

**INFLUENCE OF MANAGEMENT PRACTICES ON THE
METHANE EMISSION IN RICE FIELD**

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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
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October, 2006

CERTIFICATE

I Certify that **Mr. I.W.K. IMBULGODA**, has satisfactorily prosecuted the course of research and the thesis entitled, **“INFLUENCE OF MANAGEMENT PRACTICES ON THE METHANE EMISSION IN RICE FIELD”** is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any University.

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CERTIFICATE

This is to certify that the thesis entitled “**INFLUENCE OF MANAGEMENT PRACTICES ON THE METHANE EMISSION IN RICE FIELD**” submitted in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** of the **Acharya N.G. Ranga Agricultural University, Hyderabad** is a record of the bonafied research work carried out by **Mr. I.W.K. IMBULGODA** under my guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma or has been published. The published part has been fully acknowledged. All assistance and help received during the course of investigation have been duly acknowledged by the author of the thesis.

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(I.W.K. IMBULGODA)

LIST OF ABBREVIATIONS

C	:	Carbon
CD	:	Critical Difference
CH ₄	:	Methane
CO	:	Carbon monoxide
CO ₂	:	Carbon monoxide
Cm	:	Centimeter
CPE	:	Cumulative Pan Evaporation
⁰ C	:	Degree Centigrade
d	:	day
DAT	:	Days after transplanting
dSm ⁻¹	:	desi Siemen per meter
EC	:	Electrical conductivity
Eh	:	Redox potential
et al.	:	and others
etc.	:	Etcetera
Fe	:	Iron
FID	:	Flame Ionization Detector
Fig.	:	Figure
g	:	gramme
GC	:	Gas chromatograph
H ₂	:	Hydrogen
Ha	:	Hectare
IW	:	Irrigation water
K	:	Potassium
m ⁻²	:	Per square meter
Mn	:	Manganese
mv	:	milli volt
N	:	Nitrogen
N ₂ O	:	Nitrous oxide
O ₂	:	Oxygen
OH	:	Hydroxyl

P	:	Phosphorus
pH	:	Soil reaction
ppm	:	Parts per million
RF	:	Rain fall
RFD	:	Recommended fertilizer dose
SEm	:	Standard error of mean
Viz.	:	Namely
Zn	:	Zinc
%	:	percentage

DECLARATION

I, **I.W.K. IMBULGODA**, hereby declare that the thesis entitled **“INFLUENCE OF MANAGEMENT PRACTICES ON THE METHANE EMISSION IN RICE FIELD”** submitted to Acharya N.G. Ranga Agricultural University for the degree of **MASTER OF SCIENCE IN AGRICULTURE**, is a result of the original research work done by me. It is further declared that the thesis or any part thereof has not been published earlier in any manner.

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ABSTRACT

A field experiment on “Influence of management practices on the methane emission in rice field” was carried out during *rabi* season of 2005-2006 at the Directorate of Rice Research, Rajendranagar, Hyderabad on clay soil. The experiment was conducted in split plot design with three water regimes viz., continuous flooding, IW/CPE= 1.0 and IW/CPE= 0.75 as main treatments and five fertilizer levels viz., control, RFD, RFD + 50% more N, 50% RFD + 50% organic manure and organic manure alone as sub plot treatments.

The results revealed a distinct diurnal pattern of methane efflux at tillering stage of rice crop. There was reduction in methane emission to an extent of 25% and 40% in treatments of IW/CPE= 1.0 and IW/CPE= 0.75 respectively over continuous flooding. At flowering stage, CH₄ emission was maximum (17.75 mg m⁻² d⁻¹ from continuously flooded plots) compared with other growth stages. After irrigation (8.60 mg m⁻² d⁻¹) there was a significant enhancement in CH₄ emission when compared with before irrigation

treatment ($6.55 \text{ mg m}^{-2} \text{ d}^{-1}$) especially in the driest water regime (IW/CPE=0.75) at tillering stage.

RFD treatment recorded highest seasonal CH_4 emission which was significantly superior to all other treatments followed by 50% RFD+ 50% organic manure and organic manure alone. Among fertilizer levels, least amount of seasonal $\text{CH}_4 \text{ t}^{-1}$ of grain yield (1.49kg) was recorded with RFD treatment compared with other treatments.

Continuously flooded water regime resulted in higher grain yield (4406 kg ha^{-1}) over other water regimes. Uptake of NPK by rice crop was higher ($94.9, 34.6$ and 54.4 kg ha^{-1}) in continuously flooded plots. However, higher Zn uptake (144.6 g ha^{-1}) was recorded in the driest water regime (IW/CPE= 0.75). Fertilizer levels of RFD and RFD+50% more N recorded higher NPK and Zn uptake over other treatments.

Higher available P_2O_5 (110.2 kg ha^{-1}) resulted in drier water regimes while higher Zn status (14.8 g ha^{-1}) was reported in continuously flooded plots. The highest water use efficiency ($13.79 \text{ kg ha}^{-1} \text{ mm}^{-1}$) was resulted in driest water regime (IW/CPE= 0.75) over other water regimes and fertilizer levels of RFD+ 50% more N, RFD and 50% RFD + 50% organic manure over other treatments.

The present investigation indicated that the combination of IW/CPE= 0.75 + RFD treatment can be recommended as a suitable mitigation option owing to its least amount of seasonal $\text{CH}_4 \text{ t}^{-1}$ of grain yield (1.29kg). The combination of IW/CPE= 0.75 + RFD with 50% more N can be applied to obtain maximum water use efficiency.

CHAPTER I

INTRODUCTION

The major environmental problem today is the global warming due to accumulation of several gases like CO₂, CH₄ and N₂O, chlorofluoro carbons along with water vapour in the atmosphere causing greenhouse effect and depletion of ozone layer in stratosphere, affecting several aspects of humanity on planet earth. The global increase in CO₂ along with other greenhouse gases such as CH₄ and N₂O traps outgoing thermal radiation, leading to increased temperature at the earth's surface. Among greenhouse gases, CH₄ is ranked next only CO₂. Global mean temperature of the surface has risen by 0.3-0.6°C due to anthropogenic interferences (Hadley Centre, 1998). By 2100, increases in temperature between 1 and 3.5°C are expected to take place due to global warming because, human induced warming of the atmosphere is likely to continue.

Wetland rice fields have been identified as a major source of atmospheric methane, contributing about 10-15% to global CH₄ emission (Sass, 1995). Rice field soils, characterized by O₂ depletion, high moisture and relatively high organic substrate levels, offer an ideal environment for the activity of methanogenic bacteria and emission of CH₄. It is released from submerged soils to the atmosphere by diffusion and through roots and stems of rice plants. Since O₂ diffusion is 10,000 times lower in water than air, the O₂ demand of aerobic organisms is not satisfied under flooded conditions.

Flooding of soil results in lowering of the soil Eh, as facultative and obligate anaerobes use oxidized soil substrates as electron acceptors in respiration. Methane is exclusively produced by methanogenic bacteria that can metabolize only in the strict absence of free O₂ and at redox potentials of less than -150mv (Wang *et al.*, 1993a).

Rice is the basic food crop for nearly half the people on the earth, most of them concentrated in Asia. Intensification of rice cultivation to meet the demand for rice by increasing human population is imperative, especially in Asia where approximately 90% of the rice is grown and consumed (IRRI, 1993). Given the expected doubling in rice production in Asia, research on improving rice yield should focus on strategies that do not harm the environment.

Methane production is regulated by a number of physical and chemical factors such as soil pH, Eh, temperature, organic carbon supply, aeration and the water status. Application of chemical fertilizer improves plant growth and therefore increases methane emission and probably its production. Intermittent drying of flooded rice fields reduces total methane production and emission (Sass *et al.*, 1992). Under field conditions, the impact of different management practices such as organic versus mineral fertilizer, continuous flooding versus intermittent drainage can be predicted with reasonable accuracy. Keeping this in background, a study was planned on “Influence of management practices on the methane emission in rice field”.

The main objectives of this field experiment were to study the influence of nutrient and water management practices on:

1. Methane emission from rice fields and to suggest mitigation options.
2. Yield variation of rice crop.
3. Uptake of NPK by rice crop.

CHAPTER II

REVIEW OF LITERATURE

India produces annually 88.3 million tonnes of rice in an area of 42.5 million ha corresponding to 28% of the global rice lands (CMIE, 2004). The rice growing areas of India can be broadly categorized into rainfed upland, rainfed low land and irrigated medium land, representing about 15,40, and 45% of total rice area of the country. In India, 48% of the country's rice area is irrigated while the rest is grown under rainfed situations. The pressure on India's land resources to produce more rice will aggravate in the coming years due to increasing population and demand for food. Rice cultivation practices have to adjust, to facilitate higher yield. Increased use of fertilizers and water regime enhance the emission of methane. Thus, estimation of methane emission from rice fields under currently employed technologies is important to propose the mitigation options to have an environmental friendly rice production in India.

The literature related to the present study is reviewed and presented under following headings.

1. Global warming from atmospheric methane.
2. Rice field as an important source of methane production.
3. Factors affecting methane production in rice paddies.
4. Mitigation options.
5. Rice yield and nutrient uptake.

2.1 GLOBAL WARMING FROM ATMOSPHERIC METHANE.

2.1.1 Effect of methane on the atmospheric environment

Carbon dioxide, chlorofluorocarbons, methane and nitrous oxide in the atmosphere are the gases mainly responsible for global warming as a consequence of the so-called “greenhouse effect” (IPCC, 1992).

Aulakh *et al.* (2001) revealed that greenhouse gases are nearly transparent to the visible and near-infrared wavelengths of sunlight, but they absorb and re-emit downward, a large fraction of the longer infrared radiation emitted by earth. Among the most important greenhouse gases, CH₄ ranks next only to CO₂.

Bouwman (1991) reported that methane gas is one of the greenhouse gases that is reported to exert significant effects on the global heat balance, thus causing a possible elevation of global surface temperature. Methane plays an important role in the photochemical reactions of the troposphere, and the changes in its concentration exert a strong influence over the atmospheric chemistry (Thompson and Cicerone, 1986).

Rodhe (1990) reported that CH₄ had strong absorption bands in the infrared region of the electromagnetic spectrum leading to an increase in atmospheric temperature. Although CH₄ had a relatively short atmospheric lifetime (8-12 years), one molecule of CH₄ traps about 32 times more heat than a molecule of CO₂.

Khalil and Rasmussen (1987) showed that the concentration of atmospheric methane had more than doubled during the past 200 years, through studies conducted on of ancient air trapped in polar ice cores. Methane was increasing at an average global atmospheric concentration of about 0.016 ppm per year (1% per year). CH_4 plays an important role in the chemistry of troposphere. Key reactions include its oxidation to affect ozone, hydroxyl (OH) radicals, and CO. As the most abundant hydrocarbon in the atmosphere, CH_4 is both the major regulator of OH radicals and the primary sink for Cl atoms, which take place in ozone-destroying chain mechanisms (Tyler, 1991).

Cicerone and Oremland (1988) revealed that the global CH_4 cycle is closely linked to the CO cycle. 10-35% of the global annual production of CO is believed to result from the CH_4 oxidation.

Oberthur and Ott (1999) reported that carbon dioxide accounted for 70-72% of the additional greenhouse effect accumulated since industrialization while CH_4 had contributed 21-22%. CH_4 may significantly contribute to a negative feedback system with unpredictable consequences for the whole chemistry of the atmosphere.

2.1.2 Sources of atmospheric methane

Methane is emitted to the atmosphere from both natural and anthropogenic sources. Natural sources include wetlands, lakes, rivers, oceans and termites, etc.; whereas anthropogenic sources include mining, flooded rice

fields, biomass burning, landfills, ruminants, animal wastes, domestic sewages, etc. (Khalil and Shearer, 1993).

Aulakh *et al.* (2001) revealed that methane emission levels from a source can vary significantly from one country or region to another, depending on many factors such as climate, industrial and agricultural production characteristics, energy types and usage, and waste management practices. For example, temperature and moisture have a significant effect on the anaerobic digestion processes, which is one of the key biological processes that cause methane emission in both human related and natural sources.

Of the wide variety of sources for the atmospheric CH₄, rice paddy fields are considered as an important factor for the observed changes in atmospheric CH₄ concentration because of the recent increase in their harvest area in the world (Minami, 1994).

Flooded rice fields, with their abundant organic matter, warm temperatures and anaerobic conditions, provide an ideal environment for methanogenic activity. Significant areas under rice cultivation are major anthropogenic sources of CH₄ (Matthews *et al.*, 2000).

2.2 RICE FIELD AS AN IMPORTANT SOURCE OF METHANE PRODUCTION

Rice fields are considered to be an important anthropogenic source for methane and contribute up to 20% or ~100 Tg CH₄ to the global budget on an

annual basis (Houghton *et al.*, 1996). With intensification of rice cultivation during the coming decades, CH₄ emission from this economically important but ecologically fragile ecosystem is anticipated to increase (Anastasi *et al.*, 1992).

Neue *et al.* (1997) showed that methane emission is the interactive product of three processes;

1. CH₄ production controlled by Eh, pH and mineralizable carbon and temperature.
2. Vertical transfer controlled by water depth and rice plant growth stage.
3. CH₄ oxidation controlled by free oxygen diffusing through the rice plant, partial pressure and temperature.

2.2.1 Methane formation

Wang *et al.* (1996) reported that methane generation is considered to be the terminating step during anaerobic microbial decomposition of organic matter and any parameter affecting the biological, chemical, or physical characteristics of the flooded soil environment will influence CH₄ production and eventual emission.

Wang *et al.* (1993a) reported that methane is produced under extremely reducing electrochemical conditions in flooded rice soils. The critical redox potential for initiation of CH₄ production observed in their study was approximately from -150 to -160 mV. At Eh between -230 and -150 mV, the relation between soil Eh and CH₄ production was about neutral or slightly above

neutral (6.9-7.1) without considering the resultant change in soil redox potential from addition of acid or alkali.

Conrad (1989) suggested that the major pathways of CH_4 production in flooded soil are the reduction of CO_2 with H_2 , fatty acids or alcohols as hydrogen donor and the transmethylation of acetic acid or methyl alcohol by methane producing bacteria. Methanogens rely on a plethora of other microorganisms to provide them with the few substrates they can catabolize hydrogen, carbon dioxide, formate, acetate, methanol, methylamines and methyl sulfides.

Denier van der Gon and Neue (1995a) observed that the amount of CH_4 produced in flooded rice soils is primarily determined by the availability of methanogenic substrates and the influence of environmental factors. The sources of organic carbon for methanogenic substrates are primarily rice plants via root exudation, root senescence and plant litter or added organic matter for fertilization.

2.2.2 Inhibition of methane formation

Neue and Roger (1993) reported that decomposition of organic matter and methane production is retarded in wetland soils with acidic reaction, low and imbalanced nutrient supply, high kaolinitic clay content or high bulk density. Sodium chloride inhibits methanogenesis when added in high concentrations ($\sim 0.18\text{M}$).

Kumaraswamy *et al.* (1998) showed that application of a commercial formulation of carbofuran (2 and 12 kg active ingredient/ha) resulted in significant reduction of CH₄ emissions from flooded rice fields. It increased the oxidation of CH₄ at low rates (5 and 10 mg kg⁻¹ soil) but inhibited CH₄ oxidation when applied at a rate of 100 mg kg⁻¹ soil.

