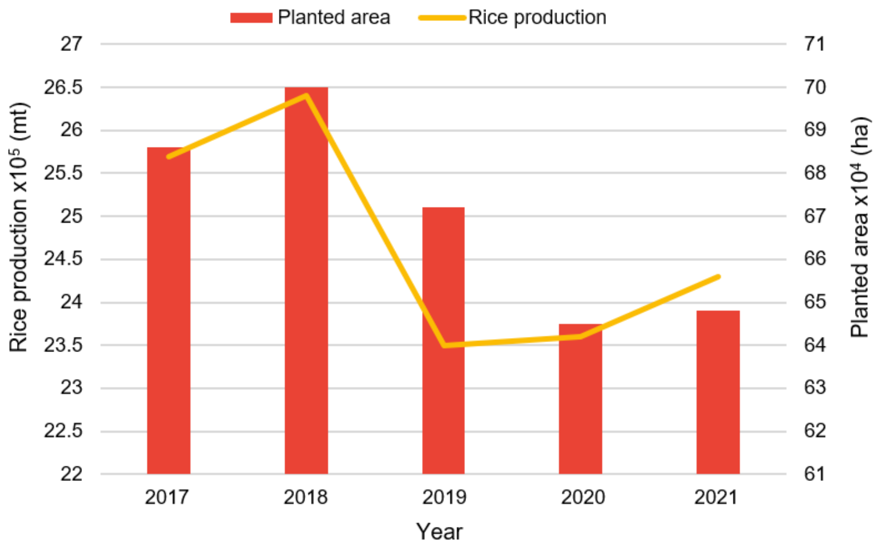

Figure 1.3: Total planted area and rice production in Malaysian rice cultivation
(Source: Malaysia Agriculture Department, 2022)

1.1.3 Greenhouse gas (GHG) production in rice cultivation

Rice is primarily grown in flooded fields. Water prevents oxygen from accessing the soil, creating anaerobic conditions where oxygen is not available inside paddy soil. Anaerobic conditions appear in an area where oxygen utilization surpasses the diffusion by the oxygen into the soil profile (P.W Inglett et al., 2006). This condition fosters the growth of methanogens bacteria that produce methane. The longer the flooding lasts, the more methanogens accumulate (WRI, 2014). The CH_4 emissions emitted from rice cultivation are produced during flooded conditions through these three processes which are; CH_4 production by methanogens under anaerobic conditions, oxidation by methanotrophs in the aerobic soil zone, and transportation of the CH_4 to the atmosphere (Figure 1.4). Methanotrophs convert the organic matter in rice soil into CO_2 and CH_4 (Kallistova et al., 2014).

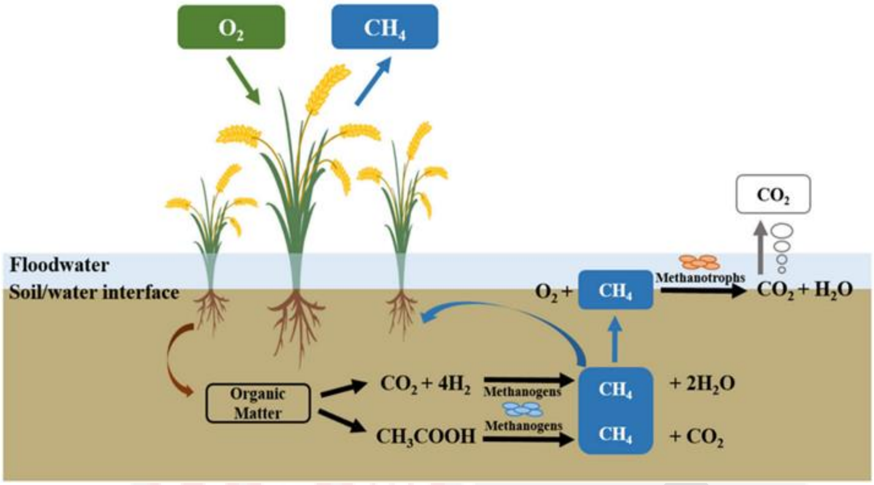

Figure 1.4: Formation of CH_4 in paddy soils by methanotrophs (Source: Gu et al., 2022)

Even with a low atmospheric concentration, CH_4 is more potent than carbon dioxide (CO2) (IPCC, 2007). Methane can trap more heat due to its higher global warming potential (GWP) than CO_2, which is 28 to 34 times more on a weight basis (IPCC, 2013). This significantly impacts the environment as heat entrapment in the atmosphere leads to climate change. Thus, CH_4 emissions should be minimized.