Adhya *et al.* (1997) reported that the supply of P and K through sulphate containing fertilizers reduces CH₄ emission from soils under laboratory and field condition due to the inhibitory effect of SO₄²⁻. For instance, application of single super phosphate and K₂SO₄ drastically reduced CH₄ production in soils.

Bharati *et al.* (2000) observed that application of dicyandiamide (DCD) at 15 mg kg⁻¹ soil inhibited CH₄ production by about 46% over the control. The inhibition of CH₄ production in DCD-amended soils was related to a high redox potential, low pH, low Fe²⁺, lower readily mineralizable C content as well as reduced population and activity of methanogenic bacteria.

Banik *et al.* (1996) reported that micronutrients like Fe and Mn showed distinct inhibition of CH₄ production in soil at concentrations of 50mg FeCl₃ kg⁻¹ soil and 10mg MnCl₂ kg⁻¹ soil, respectively. They suggested that various micronutrients at low concentration could enhance CH₄ production, whereas Fe and Mn, if present in higher concentrations, would inhibit methanogenesis in rice soils.

2.2.3 Methane oxidation

Kruger *et al.* (2001) reported that the contribution of CH₄ oxidation to total CH₄ flux, determined by specific inhibition with difluoromethane, decreased from 40% at the beginning to zero at the end of the season. The CH₄ oxidizing bacteria probably became limited by nitrogen as indicated by the seasonal decrease of NH₄. Thus, CH₄ oxidation had little effect on CH₄ emission.

Banker *et al.* (1995) reported that at the soil-water interface, CH₄ oxidation was confined to 70-95% of the produced CH₄. This small range indicated the presence or absence of the oxygen produced by algae which did not have a large influence on CH₄ oxidation. Oxidation at the soil-water interface was bypassed by ebullition.

Minami (1994) revealed that the amount of CH₄ emitted from paddy fields to the atmosphere is mainly controlled by the balance of the production, oxidation and leaching of CH₄ in paddy soils. Field measurements showed that the proportion of CH₄ emission to CH₄ production ranged between 10-81%. The remainder of the produced CH₄ is considered to be oxidized in the plowed layer of the paddy soil or leached to the lower layer.

Kumaraswamy *et al.* (1997) observed that in a flooded field planted with rice, rates of methane oxidation followed the order: rhizosphere (collected from roots at 10-20cm depth) > surface soil at (0-1cm) > sub surface soil at 10-20cm depth, diagonally 10-15cm away from the centre of hill. They suggested that

methane-oxidizing activity decreases with increasing depth in flooded soil and also showed that nitrification inhibitors inhibited CH_4 oxidizing activity of flooded rice field samples.

Cai and Mosier (2002) showed that the optimum moisture content of paddy soils for CH_4 oxidation depends on the methanotrophic bacteria in relation to the prevailing water regime. Desiccation damages the CH_4 oxidation ability of permanently flooded paddy soil more severely than that of frequently well drained soils.

2.2.4 Methane fluxes in rice fields

Methane is released from anaerobic wetland soil to the atmosphere through diffusion of dissolved methane, ebullition of gas bubbles and also through plants. Large portions of methane formed in an anaerobic soil may remain trapped in the flooded soil. Entrapped methane may be oxidized to CO_2 when the flood water is drained during the rice growing season (Neue, 1993).

Sebacher *et al.* (1983) showed that diffusion of CH_4 across the flooded soil and overlying water of the rice field to the atmosphere is a function of surface-water concentration of CH_4 , wind speed and CH_4 supply to the surface-water. The gas diffusion rate of CH_4 is very slow in the liquid phase (about 10^4 times slower than diffusion through the gas phase).

In fields planted with wetland rice and not disturbed by cultural practices during the growing season, up to 70% of the methane released to the atmosphere

is emitted through the aerenchyma of the rice plant. During the reproductive phase, more than 90% of the emission is attributed to the rice plant (Schutz *et al.*, 1989a).

Methane escape from the soil in the form of bubbles is a physical process. Ebullition of CH₄ from sediments is a common and significant mechanism accounting for 49-70% of the total flux in natural wetlands. However, in rice fields, CH₄ ebullition is a predominant mechanism only during the initial plant growth stage and during cultural operations (Wassmann and Martius, 1997).

Nouchi *et al.* (1990) suggested that the rice plant does not produce any methane by itself. It only serves as a mechanism of transport of methane dissolved in rizosphere. Rice roots could absorb methane gas in the gas phase without water uptake. They also suggested that methane dissolved in the soil water surrounding the roots diffuses into the cell-wall water of the root cells, gasifies in the root cortex, and then is mostly released through the micro pores in the leaf sheaths which are different from stomata.

Aulakh *et al.* (2000a) suggested that the rice plants had 45-246% greater potential to transport CH₄ than the highest emission rates observed under field conditions. Furthermore, plants would not emit CH₄ at early growth and, to a reduced extent close to ripening. If CH₄ is produced at a high rate during early growth of the rice crop, as often found in fields treated with crop residues or green manure, CH₄ will have to move to the atmosphere through other pathways,

such as molecular diffusion across the water-air interfaces or release of gas bubbles.

Wang *et al.* (1997) observed that methane emission rates via leaves, nodes and panicles are proportional to partial pressures of methane and cross-sections of leaf area, node and panicle numbers. Dissolved methane diffuses and gasifies quickly into the rice roots and a steep gradient of methane concentration exists in medullary cavities. Practically, no methane is present in the xylem sap and methane is not transported by mass flow and is independent of the transpiration rates.

Chanton *et al.* (1997) demonstrated that although CH₄ is transported by rice plants, predominantly via molecular diffusion, a small component was also subject to transpiration-induced flow. They also suggested that diurnal variations in the CH₄ emission rate also linked with transpiration.

2.3 FACTORS AFFECTING METHANE PRODUCTION IN RICE PADDIES

Soil properties, water management, organic amendment and temperature have been reported as the major factors controlling the amount of CH₄ emitted from rice fields (Sass *et al.*, 1991).

Minami (1994) reported that the quantity of CH₄ emitted from a rice field depends upon several important factors including soil factors, nutrient management, water regimes and cultivation practices.

2.3.1 Soil pH

Wang *et al.* (1993a) observed that methane production was significantly decreased by introduction of a small amount of acid. Although a small increase in soil pH slightly inhibited CH₄ production in the first 10 days, production of CH₄ was promoted later. Increase in soil suspension pH more than 0.7 unit by addition of alkali, decreased soil Eh chemically, but inhibited CH₄ production almost completely. They suggested that methane production in reduced soils is very sensitive to pH with an optimum range from 6.7-7.1 that varies with soil type.

In tropical flooded rice soils, where soil temperatures are 25-30°C, methane production in alkaline and calcareous soils may start hours after flooding, in neutral soils it is delayed by two to three weeks, and in acidic soils methane may only be formed five or more weeks after flooding (Neue, 1993).

Bhat and Beri (2002) observed that maximum methane emission occurs between pH 6.4 and 9.0 with peak at pH 7.5. Below pH 3.5 and above pH 9.4 methane emission was drastically reduced. Methane production at pH 9 was more due to the activity of alkaliphilic strains of organism. Low methane production at low pH values may be due to marked sensitivity of methanogens.

Oremland *et al.* (1988) showed that most methanogens preferred to grow at the relatively narrow pH range of 6-8 and optimal pH was around 7, although there also exist a few acidophilic and alkaliphilic methanogen strains.

2.3.2 Soil Redox Potential (Eh)

Soil anaerobiosis, measured in terms of redox potential (Eh) ranging from about -100 to -200mv has been reported to be needed for the initiation of CH₄ production in paddy soils. The critical soil redox potential for initiation of CH₄ production observed in their study was approximately from -150 to -160 mV. At Eh between -230 and -150 mV, the relation between soil Eh and CH₄ production was about neutral or slightly above neutral (6.9-7.1) (Wang *et al.*, 1993a).

Kludze *et al.* (1993) showed that methane production and its emission increased with decrease in soil Eh. CH₄ production increased 10-fold while its emission was enhanced 17-fold when soil Eh dropped from -200 to -300mv. A positive relationship was established between the intensity of soil anaerobiosis and both aerenchyma formation and radial oxygen loss. Root and shoot dry weights and root length decreased with decrease in soil Eh.

Minami (1994) reported that the CH₄ emission begun to increase with the decrease of soil Eh nearly a month after flooding. The period of CH₄ emission from the paddy fields to the atmosphere corresponded closely to the period of low redox potential in the paddy soil. Although, the magnitude of the flux was different among the plots, three peaks of the flux were found in all the plots.

More reduced conditions in the rhizosphere at mid day, as reflected in relatively low redox potential and low root oxidase activity, would be unfavorable for CH₄ oxidizing activity, but favorable for methanogenesis,

eventually leading high CH₄ emission. Conversely, oxidized conditions in the rhizosphere region at night, as reflected in high root oxidase activity, could be congenial for CH₄ oxidation, but not for CH₄ production in the rhizosphere leading to low emission during night (Satpathy *et al.*, 1997).

2.3.3 Soil texture

Wang *et al.* (1993b) suggested that a negative correlation between CH₄ emission and clay content. Higher clay content may promote soil entrapment of CH₄ and consequently reduce net CH₄ emissions. The role of clay in CH₄ production could be due to the protection of organic matter from microbial breakdown by clay particles.

Jackel *et al.* (2001) found that the uptake rate of atmospheric CH₄ increased three fold when the soil was amended with sterile quartz sand. Flooded microcosms with non-amended soil emitted CH₄ into the atmosphere. Atmospheric CH₄ was consumed in soil aggregates of < 6mm size, but soil aggregates of > 6mm size released CH₄ into the atmosphere.

Jain *et al.* (2000) observed that a sandy loam soil with a percolation rate of 20mm day⁻¹ emitted very low CH₄ (between 16 and 40 kg CH₄ m⁻² season⁻¹) even when the rice fields were continuously flooded. While sandy loam soils (the abundant soil type of northern India) are characterized by relatively high percolation, the conditions at the experiment site appear to be rather at the extreme end for irrigated rice.

2.3.4 Temperature

Satpathy *et al.* (1997) observed that atmospheric, soil and water temperatures reached maximum in the early afternoon when CH₄ emission was the highest. A simple regression analysis, however, indicates significant relationship between diurnal pattern of CH₄ emission and atmospheric, soil and water temperatures at tillering stage and water temperatures at maturity stage only.

Wassmann *et al.* (1998) observed a faster development of CH₄ production rates and higher maximum values with increasing temperatures from 25-35⁰C, confirming a temperature response predicable by the Arrhenius equation.

Yamane and Sato (1961) found that CH₄ formation attained maximum at 40⁰C in waterlogged alluvial soils. Above 40⁰C, CH₄ formation decreased and stopped at 60⁰C. The formation was very small below 20⁰C.

Lindau *et al.* (1991) observed that soil temperatures over the 86 days ranged from 22 to 36 ⁰C. Air temperatures collected inside the chambers and 1m above the collection units fluctuated from 25 to 45 ⁰C and from 24 to 36 ⁰C, respectively. Soil and air temperatures recorded between 09:00 and 09:30 in the morning did not show any positive correlation with CH₄ emissions measured over the growing season. Soil and air temperatures declined during the period of maximum CH₄ emissions and the decrease in soil temperatures may be partially due to shading of the soil surface by the maturing rice plants and lower air temperatures.

2.3.5 Diurnal and seasonal variations

Wang *et al.* (1994) reported a strong diurnal pattern of CH₄ emissions from both early and late rice crops. The pattern and its magnitude were quite different for early and late rice, and varied significantly during the growing season. For early rice, the most pronounced peaks were generally found in the early afternoon (1300-1600). A second peak was often found at midnight (0000-0300). For late rice, however, the highest values were consistently found in the night, while the lowest values appeared during mid day.

Neue (1997) observed that methane emissions from flooded rice field typically showed a late-season peak around the time of grain filling. The emission peaks at the end of the season indicated the presence of soil-entrapped CH₄ gas that is released after drainage.

Aulakh *et al.* (2000a) observed that at the seedling stage, methane transport capacity was the lowest with mean values of 8 mg plant⁻¹ d⁻¹. It increased by a factor of about 6 and 8 at the early tillering stage and maximum tillering respectively. Plants at panicle initiation showed maximum methane transport capacity, and further growth to the flowering stage did not change the methane transport capacity.

Lindau *et al.* (1991) observed that after flooding, a 14 d lag period in all N treatments before CH₄ emissions from the soil were detected. Methane fluxes then steadily increased over the next 28 d and reached the first maximum

emission peak at 11 d after panicle differentiation. Over the next 3 weeks, CH₄ fluxes decreased in concentration and reached a minimum plateau region about the same time that the rice plants had reached the 50% heading stage.

Schutz *et al.* (1989) observed the first CH₄ maximum before the tillering stage and the second maximum during the reproductive stages with CH₄ emissions ranging from 1.6 to 3.8 kg ha⁻¹ d⁻¹ from unfertilized rice fields. They also observed a strong diurnal variation in CH₄ efflux during the entire growing season with a maxima in the afternoon (14.00 -19.00) and a minimum in the early morning (06.00 -10.00).

Denier van der Gon *et al.* (2002) found that in a green house experiment, removing spikelets to reduce the plants' capacity to store photosynthetically fixed C in grains increased CH₄ emissions, presumably via extra C inputs to the soil. Unfavorable conditions for spikelet formation in the wet season may similarly explain high methane emissions. The observed relationship between reduced grain filling and CH₄ emission provides opportunities to mitigate CH₄ emissions by optimizing rice productivity.

Wang *et al.* (1999a) reported that the methane concentration in soil solution was a factor limiting methane emission in the course of day time. The diffusion coefficient is temperature dependent and changes significantly during the day. In the morning up to early afternoon, soil temperature was a major factor driving the increase of methane emission rate, while in the afternoon; methane

concentration in soil was the major factor limiting methane emission although soil temperature decreased slowly.

Satpathy *et al.* (1997) observed that under field conditions CH₄ emission was maximum at midday or early afternoon (12.00 -15.00) and minimum at midnight (24.00) at tillering, panicle initiation and maturity stages of the rice crop. Unlike at the seedling stage, the cumulative CH₄ emission over a 24 hr cycle was considerable at other growth stages of the crop.

Wang *et al.* (1997a) observed that concentration gradient of CH₄ in shoots did not change significantly at 2.00 pm and 8.00 pm, suggesting that the methane emission peak at early afternoon is mainly caused by a higher diffusion coefficient (which is temperature dependant) rather than by increasing concentration gradient. Methane was emitted faster in the early afternoon than any other time.

Bhat and Beri (1996) observed that methane emission trend fluctuated during a growing season, the first peak in methane appearing on 33 days after transplanting (DAT) and 2nd peak on 75th DAT. On 33 DAT, methane emission was maximum as compared to other periods of sampling. There was a decrease on 93 DAT with a small increment on 99 DAT.

2.3.6 Inorganic fertilizers

Nutrients essential for plant growth, either naturally occurring or added through fertilizers to paddy soil may effect the production and emission of CH₄

by influencing the growth of the rice plant, the activity of methanogenic microbial communities and the amount and composition of root exudates of growing rice plants (Aulakh *et al.*, 2001).

Economically sound doses of fertilizers may also be beneficial for the greenhouse gas budget because excessive supply of N entails N_2O emission and deficiencies of nutrients such as phosphorus increases root exudation and subsequently CH_4 emissions (Lu *et al.*, 1999).

Straw and green manure provide readily mineralizable carbon sources that enhance the reductive capacity of soils which finally drive CH_4 formation and emission. Substituting organic manures by mineral fertilizers reduced CH_4 emissions but entailed emissions of CO_2 and N_2O during fertilizer production and application, respectively (Wassmann *et al.*, 2000a).

Wang *et al.* (1995) suggested that addition of urea in most acidic soils enhanced CH_4 production, but in all nonacidic and alkaline soils, CH_4 production was inhibited probably because of an increase in soil pH by urea.

Lindau *et al.* (1991) observed that over the first crop-growing season approximately 210, 300, 310 and 370 kg $\text{CH}_4 \text{ ha}^{-1}$ was released to the atmosphere after application of 0, 100, 200 and 300 kg urea-N ha^{-1} , respectively. CH_4 emissions from rice field increased as the application of urea- N was increased, due to the hydrolysis of urea releases NH_4 , which in turn, stimulates CH_4 emission.

Bhat and Beri (1996) observed that urea-N significantly increased methane emission and application of 8t wheat straw ha^{-1} with 120kg N maximized methane emission to $57.3 \text{ mg m}^{-2} \text{ h}^{-1}$. The addition of wheat straw raised the mean value of methane by $34.8 \pm 3 \text{ mg m}^{-2} \text{ h}^{-1}$ over $22.5 \pm 3 \text{ mg m}^{-2} \text{ h}^{-1}$ of fertilizer N treatments.

Fluxes of CH_4 from the $(\text{NH}_4)_2\text{SO}_4$ and K_2NO_3 plots were much lower and did not exceed 9 and 18 $\text{g ha}^{-1} \text{ d}^{-1}$ respectively, over the 21-d sampling period. The type of fertilizer N and presence of rice plants affect the evolution of CH_4 from a flooded rice soil to the atmosphere (Lindau *et al.*, 1990).

Cai *et al.* (1997) showed that CH_4 emission decreased by 42 and 60% in the ammonium sulphate treatments and 7 and 14% in the urea treatments when applied at rates of 100 and 300 kg N ha^{-1} , respectively. The mean CH_4 flux decreased with the increase in N application rate and ammonium sulphate was more effective in depressing CH_4 than urea at the same application rate.

Lu *et al.* (2000) observed that the root zone dissolved organic carbon that is enriched by plant-borne C appears to be a main source for CH_4 production and the low dissolved organic carbon concentration with NO_3^- -N application are accountable for the low CH_4 emissions.

Mosier *et al.* (1991) demonstrated that the existence of NH_4 can stimulate CH_4 emission from rice paddy fields due to the competition of NH_4^+ for the oxidation with CH_4 by methanotrophs, while SO_4^{2-} acts as a proton acceptor

under strong anaerobic conditions, which in turn, depresses CH_4 production. CH_4 emission was reduced by the addition of fertilizers and was negatively correlated with pore water NH_4^+ concentration, probably as the consequence of elevated CH_4 oxidation due to fertilization. CH_4 oxidation as well as numbers of methanotrops was distinctly stimulated by the presence of rice plant (Bodelier *et al.*, 2000).

Adhya *et al.* (1997) observed increase in CH_4 production with the application of nonsulphate K-fertilizer such as KCl and K_2HPO_4 . The supply of K through fertilizer such as K_2SO_4 was found to reduce CH_4 emission from soil.

Huang *et al.* (2002) observed that the seasonal average of CH_4 emission was positively dependent on soil sand content and negatively on total N as well as $\text{NH}_4\text{-N}$ determined before rice transplanting. Copper content of soils had a significant negative impact on CH_4 emission.

Banik *et al.* (1996) evaluated the effect of different micronutrients on CH_4 production in a rice soil and found that Mo, Ni and B had more prominent effects than Zn, Fe and Co.

Jackel and Schnell (2000) found that methane emission was reduced after fertilization of the soil with ferric iron oxide-ferrihydrite. The total methane emission during the vegetation period of rice was reduced by 43% and 84%, with the addition of 15 and 30g of ferrihydrite per kg of soil, respectively.

2.3.7 Organic manures and crop residues

Easily degradable crop residues, fallow weeds, and soil organic matter are the major sources for initial methane production. At later growth stages of rice, root exudates, decaying roots and aquatic biomass were seem to be more important (Neue, 1993).

Setyanto *et al.* (2000) observed that in the wet season, FYM was completely decomposed before CH₄ emission was initiated; rice straw resulted in 40% increase in emission rates during this cropping season. In the dry season, intensive flooding in the early stage promoted high emissions from organically fertilized plots; seasonal emissions of CH₄ from FYM and rice straw increased by 72% and 37% respectively.

Chareonsilp *et al.* (2000) observed that the seasonal CH₄ emissions were highest for rice straw incorporation (619 kg ha⁻¹), moderately high for zero tillage (127 kg ha⁻¹), and low for burned straw (69 kg ha⁻¹). Mulching of straw and in zero-tillage fields slightly enhanced CH₄ emission as compared with burned straw application but significantly reduced emissions as compared with fresh straw incorporation.

Barman *et al.* (2000) reported that maximum methane emission was recorded following application of 50% NPK + 50% N through farmyard manure. Significantly higher methane emission was observed with the incorporation of organic manures than that of the control and chemical fertilizers alone.

Inubushi *et al.* (1992) reported that rice straw application at 1 and 2 months before transplanting, compared with application just before transplanting, reduced CH₄ emissions by 50% and 63% respectively.

Jain *et al.* (2000) observed that combined application of cattle manure and wheat straw (equivalent to 60kg N ha⁻¹) in conjunction with urea (60kg N ha⁻¹) enhanced CH₄ emission by 12-20% as compared to the fields treated with 120kg urea-N ha⁻¹.

Hou *et al.* (2000) observed that application of pig, chicken and cattle manures had different promoting effects, with pig manure increasing the CH₄ production rate, followed by chicken and cattle manure. Organic fertilizers including rice straw and organic manure substantially increased CH₄ production potential in flooded rice soil showing that organic matter applied in rice cropping systems makes a big contribution to CH₄ emission from rice fields.

Yagi and Minami (1990) reported that annual CH₄ emission rates from plots receiving 6 t/ha of rice straw in addition to mineral fertilizer increased approximately 2 to 3 fold as compared with the mineral fertilizer plots. Compost had only slightly increased emission compared with control plots. The stimulation of CH₄ production by organic sources under flooded conditions generally followed the order: Green manure > cellulose > rice straw > blue green algae compost > Azolla compost > farm yard manure > unamended control. Composted organic sources were less effective than the fresh organic sources in stimulating the production of CH₄ in alluvial soils (Sethunathan *et al.*, 2000).

Corton *et al.* (2000) reported that the application of rice straw compost did not reduce CH₄ emissions but rather increased it by 23-30%. But this is very small compared with the increase of 162-250% in emissions due to the fresh rice straw application. Also, the use of chicken manure did not enhance CH₄ emissions. Rice straw compost and chicken manure, which have narrow C/N ratio, had little effect on CH₄ emission.

2.3.8 Water management

Water management of rice fields is crucial for CH₄ emission because the development of an anaerobic environment in soils results from limitation of O₂ supply from the atmosphere by flooding the soils. The flooding period in rice fields vary in different regions. Even among irrigated practices, there could be continuous flooding, intermittent drainage or short term drainage at one or the other growth stages (Aulakh *et al.*, 2001).

Jain *et al.* (2000) observed that the mean CH₄ emission rate during the 4 yr of experimentation amounted to 18.33 and 25.57 kg ha⁻¹ under intermittent and continuous flooding, respectively, corresponding to a net decrease of 28% in CH₄ emission by applying intermittent irrigation over continuous flooding. This reduction was accomplished at the expense of slightly lower (3.2%) grain yields.

Wang *et al.* (2000) reported that the local irrigation practice of drying at midseason reduced CH₄ emission rates by 23%, as compared with continuous flooding. Further reduction of CH₄ emissions could be attained by alternate

flooding/drying, shifting the drying period to an earlier stage, or splitting drying into two phases.

Minami (1994) reported CH₄ emission rates of 2.6, 1.4 and 0.1 mg CH₄ m⁻² hr⁻¹ with water percolation rates of 0, 5 and 20 mm day⁻¹, respectively. Leached CH₄ would be expected to get oxidized in the subsoil and / or the ground water.

Sethunathan *et al.* (2000) observed that the field plots with deep submergence of around 30 cm emitted distinctly more CH₄ than did the plots with continuous water depth of 3-6 cm. In another incubation study, CH₄ production in flooded soil samples increased with a progressive increase in standing water column from 5 mm to 20 mm.

Wassmann *et al.* (2000b) reported that field drying at mid tillering reduced CH₄ emissions by 15-80% as compared with continuous flooding, without a significant effect on grain yield. The net impact of midtillering drainage was diminished when rainfall was strong during the drainage period and emissions were suppressed by very low levels of organic substrate in the soil.

Wang *et al.* (1999b) reported that intermittent irrigation (a few days of no standing water between two irrigations) and constant saturated moisture conditions (fields had no standing water but remain saturated) reduced CH₄ emission by 25 and 58%, respectively compared with continuous flooding. Mid season drainage, intermittent irrigation or preharvest field drying could be

effective in reducing CH₄ fluxes if the field becomes dry and these management practices appear to be useful no-regret options for reducing CH₄ emissions without reducing rice yields (Mishra *et al.*, 1997).

Lu *et al.* (2000) reported that drainage was a major modifier of seasonal CH₄ emission pattern. The local practice of mid season drainage reduced CH₄ emission by 44% as compared with continuous flooding. CH₄ emissions could further be reduced by intermittent irrigation, yielding a 30% reduction as compared with mid season drainage.

2.3.9 Cultural practices

Xu *et al.* (2000) observed that compared with the management of flooded fallow in the winter crop season, planting winter wheat or dry fallow could result in significantly reduced CH₄ emissions during the following flooded and rice-growing period.

Ying *et al.* (2000) showed that when the flood water had been inoculated with *Azolla* for 5 consecutive years, CH₄ emission was 70% higher than the control. The observed increase in CH₄ emission in the presence of *Azolla* could be explained by soil conditions promoting CH₄ availability and CH₄ diffusion into the overlying water and by the fact that *Azolla* served as an additional pathway for CH₄ transport into the atmosphere.

Ko and Kang (2000) showed that transplanting 30 days old seedlings, direct seeding on wet soil and direct seeding on dry soil reduced CH₄ emission

by 5%, 13%, 37% respectively, when compared with transplanting 8 days old seedlings. Among the cultural practices tested, direct seeding on dry soil was the most effective in reducing CH₄ emission.

Hanaki *et al.* (2002) reported that no-tillage cultivation suppressed methane emission from paddy soil with a low concentration of electron accepters and slightly increased methane emission from paddy soil with a high concentration of electron accepters, as compared to emissions under tilled cultivation, with rice straw application.

Wang *et al.* (1999b) observed that methane fluxes from a directly seeded rice field were 75% lower than from a transplanted rice field despite the fact that both dry-seeded and transplanted rice fields were initially flooded at the same time. Under actual conditions, large portions of the soil trapped methane escape to the atmosphere through ebullition caused by such cultural practices as wet tillage, puddling, harrowing, transplanting, fertilization, weeding, pest management and harvest (Neue, 1993)

2.3.10 Rice cultivars

Wang and Adachi (2000) observed that methanotrophic bacterial population differed significantly in roots among rice cultivars at ripening. They suggested that rice cultivars with few unproductive tillers, higher harvest index, smaller root system and higher oxidative capacity are ideal for mitigating CH₄ emissions in rice fields.

Wassmann *et al.* (2000c) observed that IR 72 consistently gave the highest seasonal emission. Their results indicated a 33% higher CH₄ emission potential for the semi dwarf cultivar (IR 72) than the tall cultivars.

Verma *et al.* (2003) reported that seasonal variation was mainly linked to plant activities, while the diurnal variation was the function of sediment temperature. A higher CH₄ efflux from the IR 64 grown in the plastic tub was the result of high water regime, which favoured methanogenesis.

Aulakh *et al.* (2000b) reported that new plant type cultivars that had the minimum number of tillers, a high proportion of productive tillers, large panicles on each tiller and strong stems exhibited low methane transport capacity seems to be an economically feasible, environmentally sound and promising approach to mitigate CH₄ emission from rice fields.

Ding *et al.* (1999) found that seasonal methane emission has a positive linear correlation with post heading rice plant height. It is suggested that plant height may be a good criteria in choosing cultivars for mitigation of methane emission.

2.4 MITIGATION OPTIONS

Cai *et al.* (1997) suggested that intermittent irrigation of rice paddies significantly depressed CH₄ emission and (NH₄)₂SO₄ was more effective in depressing CH₄ than the urea at the same application rate. It is important to evaluate the integrative effects of water management and fertilizer application

for mitigating greenhouse gas emissions in order to attenuate the greenhouse effect contributed by rice paddy fields.

There are some possible mitigation options to reduce CH₄ emission from rice fields including water management, cultivar selection and breeding, cultivation practices and soil amendments. Intermittent irrigation of rice paddies, which causes anaerobic cycling, is considered to be one of the options for reducing CH₄ emission (Wassmann *et al.*, 1993).

Patrick and Delaune (1977) showed that potassium nitrate addition has resulted into less methanogenesis in comparison to other fertilizers. Thermodynamically, nitrate present in a system will be reduced first, and Eh would be much higher than critical Eh (-150mv) required for methane production and its production would be slowed.

Lindau *et al.* (1994) observed that the low and high rate of CaSO₄ treatments reduced CH₄ evolution by 29 and 46% respectively, compared with control plot CH₄ emissions. Inhibiting of CH₄ evolution may have been caused by SO₄²⁻, inducing elevated soil redox potentials, sulphate reducing bacteria out-competing methanogenic bacteria. Denier van der Gon and Neue (1994) also observed that a 50-72% reduction in CH₄ emission was reported for wetland rice fields amended with gypsum, most likely caused by competition between methanogenic and sulphate-reducing bacteria.

Watanabe *et al.* (1995) reported that following temporary interruption of irrigation at the flowering stage, CH₄ emission rates decreased drastically and

remained at very low levels until the harvesting stage, indicating its great effectiveness for the suppression of CH₄ emission. However, to prevent a decrease in the grain yield, the interruption of irrigation at the booting stage should be avoided and the period of interruption at the flowering stage should be shorter.

Wang *et al.* (1993) suggested that a small decrease in pH resulting from the introduction of acidic materials significantly decreased CH₄ production. Modified agricultural practice that can slightly decrease soil pH might be a promising way to control CH₄ production and its emission.

Denier van der Gon and Neue (1995b) showed that the addition of salt (mainly NaCl) to a rice field, increased water EC to approximately 4 dSm⁻¹ and reduced CH₄ emissions by about 25%. The reduction in CH₄ emission is much smaller than the reduction in total CH₄ production, showing that CH₄ emission is not necessarily proportional to CH₄ production. Reduced CH₄ production has a limited impact only on CH₄ emission because CH₄ oxidation is even stronger than reduction.