However, dying paddy fields create aerobic conditions where oxygen is available inside paddy soil, which could release nitrous oxide gas into the atmosphere. Nitrous oxide is another potent greenhouse gas (Wang et al., 2020) formed predominantly in soils through the two biological mechanisms of nitrification and denitrification (Hou et al., 2012). Nitrification in soils is carried out by aerobic, ammonia-oxidizing bacteria (AOB), which create nitrate from ammonium in the soil but can also emit some nitrous oxide. Compared to CO_2, N_2O is approximately 265 times more potent (IPCC, 2013). Human activities such as agriculture, fuel combustion, industry, and waste are responsible for 40% of total N_2O emissions worldwide (IPCC, 2021).

Greenhouse gas emissions caused by the agricultural sector were reported to have increased by 1.1% annually from 2005 to 2010 (Tubiello et al., 2013). If no climate action is taken, the GHG emitted from the agriculture sector will keep increasing annually. In order to reduce agricultural impacts on climate change, we have to start opting for sustainable agriculture. These greenhouse gasses need to be reduced to an acceptable rate to minimize their environmental impacts.

1.1.4 Alternative irrigation regimes

Yuan et al. (2018) stated that flooded paddy fields have been identified as one of the major culprits in producing methane (CH_4) which is a potent greenhouse gas (GHG). One of the ways to minimize CH_4 emissions in paddy fields is by practicing proper water management (Gu et al., 2022). Aeration of the soil does not only reduce CH_4 emissions, but it also reduces water usage (Wang et al., 2020).

Alternate wetting and drying (AWD) is one of the water management techniques that can potentially reduce CH_4 emissions in paddy fields (Allen JM and Sander BO, 2019). AWD controls water usage and supplies it intermittently to paddy fields. Another water management technique that may potentially reduce CH_4 emission is mid-season drainage (MD) (Liu et al., 2019). MD supplies water to crops throughout the planting except for about seven days toward the end of the tillering stage.

Both of these techniques may contribute to increased nitrous oxide (N_2O) emissions. Nitrous oxide is produced from soils under aerobic conditions, which are favorable environmental conditions for nitrifying and denitrifying bacteria that produce N_2O (Li et al., 2018).

Moreover, alternative irrigation techniques reducing water irrigation in paddy fields may cause plant water stress due to water scarcity. Rice plants are susceptible to water drought, which is the most severe and significant constraint for rice production in the rainfed ecosystem (Pandey & Shukla, 2015).

1.2 Problem statement

Rice flourishes in a flooded field. However, flooding of rice fields contributes to emissions of CH_4. Methane emission can be controlled by implementing a dry period in the field, but it may increase emissions of N_2O, another greenhouse gas with a higher GWP than CH_4. Changing soil conditions from an anaerobic to aerobic state results in changing soil microbiomes responsible for producing GHG emissions. Anaerobic conditions activated methanogenic microbes in paddy soil to respond and produce methane gas as their product. While aerobic conditions activated methanotroph microbes that utilize methane as carbon and energy source.

In addition, implementing alternative irrigation regimes where irrigation is controlled may impact paddy growth due to the paddy experiencing water stress. Water stress is abiotic stress due to water scarcity, and this could affect the physiological and morphological characteristics of rice plants, such as stunted rice plants, wilting, senescence, and others. Plant water stress will result in low photosynthesis rate and grain yield.

Respectively, this study determined the effectiveness of alternative irrigation regimes in reducing GHG emissions without affecting paddy growth and grain yield.

1.3 Scope of research

The scopes of this study were determined as follows.

Malaysia's rice is cultivated in lowland and upland; this study focuses on lowland paddy cultivation. This study was performed in a rain shelter for only one season of the planting cycle. In this study, tap water was the only water source used to irrigate the tanks and was measured daily. Farmers practiced direct seeding and transplanting seedling systems at the real paddy field, but in this study, the transplanted seedling was used in the tank. This study uses the rice cultivar MR297 from MARDI, which specializes in Karah diseases and gives a high yield.

The GHG gas emissions were released all the time throughout the planting stage. Due to time constraints and the lack of human resources, this study is limited to taking the gas sample only once a week from 0900 to 1000. Besides that, 16s rRNA sequencing was assigned to identify the anaerobic methanogenic microbes and aerobic nitrifying microbes. Due to the financial constraint, this study only focuses on two batches on the 58th DAT, after practicing MD treatments, and on the 96th DAT, after the flowering stage.

This study focuses on water management's effectiveness in reducing GHG emissions without affecting paddy growth and grain yield. This study will show how water management affects GHG emissions due to the microbial activities inside the paddy soil.

1.4 Objectives

The purpose of this study are:

1. to determine the plant physiological effects during water stress on both alternative irrigation regimes compared to CF.

2. to determine the methane and nitrous oxide emissions under CF, AWD and MD practices.

3. to determine the soil microbial diversity and abundance that contribute to methane and nitrous oxide emissions under CF, AWD and MD practices using 16S rRNA microbiome communities sequencing.

4. to determine plant growth and rice yield on both alternate irrigation regimes compared to CF.

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