In baseline practice with high organic amendments, use of compost (58-63%), and biogas residues (10-16%) and direct wet seeding (16-22%) should be considered as mitigation options. Using prilled urea as sole N source, use of ammonium sulphate could reduce CH₄ emission by 10-67%. CH₄ emissions can be reduced by fallow incorporation (11%) and mulching (11%) of rice straw as well as addition of phosphogypsum (9-73%) (Wassmann *et al.*, 2000a).

Methane mitigation options used in rice fields must both reduce CH₄ emission and sustain rice production. Water control is one of the most important factors in rice production. Midseason drainage and alternative flooding management reduced CH₄ emissions by 23-59% while yield increased by 16% (Wang *et al.*, 2000).

Corton *et al.* (2000) suggested that combined with a package of technologies, CH₄ emission can best be reduced by the practice of midseason drainage instead of continuous flooding. The use of sulphate-containing fertilizers, direct seeding crop establishment and use of low C/N organic fertilizers such as chicken manure and rice straw compost are the other mitigation options.

Furukawa and Inubushi (2004) reported that methane emission from the low-iron paddy soil could be suppressed over four cropping seasons without loss of grain yield by single application of revolving furnace slag. The inhibitory effect rose year by year.

Setyanto *et al.* (2000) showed that in irrigated rice, deep placement of urea tablets decreased CH₄ emission rates by 39% in wet season and 10% in dry season as compared with broadcasting of prilled urea. In rainfed rice, however, tablet urea caused an increase of 21% and 16% in wet season and dry season, respectively.

Adhya *et al.* (2000) reported that application of Azolla resulted in a lower CH₄ flux per ton of grain yield. CH₄ emission was reduced by 15% when

intermittent irrigation was practiced during the dry season and nitrification inhibitor DCD distinctly inhibited CH₄ fluxes.

Direct seeding on dry soil was most effective in reducing CH₄ emission. As to plowing time, CH₄ emission following fall plowing were 26% less than those following spring plowing. In addition, fall plowing promoted early crop growth because the readily mineralizable nutrients in the soil increased as the organic matter decomposed during winter (Ko and Kang, 2000).

Rath *et al.* (2002) observed that in ammonium thiosulphate applied rice field plots, mean methane efflux decreased by about 38 and 60% at 45.6 and 60kg N/ha, respectively over that of control. Inhibition of CH₄ production by ammonium thiosulphate is, at least in part, due to the stimulation of sulphate reducing bacteria.

Xu *et al.* (2002) observed that application of hydroquinone (a urease inhibitor) + dicyandiamide (a nitrification inhibitor) together with urea seemed to improve the rice growth and to reduce CH₄ emission.

Sethunathan *et al.* (2000) observed that application of carbamate Insecticide, carbofuran, at 2kg ha⁻¹ to rice field retarded CH₄ emission through enhanced CH₄ oxidation.

Rath *et al.* (1999) reported that sub surface application of urea super granules was effective in reducing the methane flux over that of the control.

Methane emission was lowest in plots treated with the mixture of prilled urea and Nimin (a nitrification inhibitor).

Zero tillage in conjunction with straw mulching has been found as a feasible mitigation practice. This technique is associated with low CH₄ emission rates and had very little effect on rice yield (Aulakh *et al.*, 2001).

Goto *et al.* (2004) showed that the combination of intermittent irrigation during the rice cultivation period and application of a decompositional accelerator with nitrogen fertilizer after the harvest of rice decreased methane emission, as compared with the case of leaving rice straw on the soil surface during the winter and continuous irrigation during the rice cultivation period.

Mohanty *et al.* (2001) observed that application of a commercial formulation of the herbicide butachlor at 1kg ha⁻¹ to an alluvial soil planted with direct seeded flooded rice, significantly inhibited both crop mediated emission and ebullition fluxes of CH₄.

2.5 RICE YIELD AND NUTRIENT UPTAKE

Sarwar and Khanif (2005) showed that yields and yield components and nutrient concentration were not affected by different water levels. It is highly possible to produce rice under low water input, which is capable of saving between 25-30% of water without any affect on grain yield and nutrient concentration.

Horie *et al.* (2005) observed that the practice of applying a large amount of compost and intermittent irrigation increased roots in deeper soil layers, maintain their activities and presumably promote grain yield and N uptake at later stages. Remarkable progress has been made in improved N management, agronomic efficiency of N increased from about 15 kg kg⁻¹ for a single dose at transplanting to 40 kg kg⁻¹ for banded controlled release fertilizer.

Tuong *et al.* (2003) reported that water-saving irrigation, such as saturated-soil culture and alternate wetting and drying, can drastically cut down the unproductive water outflows and increase water productivity. Through the adoption of water-saving irrigation technologies, some can be perceived as positive, e.g. water conservation and decreased methane emission, and some others are perceived as negative, e. g. release of nitrous oxide from the soil and decline in soil organic matter.

Singh *et al.* (2004) observed that grain yield differences of hybrid rice PAC 831 between continuous submergence and cyclic submergence were not significant; showing that continuous submergence for the crop growth period is not beneficial, except in very light-textured soils and under conditions of high evaporative demands. The highest grain yield was recorded when total N (150 kg ha⁻¹) through urea super granules (UGS) was placed at the root zone, 10 days after transplanting. Application of prilled urea in three splits (50% basal + 25% at tillering + 25% at booting) was at par with the USG treatment.

Bhuiyan (1992) reported that there was 40% saving in water without yield loss by replacing shallow regimes with a saturated soil regime. Water can be applied just when fine cracks appear, which saves large amount of water. Under high weed pressure, shallow flooding (2.5cm) during the first 45 days after transplanting, followed by maintenance of a saturated regime for the rest of the season, resulted in similar yields but a 30% saving in water, over the flooded regime.

Behera and Ram (2004) revealed that highest rice production of 4.6 and 4.7 t ha⁻¹ for grain and straw respectively was obtained in the treatment NPK + FYM. It was significantly superior to optimal NPK fertilizer (100% NPK). Incorporation of FYM @ 15 t ha⁻¹ year⁻¹ along with optimal NPK led to significant increase of 20.0, 9.7 and 19.7 kg ha⁻¹ in the uptake of N, P and K respectively over optimal NPK alone. Highest nutrient uptake in FYM treatment may be due to its contribution to soil available nutrient pool resulting in high rice yield as well as the enhanced nutrient concentration in plants.

Pandey *et al.* (2000) reported that the application of N up to 120 kg ha⁻¹ significantly increased the grain yield, panicles m⁻², grains panicle⁻¹ and nitrogen uptake. The test weight also increased with increasing levels of N up to 80 kg ha⁻¹. This indicated that N application increased N supply to plant, increased concentration and above ground biomass and finally the uptake. The N use efficiency decreased with increased levels of N.

Patra (2000) reported that water regimes and soil types, combinedly influenced P and Fe nutrition of rice during vegetative as well as ripening stages. Rice plants grown on Alfisols showed significantly higher P intake in shoots and straw than Ultisols. Drying and flooding of soil at any stage, adversely affected P nutrition of rice in Alfisols. Iron in rice plant, was higher in Ultisols because of higher active iron content. Soil drying decreased iron content of straw in all soils. While soil drying and reflooding significantly increased grain yield in Tropudult. This increase in grain yield was related to the decrease in water soluble Fe^{+2} as a result of soil drying.

Rammohan *et al.* (2000) observed that the number of grains panicle⁻¹ and test weight increased with increase in N levels and was maximum in 150 kg N ha⁻¹. This may be due to lower spike let sterility and higher dry matter production. The mean grain and straw yields were higher by 202 and 126%, respectively at 150 kg N ha⁻¹ over control. The increased yield is attributed to the production of higher number of productive tillers hill⁻¹, grains panicle⁻¹ and test weight.

The replacement of urea-N to the extent of 25 and 50% through FYM and vermicompost respectively did not result in significant reduction in nitrogen uptake. Maximum P uptake was observed with the application of 25:75 proportions of FYM and straight fertilizer while significant increase in K uptake was observed in the treatment of 25:75 proportions of FYM and straight fertilizer (Jadhav *et al.*, 1997).

Kumar *et al.* (2004) reported that the grain, straw and total dry matter yields of rice were highest with application of any of the manures and N at 120kg ha^{-1} , regardless of the P and K applications. K content in straw was higher in treatments receiving one of the organic manures with K at 60 kg ha^{-1} compared to other treatments. K uptake was higher in treatments receiving 120 kg ha^{-1} with one of the manures compared to other treatments.

Patil and Meisheri (2003) observed that the Zn uptake by straw and grain and its content in the soil increased when Zn was applied. The increases were significantly higher when Zn was combined with FYM. Application of Zn forms with and without FYM resulted in significant increases in grain and straw yields of subsequent rice crop. The Zn uptake and available Zn in the soil increased significantly when Zn was applied for the first crop.

Powar (2004) reported that N uptake was highest with vermicompost + NPK. Among the organic manures, significantly highest available N and P in rice was observed with Gliricidia + NPK treatment, while significantly highest available K was observed with vermicompost + NPK treatment.

Sudha and Chandini (2002) reported that the highest NPK rate was superior in increasing N, P and K uptake and grain and straw yields. They suggested that NPK up to $105:52.5:52.5\text{ kg ha}^{-1}$ and S up to 25 kg ha^{-1} , along with organic manures either as 10 t FYM or $5\text{ t vermicompost ha}^{-1}$, were effective in the improvement of the grain yield of rice.

Lal *et al.* (2000) reported that the maximum grain yield (33.35 q ha^{-1}) and P uptake (10.06 kg ha^{-1}) were observed with the combined application of $33 \text{ kg P ha}^{-1} + 12 \text{ kg Zn ha}^{-1}$. Available P in soil samples after harvest increased considerably with increasing rates of P and Zn application.

Reddy and Reddy (2003) Observed that N,P and K were the highest with the application of 100% recommended dose of N applied as N fertilizer and lowest with the application of 100% FYM.

Jadhav and Dahiphale (2005) conducted an experiment to evaluate the effects of irrigation (0.8, 1.2 and 1.6 IW/CPE) and N application ($40, 80$ and 120 kg ha^{-1}) on the yield and uptake of basmati rice in Vertisols. Grain yield was highest when the crop was irrigated at 1.6 IW/CPE (22.61 q ha^{-1}) and treated with N at 120 kg ha^{-1} (22.96 q ha^{-1}). N uptake in both grain and straw also increased with increasing IW/CPE ratios and N fertilizer levels.

Bhat *et al.* (2005) observed that a significant increase in the uptake of N, P and K by grain due to the combined application of blue green algae (BGA), FYM and NPK. Available P and K in the soil showed an increasing trend. The highest yield (48.15 q ha^{-1}) was observed with the 100% recommended dose of NPK in combination with FYM and BGA.

Arivazhagan and Ravichandran (2005) reported that the nutrient uptake in grain and straw increased with the increase in the level of N and K. Basal skipping of K_2O resulted in highest grain and straw yields.

Satyanarayana et al. (2002) showed that application of FYM at 10 t ha^{-1} increased grain yield of rice by 25% compared to the no FYM control. The highest grain yield of rice was obtained with the application of FYM at 10 t ha^{-1} and inorganic fertilizer at $120:60:45 \text{ kg N: P}_2\text{O}_5:\text{K}_2\text{O ha}^{-1}$. The increased grain yield was due mainly to increased nutrient uptake and number of tillers, filled grains per panicle and 1000- grain weight.

Parihar (2004) reported that irrigation schedule had a significant effect and it was found that 1 day drying period after disappearance of $7 + \text{ or } - 2 \text{ cm}$ ponded water recorded higher yield but comparable to 3 days drying period. However, 5 days drying period resulted in significantly lower yield than one and three days.

Raj *et al.* (2002) observed that the Zn contents of grain and straw were highest at 30 ppm Zn, whereas the P contents of grain and straw were highest at 0 ppm Zn. Among the P rates, 20 ppm resulted in the highest grain and straw yields as well N, P, K and Zn contents in both grain and straw.

CHAPTER III

MATERIALS AND METHODS

In this chapter, the details of material used and methodologies adopted during the course of present investigation are elucidated under appropriate heads.

3.1 LOCATION

The experiment entitled “Influence of management practices on the methane emission in rice field” was conducted during *rabi* season of 2005-2006 at the Directorate of Rice Research, Rajendranagar, Hyderabad. The geographical location of the experimental field is 17° 19' North latitude and 78° 23' East longitudes with an altitude of 542.6m above mean sea level.

3.2 CHARACTERS OF THE EXPERIMENTAL FIELD

3.2.1 Physical and chemical properties

Soil samples were drawn at random from 0-30 cm soil depth in the experimental field and analyzed for their physical and chemical soil properties by adopting standard procedures. The results are summarized in Table 1.

Table 1: Physical, Physico-chemical and Chemical soil properties of the experimental field

S. No.	Soil property	Value	Method adopted
1	Physical properties		
	Mechanical analysis		Bouyoucos Hydrometer Method (Piper, 1966)
	Sand (%)	29	
	Silt (%)	18	
	Clay (%)	53	
	Textural Class	Clay	
2	Physico-chemical properties		
	Soil reaction (pH) (1:2.5 Soil : Water)	8.18	Glass electrode pH meter (Jackson, 1967)
	Electrical Conductivity (dSm ⁻¹) (1:2.5 Soil : Water)	0.69	Conductivity bridge method (Jackson, 1967)
2	Chemical properties		
	Organic Carbon (%)	0.90	Walkley and Black's Modified method (Jackson, 1967)
	Available Nitrogen (kg ha ⁻¹)	252.00	Alkaline permanganate method (Subbaiah and Asija, 1956)
	Available P ₂ O ₅ (kg ha ⁻¹)	133.10	Olsen's method using colorimeter (Olsen et al., 1954)
	Available K ₂ O (kg ha ⁻¹)	654.00	Neutral normal ammonium acetate method using Flame Photometer (Jackson, 1967)
	Micronutrients (DTPA extractable)		DTPA method (Lindsay and Norvell, 1978)
	Zn (ppm)	9.87	
	Fe (ppm)	41.87	

A perusal of data in Table 1 reveals that the soil is clay in texture, slightly alkaline in reaction, low in available nitrogen, high in available phosphorus and potassium and deficient in Zinc.

3. 3 CROPPING HISTORY OF THE EXPERIMENTAL PLOT

Year	Kharif	Rabi
2002 -03	Paddy	Paddy
2003 -04	Paddy	Paddy
2004 -05	Paddy	Paddy
2005 -06	Present investigation	

3. 4 WEATHER CONDITIONS DURING THE CROP PERIOD

To characterize the weather during the crop growing season, weekly weather data was recorded from the meteorological observatory located at Agricultural Research Institute, Rajendranagar which is presented in Appendix I and illustrated in Fig. 1.

During the crop growth period of rice, a total amount of 167.9mm of rainfall was received in 8 rainy days. The weekly mean maximum temperature during the crop period ranged from 27.2 to 40.0⁰C with an average of 33.1⁰C. The decennial mean maximum temperature of the corresponding period was 35.0⁰C. The weekly mean minimum temperature ranged from 10.6 to 26.7⁰C with an average of 19.2⁰C. The decennial mean minimum temperature for the corresponding period was 19.5⁰C. The weekly

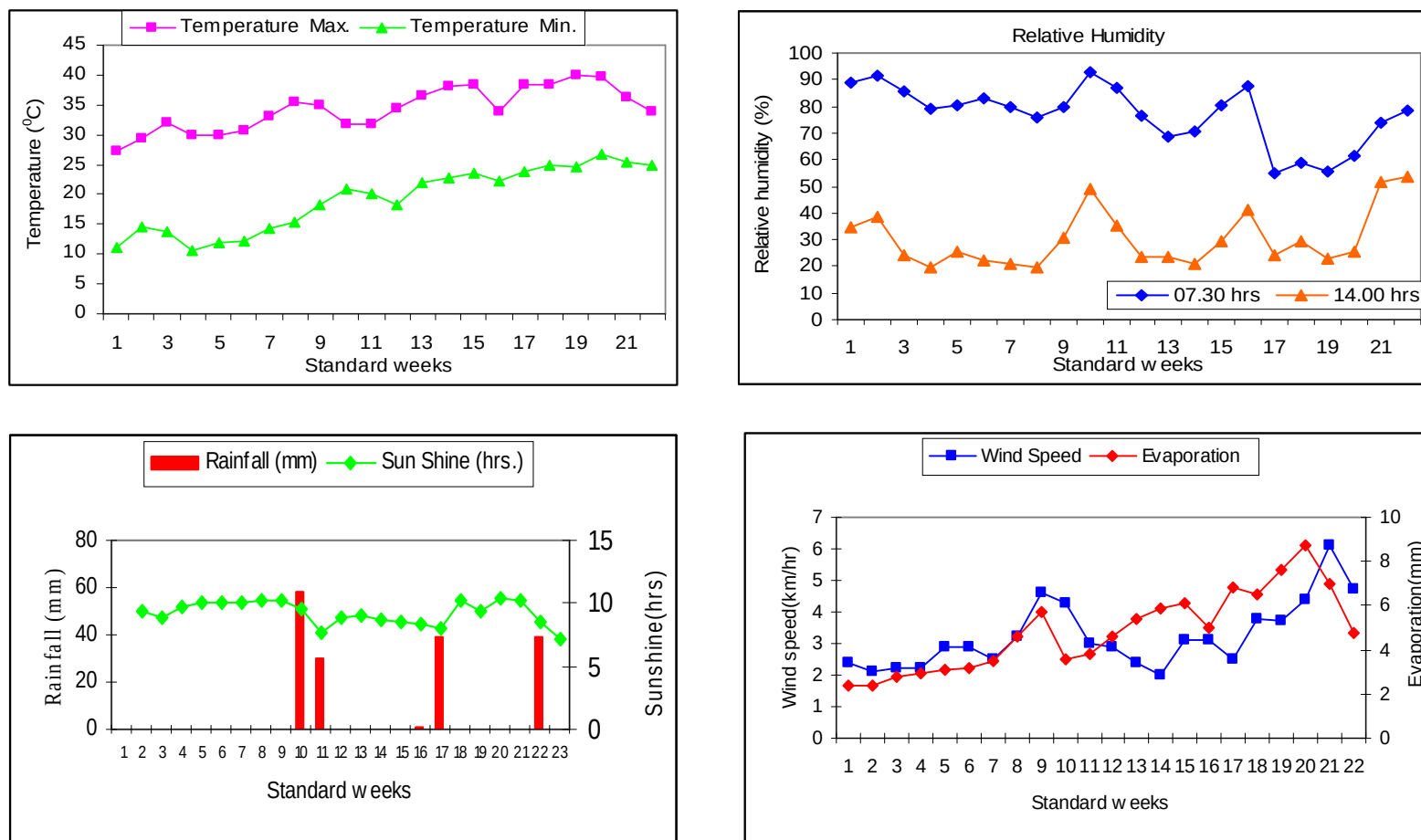


Fig. 1: Weekly mean meteorological data during crop growth period

at 7.30 hrs during the crop period ranged from 54.9 to 92.7 per cent with an average of 76.8 per cent and the decennial relative humidity for the corresponding period ranged from 59.0 to 85.0 with an average of 72.0 per cent.

The weekly mean bright sunshine hours day^{-1} during the crop period ranged from 7.1 to 10.4 hours day^{-1} with an average of 9.2 hours day^{-1} . The decennial average for the corresponding period ranged from 8.6 to 9.5 hours day^{-1} with an average of 9.1 hours day^{-1} . The evaporation (USWB Class A open pan evaporimeter) ranged from 2.4 to 9.7 mm day^{-1} with an average of 4.8 mm day^{-1} . The decennial mean for the corresponding period ranged from 3.5 to 8.7 mm day^{-1} with an average of 6.2 mm day^{-1} .

3.5 EXPERIMENTAL DETAILS

The present experiment was laid out in a split plot design, replicated thrice with 15 treatments (Fig 2).

Details of treatments

Main plots: Water management practices (3)

M_1 : Continuous flooding

M_2 : IW / CPE = 1.0

M_3 : IW / CPE = 0.75

Sub plots: Fertilizer levels (5)

S_1 : Control

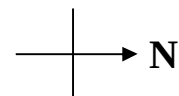
S_2 : RFD (N 120: P_2O_5 60: K_2O 60+ $ZnSO_4$ 40 kg/ha)

S_3 : RFD + 50% more N *

S_4 : Organic fertilizer alone (quantity to match S_2)

S_5 : 50% RFD with 50% organic manure ($\sim S_2$)

* From Table 4 – 11, S_3 was not included because methane flux measurements were taken from S_1 , S_2 , S_4 and S_5 sub plots only.



RI	M_2S_1	M_3S_4	M_1S_2
	M_2S_4	M_3S_1	M_1S_5
	M_2S_2	M_3S_5	M_1S_3
	M_2S_3	M_3S_2	M_1S_1
	M_2S_5	M_3S_3	M_1S_4

RII	M_2S_3	M_3S_4	M_1S_5
	M_2S_4	M_3S_2	M_1S_1
	M_2S_5	M_3S_5	M_1S_2
	M_2S_1	M_3S_3	M_1S_4
	M_2S_2	M_3S_1	M_1S_3

RIII	M_2S_3	M_3S_2	M_1S_1
	M_2S_5	M_3S_1	M_1S_4
	M_2S_4	M_3S_5	M_1S_2
	M_2S_1	M_3S_4	M_1S_5
	M_2S_2	M_3S_3	M_1S_3

Gross plot: 5.0 x 3.2 m
Net plot : 4.5 x 2.7 m

Fig. 2: Layout plan of experiment



Plate 1 : General view of experimental field

3. 6 CULTIVATION DETAILS

The main field, after thorough puddling and levelling, was divided into replication blocks each having three sub blocks for allotting randomly the main plot treatments (water regimes) viz., continuous flooding, IW / CPE = 1.0 and IW / CPE = 0.75. Each main plot was further divided into 5 sub plots of 5m x 3.2m area (as shown in the layout) for allotting randomly the sub plot treatments (fertilizer levels) viz., control, RFD, RFD + 50% more N, 50% RFD + 50% organic manure and organic manure alone.

RFD used for the experiment were 60kg P_2O_5 ha⁻¹ applied at the time of planting, 60kg K_2O ha⁻¹ applied half at planting and the rest at PI stage, 120kg N ha⁻¹ applied in 3 splits doses of 1/3:1/3:1/3 each at basal, early tillering and PI stage supplied through single super phosphate (SSP), muriate of potash (MOP) and urea respectively. 40kg $ZnSO_4$ ha⁻¹ applied at the time of planting. The level of organic manure used for the experiment was 8.25 t ha⁻¹ of vermicompost.

Rice variety, IR 64 was used as the check variety for this experiment. Four weeks old healthy seedlings were transplanted in the plots with two plants per hill at a spacing of 15 cm x 15 cm.

Irrigation was given according to the main plot treatments. For the main plot of continuous flooding, irrigation was given to maintain water level between 5 – 10 cm during the entire period of crop growth. For alternate flooding



Plate 2: V-notch weir for measuring irrigation water

treatments of $IW / CPE = 1.0$ and $IW / CPE = 0.75$, water requirement ($CPE - RF$) was measured by using V- notch weir (Plate-2).

Plant protection measures were taken against pest and disease incidence by spraying agrochemicals as and when required. Weed control for all the plots was done manually.

3 . 7 METHANE SAMPLE COLLECTIONS AND ANALYSIS

Methane gas collection was carried out by manual sampling which was done by using the closed chamber technique as described by Hutchinson and Mosier (1981). For measuring methane emission, six hills of rice plants were covered with a locally fabricated acrylic (Perspex) box of 53 cm length, 33 cm width and 71cm height (Plate-3). The air inside the chamber was mixed by 2 battery operated small fans. The acrylic chambers were placed over the aluminum jackets preinserted into the soil to a depth of 5 cm in each plot. The water seal surrounding the acrylic chamber in a channel made the system airtight. Gas samples were drawn at fixed intervals of 0, 15 and 30 minutes through a three-way stopcock after installation of chamber using an air tight syringe (capacity 50 ml). The temperature of inside and outside the chamber was recorded at the time of sampling. Soil and water temperatures were measured by using the digital thermometer, giving temperature values in $^{\circ}C$. Soil temperature was measured at a depth of 10 cm.



Plate 3: Fabricated acrylic box for collecting methane samples

For diurnal variation of CH₄ emission, flux measurements were taken at 2hr intervals over a 10 hr period (7.00 am – 5.00 pm) at the tillering (12 DAT) stage of the crop from the field. For treatment-wise CH₄ emission, flux measurements were taken at tillering (29 - 32 DAT), panicle initiation (48 – 51 DAT), flowering (69 – 72 DAT) and maturity (88 – 91 DAT) stage of the crop from each treatment before and after irrigation.

Methane concentrations in samples collected from field experiment were analyzed with a Shimadzu GC- 14A gas chromatograph (GC) equipped with FID and Porapak N column. The column and detector were maintained at 70 and 150 °C respectively.

The CH₄ flux (**F**) was calculated using the following equation (Debnath et al., 1996):

$$F = [(C_t - C_0)/t] \times H \times 42.857 \text{ mg m}^{-2} \text{ h}^{-1}$$

Where **t** is time interval (min), **H** is height of headspace (m), **C₀** is initial concentration of CH₄ at time **0** (ppmv), and **C_t** is final concentration of CH₄ at time **t** (ppmv).

3. 8 AGRONOMIC PARAMETERS OF RICE PLANTS

Agronomic parameters of the rice plants were measured along with methane sample collection. Number of tillers per hill, plant height and number of panicles per hill (after flowering) were counted. One rice hill was uprooted from each plot, roots were thoroughly washed and measured for shoot length, root

length, total plant volume, fresh weight as well as for dry weight to determine both below and above ground biomass.

At physiological maturity, the crop was harvested by cutting above ground plants from a net plot area of 12.15 m² for recording grain and straw yields. The grain yield data are presented at 14 per cent moisture while straw yield was computed after oven drying at 70 °C to constant weight.

Plant samples collected for dry matter estimation at final harvest were used for chemical analysis after grinding into fine powder. Nitrogen, phosphorus and potassium content in the plant samples were estimated by alkaline distillation, colorimeter and flame photometer (Muhr et al., 1965) method respectively. From the results of chemical analysis N, P and K uptake was calculated as indicated below.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)}}{100} \times \text{weight of dry matter (kg ha}^{-1}\text{)}$$

Water use efficiency (WUE) was calculated as the ratio of crop yield to the irrigation water applied and expressed as t ha⁻¹ mm⁻¹.

$$\text{WUE} = \frac{\text{Crop yield (t ha}^{-1}\text{)}}{\text{Water applied (mm)}}$$

3.9 STATISTICAL ANALYSIS

The data were subjected to statistical analysis following standard procedures (Gomez and Gomez, 1984) at the Statistics Department of Directorate of Rice Research (DRR), Hyderabad.

CHAPTER IV

RESULTS

The results obtained in the present investigation on “Influence of management practices on the methane emission in rice field” are presented below under different heads.

4.1 DIURNAL VARIATION IN METHANE EFFLUX

The results of methane flux as influenced by diurnal variation are presented in Table 2 and are depicted in Fig. 3. The methane emission rates over a period of 10 hours showed a distinct diurnal pattern.

In the morning, methane emission rates increased at accelerating rates and were maximum during the early afternoon (12.30pm- 2.30pm), followed by rapid decrease during late afternoon.

Soil, water and ambient temperatures showed similar diurnal patterns (Table 3 and Fig. 4) as that of methane emission and they reached maximum in the early afternoon when CH₄ emission was highest.

4.2 EFFECT OF NUTRIENT AND WATER MANAGEMENT PRACTICES ON METHANE EMISSION FROM RICE FIELD

4.2.1 Emission of methane at maximum tillering stage

Emission of methane due to different water regimes and fertilizer levels at maximum tillering stage (before and after irrigation) is presented in

Table 2: Methane efflux as influenced by diurnal variation at tillering stage.

Time	Methane Emission ($\text{mg m}^{-2} \text{ hr}^{-1}$)
7.30 am	0.512
9.30 am	0.622
11.30 am	0.819
1.30 pm	1.098
3.30 pm	0.557
5.30 pm	0.413

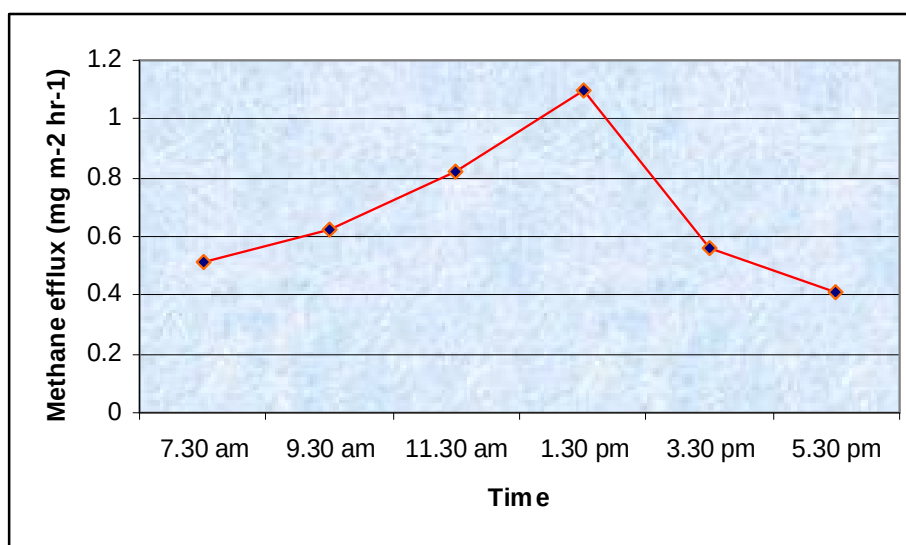


Fig. 3: Diurnal variation in methane efflux at tillering stage.

Table 3: Soil, water and ambient temperatures as influenced by diurnal Variation at sampling time.

Time	Soil Temperature ($^{\circ}\text{C}$)	Water Temperature ($^{\circ}\text{C}$)	Ambient Temperature ($^{\circ}\text{C}$)
7.30 am	18.0	16.7	16.0
9.30 am	20.1	21.2	29.0
11.30 am	24.2	25.4	34.5
1.30 pm	27.5	30.8	35.5
3.30 pm	28.3	27.4	35.0
5.30 pm	27.0	24.5	30.5

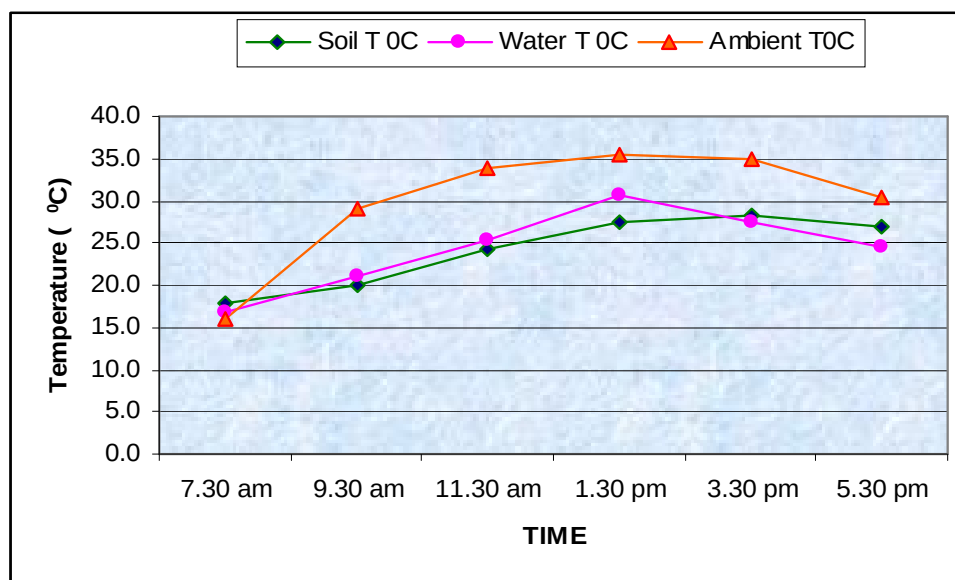


Fig. 4: Diurnal variation in soil, water and ambient temperatures at sampling time.

Table 4 and Fig. 5. Water regimes significantly influenced CH₄ emission at 28 DAT (before irrigation). The highest mean CH₄ emission (13.16 mg m⁻²d⁻¹) was observed in continuous flooding followed by water regime of IW/CPE = 1.0. Lowest mean CH₄ emission (6.55 mg m⁻²d⁻¹) was observed when irrigation was given at IW/CPE = 0.75.

Among the fertilizer levels, mean CH₄ emission was the highest in the plots treated with RFD which was significantly superior to all other treatments. Mean CH₄ emission from plots treated with organic manure alone and 50% RFD+50% organic manure were at par with each other and both of them were significantly superior to control plot.

The data on the interaction effect of water regimes and fertilizer levels revealed that higher CH₄ emission (16.06 mg m⁻²d⁻¹) was associated with the combination of continuous flooding and RFD treatment followed by continuous flooding and 50% RFD+50% organic manure (15.10 mg m⁻²d⁻¹), both of which were at par with each other but significantly superior to all other treatment combinations. The driest water regime (IW/CPE=0.75) and control registered the lowest CH₄ emission (4.28 mg m⁻²d⁻¹) from rice crop at maximum tillering stage.

CH₄ emission was significantly influenced by water regimes and fertilizer levels at 33 DAT (after irrigation). Among the water regimes continuous flooding resulted in the highest mean methane emission (14.65 mg m⁻²d⁻¹) followed by IW/CPE of 1.0 (10.61 mg m⁻²d⁻¹). Both of these were

Table 4 : Influence of nutrient and water management practices on CH₄ emission (mg m⁻² d⁻¹) at maximum tillering stage
28 DAT – (Before irrigation):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	8.72	5.76	4.28	6.25
S ₂ -RFD	16.06	9.72	8.11	11.29
S ₄ -Organic manure alone	12.77	7.69	7.61	9.36
S ₅ -50% RFD with 50% organic manure	15.10	8.81	6.22	10.04
Mean	13.16	7.99	6.55	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.22	0.46	0.55	
CD (p=0.05)	0.62	0.96	1.20	

33 DAT – (After irrigation):

S ₁ -Control	10.49	6.80	5.46	7.58
S ₂ -RFD	18.09	14.41	10.85	14.45
S ₄ -Organic manure alone	13.60	8.70	8.83	10.38
S ₅ -50% RFD with 50% organic manure	16.40	12.52	9.25	12.72
Mean	14.65	10.61	8.60	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.29	0.31	0.57	
CD (p=0.05)	0.81	0.66	1.31	

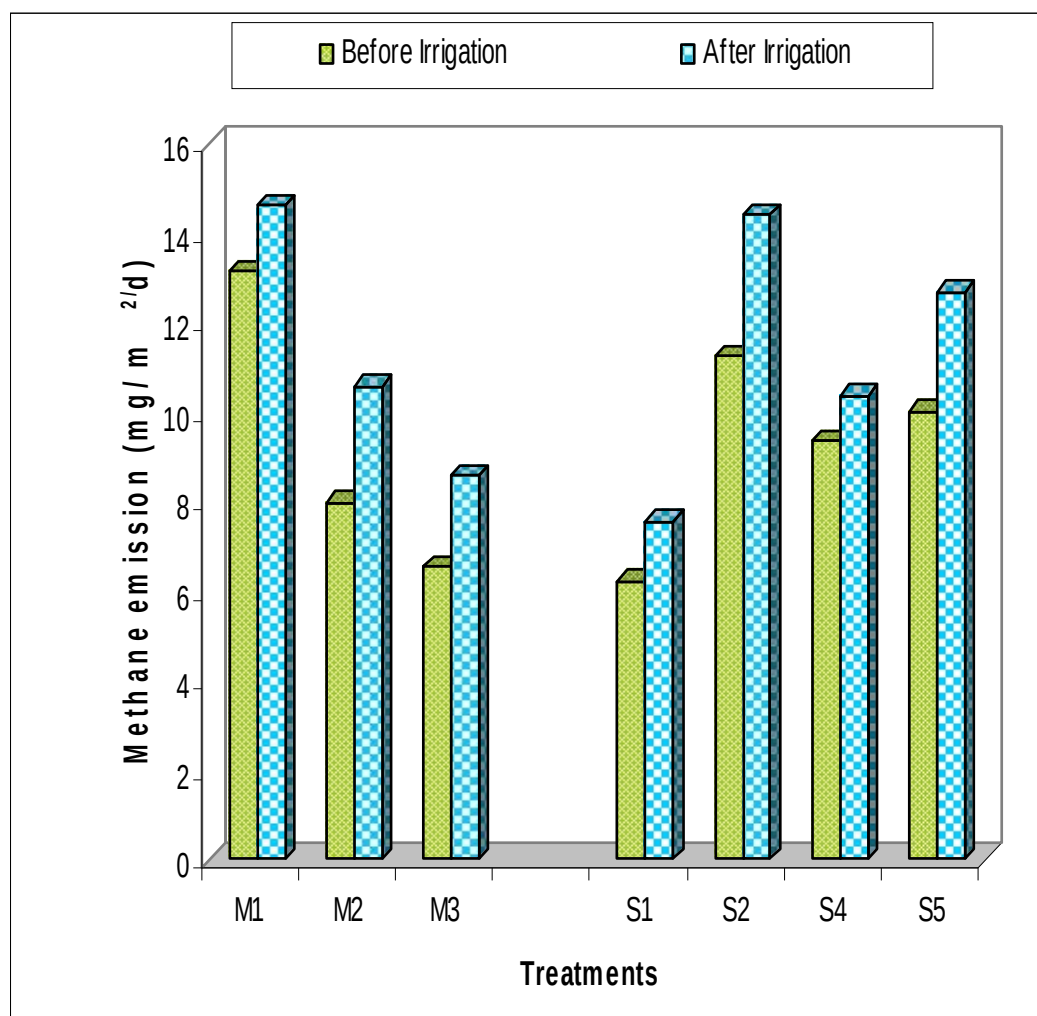


Fig. 5: Influence of nutrient and water management practices on CH₄ emission at tillering stage

significantly superior to IW/CPE=0.75, which recorded the lowest mean methane emission ($8.60 \text{ mg m}^{-2}\text{d}^{-1}$).

Among the fertilizer levels, RFD resulted in the highest mean CH_4 emission ($14.45 \text{ mg m}^{-2}\text{d}^{-1}$) followed by 50% RFD+50% organic manure. Both of them were significantly superior to organic manure alone and control plots. Lowest mean CH_4 emission ($7.58 \text{ mg m}^{-2}\text{d}^{-1}$) was associated with control plot.

CH_4 emission was also significantly influenced by the interaction effect of water regime and fertilizer levels as observed in before irrigation treatment. Maximum CH_4 emission ($18.09 \text{ mg m}^{-2}\text{d}^{-1}$) was recorded from continuous flooding + RFD and lowest emission ($5.46 \text{ mg m}^{-2}\text{d}^{-1}$) from (IW/CPE=0.75) + control.

After irrigation there was a significant increment of CH_4 emission from plots which were irrigated intermittently when compared to plots of before irrigation.

4.2.2 Emission of methane at PI stage

Data in Table 5 revealed that CH_4 emission at panicle initiation stage (before and after irrigation) was significantly influenced by water regimes and fertilizer levels.

Water regimes significantly influenced mean CH₄ emission at 48 DAT (before irrigation). It was significantly higher (14.52 mg m⁻² d⁻¹) with continuous flooding, followed by IW/CPE of 1.0. The lowest mean CH₄ emission was (7.78 mg m⁻² d⁻¹) registered with IW/CPE of 0.75.

Among fertilizer levels, mean CH₄ emission from rice crop was the highest (13.27 mg m⁻² d⁻¹) in the plots treated with RFD and was significantly superior to all other treatments. The effect of fertilizer treatments of organic manure alone and 50% RFD+50% organic manure were at par with each other and were significantly superior to control plot which recorded the lowest mean CH₄ emission (7.61 mg m⁻² d⁻¹)

CH₄ emission was also significantly influenced by the interaction effect of water regime and fertilizer levels at this stage. It was the highest with the combination of continuous flooding and RFD followed by continuous flooding and 50% RFD+50% organic manure, which were at par with each other but significantly superior to all other combinations. The lowest CH₄ emission was associated with the driest water regime (IW/CPE of 0.75) and control.

Both water regimes and fertilizer levels significantly influenced the CH₄ emission at 50 DAT (after irrigation). The highest mean methane emission (16.40 mg m⁻² d⁻¹) was recorded with the continuous flooding which was significantly superior to other water regimes. The lowest mean methane

Table 5: Influence of nutrient and water management practices on CH₄ emission (mg m⁻² d⁻¹) at PI stage

48 DAT – (Before irrigation):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	9.03	8.95	4.85	7.61
S ₂ -RFD	17.27	12.78	9.73	13.27
S ₄ -Organic manure alone	15.08	10.09	8.07	11.08
S ₅ -50% RFD with 50% organic manure	16.70	10.36	8.48	11.85
Mean	14.52	10.54	7.78	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.16	0.31	0.39	
CD (p=0.05)	0.46	0.64	0.85	

50 DAT – (After irrigation):

S ₁ -Control	11.40	8.35	7.40	9.05
S ₂ -RFD	19.09	15.07	11.71	15.29
S ₄ -Organic manure alone	17.34	12.45	10.56	13.45
S ₅ -50% RFD with 50% organic manure	17.75	13.09	9.44	13.42
Mean	16.40	12.24	9.78	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.37	0.50	0.77	
CD (p=0.05)	1.03	1.05	1.73	

emission ($9.78 \text{ mg m}^{-2}\text{d}^{-1}$) was recorded with the water regime of IW/CPE of 0.75.

Fertilizer levels also significantly influenced the CH_4 emission. The highest mean CH_4 emission ($15.29 \text{ mg m}^{-2}\text{d}^{-1}$) was noticed with RFD, which was significantly superior to other treatments. Fertilizer treatments of organic manure alone and 50% RFD+50% organic manure were at par with each other and both of them were significantly superior to control plot which recorded the lowest mean methane emission ($9.05 \text{ mg m}^{-2}\text{d}^{-1}$).

The interaction effects indicated that continuous flooding coupled with RFD treatment resulted in highest CH_4 emission ($19.09 \text{ mg m}^{-2}\text{d}^{-1}$) closely followed by continuous flooding and 50% RFD+50% organic manure ($17.75 \text{ mg m}^{-2}\text{d}^{-1}$). Both were at par with each other and significantly superior to combination of (IW/CPE=0.75) + control which registered lowest methane emission ($7.40 \text{ mg m}^{-2}\text{d}^{-1}$).

After irrigation, there was a considerable enhancement of CH_4 emission from most of the intermittently irrigated plots when compared to that of before irrigation. Between tillering and PI stages, higher CH_4 emission was observed at PI stage than that of tillering stage.

4.2. 3 Emission of methane at flowering stage

The data on CH_4 emission at flowering stage (before and after irrigation) are presented in Table 6.

Table 6 : Influence of nutrient and water management practices on CH₄ emission (mg m⁻² d⁻¹) at flowering stage

69 DAT – (Before irrigation):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	11.87	9.36	8.82	10.02
S ₂ -RFD	18.44	15.37	12.24	15.35
S ₄ -Organic manure alone	16.64	13.10	10.41	13.38
S ₅ -50% RFD with 50% organic manure	18.37	14.93	11.55	14.95
Mean	16.33	13.19	10.75	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.32	0.19	0.58	
CD (p=0.05)	0.89	0.41	1.44	

71DAT – (After irrigation):

S ₁ -Control	12.58	10.01	7.94	10.18
S ₂ -RFD	20.39	15.18	12.40	15.99
S ₄ -Organic manure alone	18.78	12.83	12.19	14.60
S ₅ -50% RFD with 50% organic manure	19.25	14.68	10.14	14.69
Mean	17.75	13.18	10.67	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.48	0.49	0.93	
CD (p=0.05)	0.94	0.96	1.83	

Among all water regimes, the highest mean CH₄ emission (16.33 mg m⁻²d⁻¹) was recorded with continuous flooding at 69 DAT (before irrigation), followed by IW/CPE=1.0. Lowest CH₄ mean emission (10.75 mg m⁻²d⁻¹) was observed when irrigation was given at IW/CPE=0.75.

Among the fertilizer levels, RFD resulted in higher mean CH₄ emission (15.35 mg m⁻²d⁻¹) followed by 50% RFD+50% organic manure. Both of these were significantly superior to other treatments. The lowest mean CH₄ emission (10.02 mg m⁻²d⁻¹) was associated with control plot.

Among the interaction effects, higher CH₄ emission was recorded with combination of continuous flooding and RFD followed by continuous flooding and 50% RFD+50% organic manure, both of which were at par with each other but significantly superior to all other combinations. The lowest CH₄ emission was associated with the driest water regime (IW/CPE of 0.75) and control.

CH₄ emission was significantly influenced by water regimes and fertilizer levels at 71 DAT (after Irrigation). Among the water regimes, continuous flooding resulted in highest mean CH₄ emission (17.75 mg m⁻²d⁻¹) followed by IW/CPE=1.0, both of which were significantly superior to IW/CPE of 0.75, which recorded lowest CH₄ mean emission (10.67 mg m⁻²d⁻¹).

Among the fertilizer levels, RFD resulted in higher mean CH₄ emission (15.99 mg m⁻²d⁻¹) followed by 50% RFD+50% organic manure and organic

manure alone which were at par with each other but were significantly superior to control plot. Lowest mean CH₄ emission (10.18 mg m⁻²d⁻¹) was associated with control plot.

The data on the interaction effect of water regimes and fertilizer levels revealed that higher CH₄ emission was associated with the combination of continuous flooding + RFD followed by continuous flooding + 50% RFD with 50% organic manure and continuous flooding + organic manure alone. Above 3 combinations were at par with each other but were superior to all other combinations. IW/CPE of 0.75 + control fertilizer level registered lowest CH₄ emission.

At flowering stage also, after irrigation most of the intermittently irrigated plots showed higher CH₄ emission than that of before irrigation. Among the growth stages of rice crop, flowering stage showed maximum CH₄ emission.

4.2. 4 Emission of methane at maturity stage

From the data presented in Table 7, it can be noticed that both water regimes and fertilizer levels significantly influenced the CH₄ emission at maturity stage (before and after irrigation).

The highest mean CH₄ emission (10.01mg m⁻²d⁻¹) was observed in water regime of continuous flooding at 88 DAT (before irrigation) followed by

Table 7 : Influence of nutrient and water management practices on CH₄ emission (mg m⁻² d⁻¹) at maturity stage

88 DAT – (Before irrigation):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	7.10	6.34	3.82	5.75
S ₂ -RFD	11.91	9.75	7.78	9.81
S ₄ -Organic manure alone	10.36	8.88	7.51	8.91
S ₅ -50% RFD with 50% organic manure	10.68	9.31	7.57	9.19
Mean	10.01	8.57	6.67	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.22	0.22	0.42	
CD (p=0.05)	0.60	0.47	0.97	

90 DAT – (After irrigation):

S ₁ -Control	5.85	4.54	2.95	4.45
S ₂ -RFD	8.70	7.54	6.34	7.52
S ₄ -Organic manure alone	7.31	6.59	6.32	6.77
S ₅ -50% RFD with 50% organic manure	8.02	7.22	5.87	7.03
Mean	7.49	6.47	5.37	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.22	0.27	0.44	
CD (p=0.05)	0.59	0.58	0.99	

IW/CPE=1.0. The lowest mean CH_4 emission ($6.67 \text{ mg m}^{-2}\text{d}^{-1}$) was observed with water regime of IW/CPE of 0.75.

RFD treatment recorded the highest mean CH_4 emission ($9.81 \text{ mg m}^{-2}\text{d}^{-1}$) followed by 50% RFD+50% organic manure and organic manure alone. Above 3 treatments were at par with each other but were significantly superior to control treatment which recorded lowest mean CH_4 emission ($5.75 \text{ mg m}^{-2}\text{d}^{-1}$).

CH_4 emission was also significantly influenced by the interaction of water regimes and fertilizer levels. It was the highest with the combination of continuous flooding + RFD which was significantly superior to all other combinations. The lowest CH_4 emission was associated with the driest water regime (IW/CPE of 0.75) and control.

Both water regimes and fertilizer levels had significantly influenced the mean CH_4 emission at 90 DAT (after irrigation). It was significantly higher with continuous flooding ($7.49 \text{ mg m}^{-2}\text{d}^{-1}$) compared to other water regimes viz., water regime of IW/CPE = 1.0 and IW/CPE = 0.75. Lowest mean CH_4 emission ($5.37 \text{ mg m}^{-2}\text{d}^{-1}$) was registered with water regime of IW/CPE of 0.75.

Higher mean CH_4 emission ($7.52 \text{ mg m}^{-2}\text{d}^{-1}$) was observed in plots treated with RFD followed by 50% RFD+50% organic manure and organic manure alone. Above 3 treatments were at par with each other but

significantly superior to control treatment which recorded the lowest mean CH_4 emission ($4.45 \text{ mg m}^{-2}\text{d}^{-1}$).

The interaction effects indicated that continuous flooding coupled with RFD treatment resulted in the highest CH_4 emission closely followed by continuous flooding + 50% RFD with 50% organic manure, both of which were at par with each other. The lowest CH_4 emission was recorded with the combination of $\text{IW/CPE} = 0.75$ + control fertilizer treatment.

There was significant reduction in CH_4 emission after irrigation when compared to before irrigation treatment. Among the growth stages of rice crop, maturity stage showed the lowest CH_4 emission.

4. 2. 5 Seasonal CH_4 flux

Data presented in Table 8 and Fig. 6 revealed that seasonal CH_4 emission was significantly influenced by water regimes and fertilizer levels.

The highest mean seasonal CH_4 emission (7.69 kg ha^{-1}) was observed in water regime of continuous flooding followed by $\text{IW/CPE} = 1.0$. The lowest mean seasonal CH_4 emission (4.65 kg ha^{-1}) was associated with the driest water regime (IW/CPE of 0.75).

RFD treatment recorded the highest mean seasonal CH_4 emission (7.32 kg ha^{-1}) which was significantly higher to all other treatments. The lowest mean seasonal CH_4 emission (4.21 kg ha^{-1}) was observed in control treatments.

Seasonal CH_4 emission was also significantly influenced by the interaction effect of water regime and fertilizer levels. It was the highest with the combination of continuous flooding + RFD which was significantly superior to all other combinations. The lowest CH_4 emission was recorded in combination of $\text{IW/CPE} = 0.75$ + control fertilizer treatment.

From the data presented in Table 9, it can be seen that fields plots where water regime of $\text{IW/CPE} = 1.0$ and $\text{IW/CPE} = 0.75$ were adopted, there was reduction of seasonal CH_4 flux by about 25% and 40%, respectively as compared to continuously flooded plots .

The lowest grain yield was recorded from the intermittently irrigated plots as compared to continuously flooded plots. When the quantity of methane production per unit weight of grain yield was calculated, the least amount of $\text{CH}_4 \text{ t}^{-1}$ grain yield was recorded in the plots when irrigated intermittently.

Seasonal flux of CH_4 increased to an extent of 74% following application of RFD as compared to control treatment. Seasonal flux of CH_4 increased by 45% and 54%, respectively, following application of organic manure alone and 50% RFD+50% organic manure.

The highest grain yield was recorded from the plots treated with RFD compared to the other treatments. The least amount of $\text{CH}_4 \text{ t}^{-1}$ grain yield was recorded in control treatment followed by RFD treatment. Lower amount of

Table 8 : Influence of nutrient and water management practices on Seasonal CH₄ flux (kg ha⁻¹)

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S1 -Control	5.46	3.97	3.20	4.21
S2 -RFD	9.14	7.15	5.66	7.32
S4 -Organic manure alone	7.71	5.59	5.04	6.12
S5 -50% RFD with 50% organic manure	8.43	6.30	4.72	6.48
Mean	7.69	5.76	4.65	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.12	0.06	0.21	
CD (p=0.05)	0.33	0.12	0.54	

Table 9 : Seasonal methane emission from rice field as affected by water regimes and fertilizer levels

Treatment	Seasonal flux (kg ha ⁻¹)	Grain yield (t ha ⁻¹)	Kg CH ₄ t ⁻¹ of grain yield	% change
<u>Water regime:</u>				
M ₁ -Continuous flooding	7.69	4.41	1.74	-
M ₂ -IW/CPE =1.0	5.76	3.63	1.59	25
M ₃ -IW/CPE =0.75	4.65	3.64	1.28	40
<u>Fertilizer levels:</u>				
S ₁ -Control	4.21	2.90	1.45	-
S ₂ -RFD	7.32	4.93	1.49	74
S ₄ -Organic manure alone	6.12	2.85	2.15	45
S ₅ - 50% RFD with 50% organic manure	6.48	4.03	1.61	54

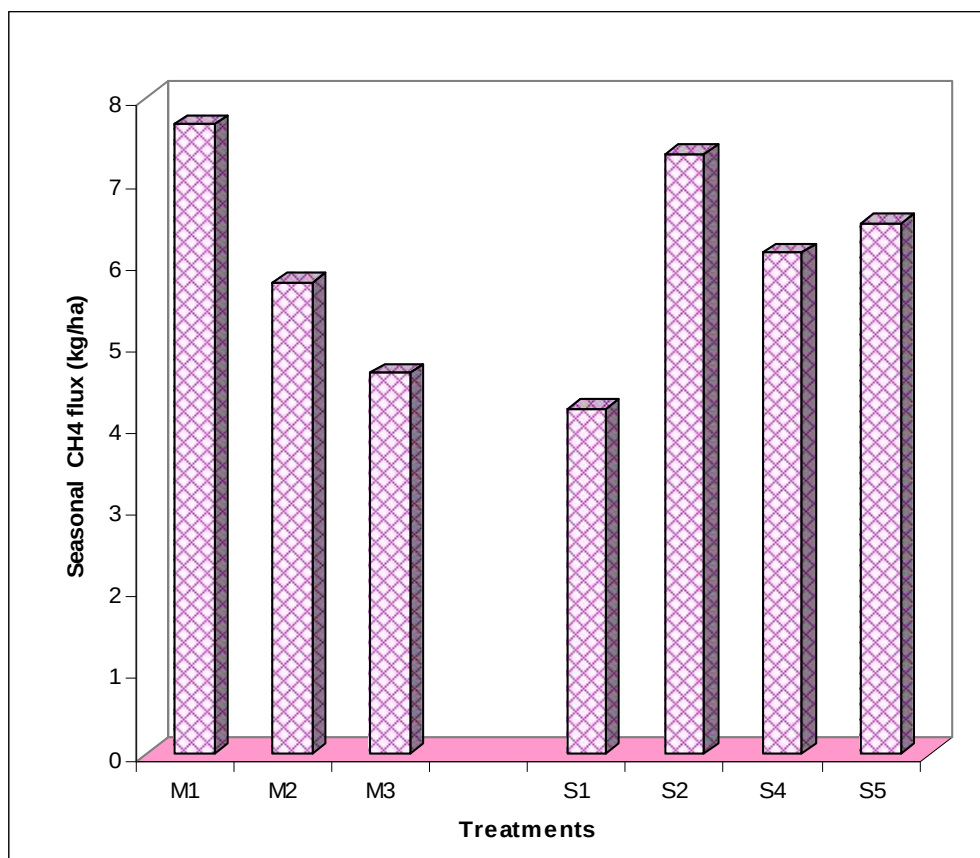


Fig. 6: Influence of nutrient and water management practices on Seasonal CH₄ emission

$\text{CH}_4 \text{ t}^{-1}$ grain yield was recorded in 50% RFD+50% organic manure compared to organic manure alone.

From the data presented in Table 10, it can be seen that less amount of $\text{CH}_4 \text{ t}^{-1}$ grain yield was observed in combinations of M_2S_1 , M_3S_1 and M_3S_2 .

4. 2. 6 Seasonal variations in methane efflux

The data presented in Table 11, Fig. 7 and Fig. 8 revealed that the highest CH_4 emission was registered with continuous flooding throughout the rice growing season followed by water regime of $\text{IW/CPE} = 1.0$. The lowest CH_4 emission was observed with water regime of $\text{IW/CPE} = 0.75$.

Among the fertilizer levels, the highest CH_4 emission was observed in plots treated with RFD throughout the season followed by 50% RFD+50% organic manure and organic manure alone. The lowest CH_4 emission was observed in control fertilizer plots.

Emission of CH_4 increased steadily over the cropping season, reaching a peak at flowering stage (71 DAT). Intermittently irrigated plots always showed a distinct increment of CH_4 emission after irrigation.

4. 3 EFFECT OF NUTRIENTS AND WATER MANAGEMENT PRACTICES ON GRAIN AND STRAW YIELD OF RICE CROP

Data on grain and straw yield are presented in Table 12 and Fig. 9. Grain yield was significantly influenced by water regimes, fertilizer levels and their interactions.

Table 10: Seasonal methane emission from rice field as affected by interaction effects of water regimes and fertilizer levels.

Treatment	Seasonal flux (kg ha ⁻¹)	Grain yield (t ha ⁻¹)	Kg CH ₄ t ⁻¹ grain yield
M ₁ S ₁	5.46	2.92	1.87
M ₁ S ₂	9.14	5.93	1.54
M ₁ S ₄	7.71	2.98	2.59
M ₁ S ₅	8.43	5.08	1.66
M ₂ S ₁	3.97	3.21	1.24
M ₂ S ₂	7.15	4.48	1.60
M ₂ S ₄	5.59	2.65	2.11
M ₂ S ₅	6.30	3.46	1.82
M ₃ S ₁	3.20	2.58	1.24
M ₃ S ₂	5.66	4.39	1.29
M ₃ S ₄	5.04	2.92	1.73
M ₃ S ₅	4.72	3.55	1.33

M₁- Continuous flooding

M₂- IW/CPE =1.0

M₃- IW/CPE =0.75

S₁ - Control

S₂ - RFD

S₄ - Organic manure only

S₅ - 50% RFD+50% organic manure

Table 11 : Mean methane emission ($\text{mg m}^{-2} \text{ d}^{-1}$) from rice crop as affected by water regimes and fertilizer levels at different growth stages.

Treatment	Growth stage							
	Tillering		P I		Flowering		Maturity	
	B/I	A/I	B/I	A/I	B/I	A/I	B/I	A/I
<u>Water regime:</u>								
M ₁ - Continuous flooding	13.16	14.65	14.52	16.40	16.33	17.75	10.01	7.49
M ₂ - IW/CPE =1.0	7.99	10.61	10.54	12.24	13.19	13.18	8.57	6.47
M ₃ -IW/CPE =0.75	6.55	8.60	7.78	9.78	10.75	10.67	6.67	5.37
<u>Fertilizer levels:</u>								
S ₁ -Control	6.25	7.58	7.61	9.05	10.02	10.18	5.75	4.45
S ₂ -RFD	11.29	14.45	13.27	15.29	15.35	15.99	9.81	7.52
S ₄ -Organic manure alone	9.36	10.38	11.08	13.45	13.38	14.60	8.91	6.77
S ₅ -50% RFD with 50% organic manure	10.04	12.72	11.85	13.42	14.95	14.69	9.19	7.03

B/I – Before Irrigation
A/I – After Irrigation

P I – Panicle Initiation

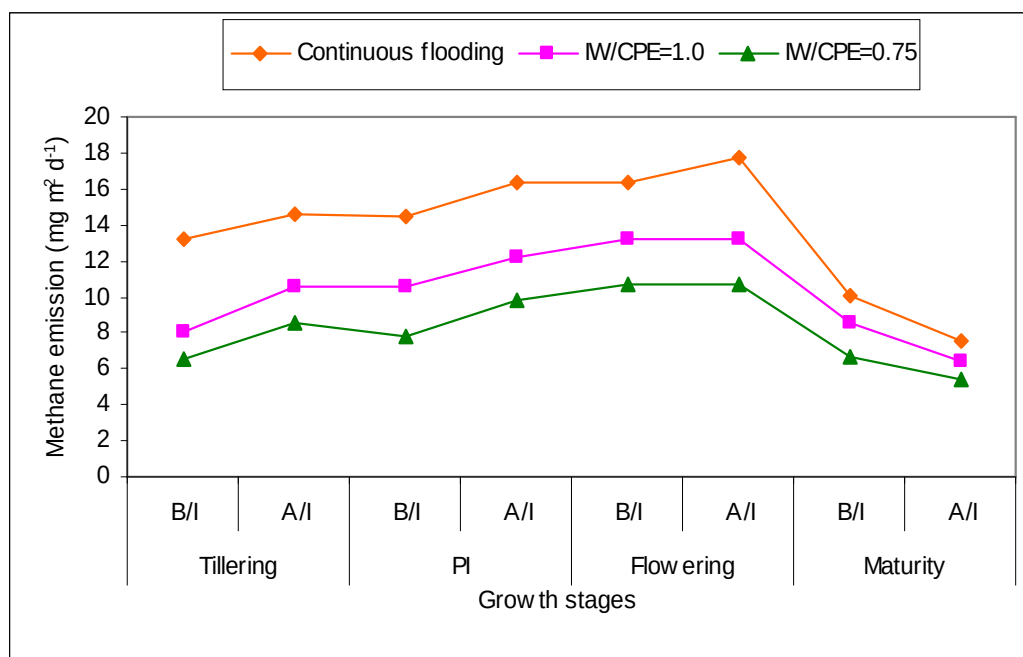


Fig. 7: Seasonal patterns of methane emission as affected by water regimes (B/I- Before Irrigation, A/I- After Irrigation)

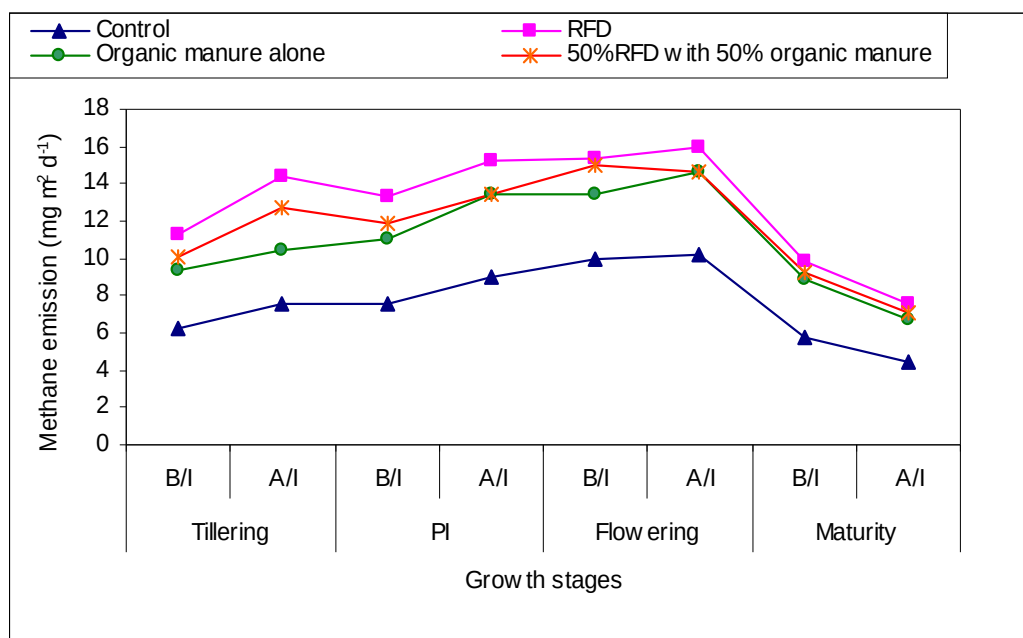


Fig. 8: Seasonal patterns of methane emission as affected by fertilizer levels (B/I- Before Irrigation, A/I- After Irrigation)

Among the water regimes, mean grain yield was highest (4406 kg ha^{-1}) in M_1 which was significantly superior to other water regimes. Mean grain yield in M_2 and M_3 were on par with each other.

Higher mean grain yield (4931 kg ha^{-1}) was registered with S_2 followed by S_3 . Both were at par with each other and were significantly superior to other fertilizer levels. S_5 was significantly superior to S_1 and S_4 . The lowest mean grain yield (2850 kg ha^{-1}) was observed in S_4 (organic manure alone).

The data on the interaction effect of water regime and fertilizer levels revealed that higher grain yield (5926 kg ha^{-1}) was associated with M_1S_2 followed by M_1S_3 and M_1S_5 which were at par with each other and were significantly superior to other treatment combinations. M_3S_1 combination registered the lowest grain yield.

Straw yield was also significantly influenced by water regimes, fertilizer levels and their interactions.

The highest mean straw yield (5458 kg ha^{-1}) was recorded in M_1 which was at par with M_3 and was significantly superior to M_2 . The lowest mean straw yield (4083 kg ha^{-1}) was recorded in M_2 .

Among fertilizer levels, higher mean straw yield (5979 kg ha^{-1}) was observed in S_2 followed by S_3 . S_2 was significantly superior to S_5 , S_4 and S_1 . The lowest mean straw yield (3285 kg ha^{-1}) was observed in S_1 .

Table 12 : Effect of treatments on grain & straw yield of rice crop
Grain yield (kg ha⁻¹):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	2918	3209	2578	2902
S ₂ -RFD	5926	4483	4385	4932
S ₃ -RFD+50% more N	5126	4328	4779	4745
S ₄ -Organic manure alone	2978	2652	2922	2850
S ₅ -50% RFD with 50% organic manure	5082	3455	3552	4030
Mean	4406	3625	3643	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	340.71	328.10	727.27	
CD (p=0.05)	667.79	643.07	1425.45	

Straw yield (kg ha⁻¹):

S ₁ -Control	3244	3659	2954	3285
S ₂ -RFD	7446	4447	6044	5979
S ₃ -RFD+50% more N	6865	4355	5303	5508
S ₄ -Organic manure alone	3484	3051	3519	3351
S ₅ -50% RFD with 50% organic manure	6252	4900	4020	5057
Mean	5458	4083	4368	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	556.92	446.44	1166.28	
CD (p=0.05)	1081.56	875.03	2285.91	

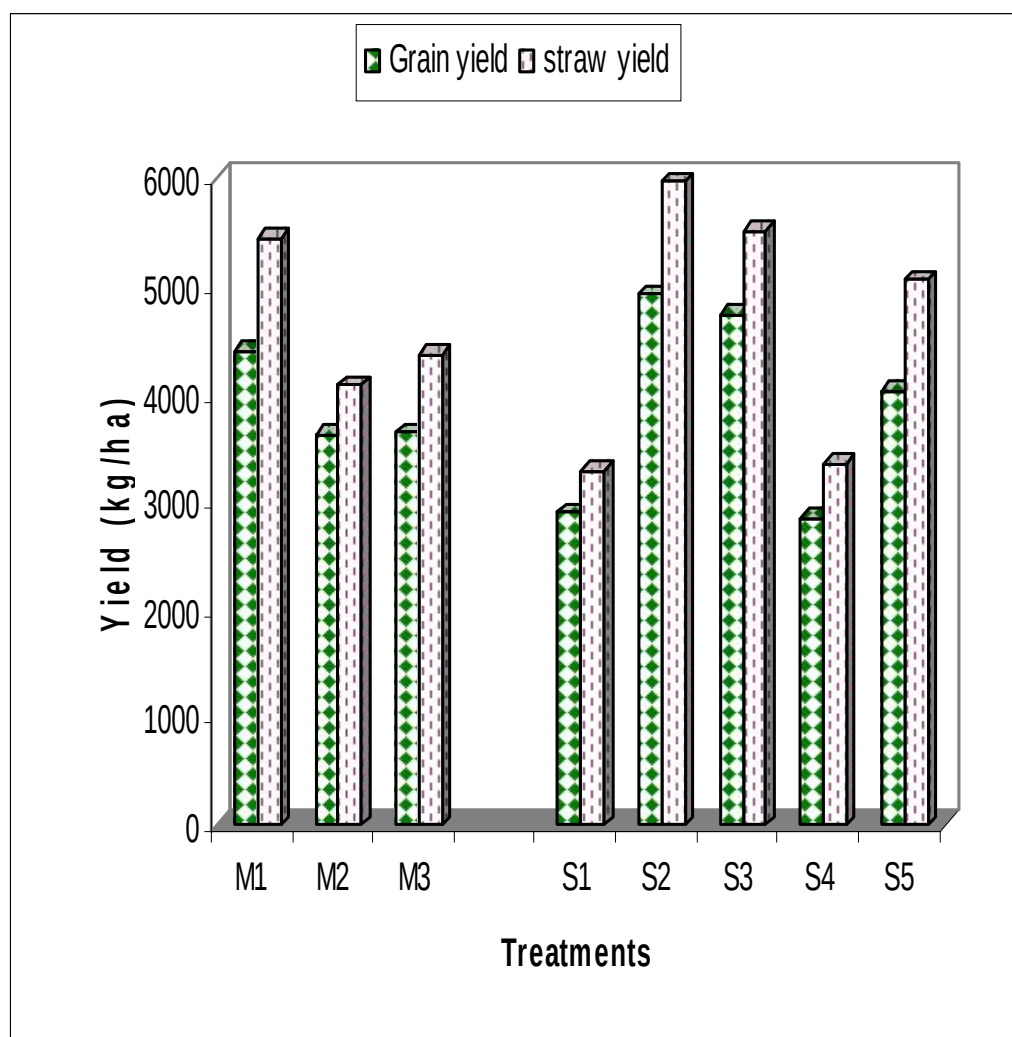


Fig. 9: Influence of nutrient and water management practices on Grain and Straw yield

Among the interaction effects, higher straw yield was observed in M_1S_2 followed by M_1S_3 and M_1S_5 which were at par with each other and was significantly superior to most of other treatment combinations. Lowest straw yield was recorded in M_3S_1 combination.

4.4 Effect of nutrient and water management practices on number of tillers and panicles

Data in table 13 revealed that number of tillers and panicles were significantly influenced by water regimes, fertilizer levels and their interactions.

Higher mean number of tillers (11.4) was recorded in M_1 followed by M_2 and both of these were at par with each other. M_1 was significantly superior to M_3 which recorded the lowest mean number of tillers (10.32).

Among the fertilizer levels, mean number of tillers was higher in S_3 (12.22) followed by S_3 and S_2 which were at par with each other but significantly superior to other fertilizer levels. The lowest mean number of tillers was observed in S_4 treatment (9.40).

The interaction effects indicated that M_1S_3 recorded higher number of tillers followed by M_1S_2 and M_1S_5 which were at par with each other. M_1S_3 was significantly superior to all other combinations. The lowest number of tillers was recorded in M_3S_4 combination.

Table 13 : Effect of treatments on number of tillers & number of panicles at harvest stage of rice crop

Number of tillers hill⁻¹ (Average of 5 hills):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	10.07	10.47	9.33	9.96
S ₂ -RFD	12.33	10.73	10.53	11.20
S ₃ -RFD+50% more N	13.8	11.73	11.13	12.22
S ₄ -Organic manure alone	9.33	10.00	8.87	9.40
S ₅ -50% RFD with 50% organic manure	11.67	11.93	11.73	11.78
Mean	11.44	10.97	10.32	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.34	0.64	0.84	
CD (p=0.05)	0.67	1.26	1.65	

Number of panicles hill⁻¹ (Average of 5 hills):

S ₁ -Control	8.87	9.87	8.40	9.04
S ₂ -RFD	11.20	10.33	9.67	10.40
S ₃ -RFD+50% more N	13.80	10.53	9.27	11.20
S ₄ -Organic manure alone	9.33	9.00	8.73	9.02
S ₅ -50% RFD with 50% organic manure	11.67	11.00	10.60	11.09
Mean	10.97	10.15	9.33	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.24	0.59	0.67	
CD (p=0.05)	0.48	1.16	1.31	

Among the water regimes, M_1 resulted in the highest mean number of panicles (10.97) and significantly superior to other water regimes. The lowest mean number of panicles (9.33) was associated with M_3 .

Higher mean number of panicles (11.22) was recorded in S_3 followed by S_5 and S_2 which were at par with each other and significantly superior to S_1 and S_4 . The lowest mean number of panicles (9.02) was recorded in S_4 treatment.

Number of panicles was also significantly influenced by the interaction effect of water regimes and fertilizer levels. It was the highest with combination of M_1S_3 which was significantly superior to all other combinations. The lowest number of panicles was recorded in M_3S_1 combination.

4.5 NPK & ZINC CONTENT AND UPTAKE AT HARVEST

The data obtained on content and uptake of N, P, K and Zn are presented in Tables 14, 15, 16, 17 and Fig. 10 and 11.

4.5.1 Nitrogen content and uptake

The data presented in Table 14 revealed that the highest plant nitrogen content (1.91%) was observed in M_1 which was significantly superior to other water regimes. The lowest nitrogen content (1.71%) was observed in M_2 .

Table 14: Effect of treatments on Nitrogen content & uptake at harvest stage of rice crop

Nitrogen content (%):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	1.75	1.62	1.65	1.67
S ₂ -RFD	2.04	1.75	1.99	1.93
S ₃ -RFD+50% more N	2.19	1.75	2.13	2.02
S ₄ -Organic manure alone	1.73	1.70	1.71	1.71
S ₅ -50% RFD with 50% organic manure	1.84	1.74	1.87	1.81
Mean	1.91	1.71	1.86	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.025	0.056	0.067	
CD (p=0.05)	0.049	0.110	0.131	

Nitrogen uptake (kg ha⁻¹):

S ₁ -Control	53.4	55.3	45.1	51.3
S ₂ -RFD	133.1	78.6	102.9	104.9
S ₃ -RFD+50% more N	129.6	76.3	90.6	98.8
S ₄ -Organic manure alone	55.6	47.9	54.1	52.5
S ₅ -50% RFD with 50% organic manure	102.7	70.6	68.8	80.7
Mean	94.9	65.7	72.3	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	9.60	10.70	20.92	
CD (p=0.05)	18.82	20.96	41.01	

Among the fertilizer levels, RFD+50% more N (S_3) recorded higher mean N content (2.02%) followed by S_2 . Both of which were at par with each other and were significantly superior to other treatments. The lowest mean N content (1.67%) was observed in S_1 .

Among the interaction effects, M_1S_3 combination registered the highest N content followed by M_3S_3 . Both of which were at par with each other and were significantly superior to all other combinations. M_2S_1 combination registered the lowest N content.

Mean nitrogen uptake was significantly higher (94.9 kg ha^{-1}) with water regime of M_1 , compared to the other water regimes. The lowest mean N uptake (65.7 kg ha^{-1}) was registered with M_2 .

Among the fertilizer levels, mean N uptake by the crop was the highest (104.8 kg ha^{-1}) in the plots treated with RFD (S_2) followed by S_3 . Both were at par with each other. S_2 was significantly superior to S_5 , S_4 and S_1 . Mean N uptake was the lowest (51.3 kg ha^{-1}) in control plots (S_1).

The data on the interaction effect of water regimes and fertilizer levels revealed that higher N uptake was associated with the combination of M_1S_2 followed by M_1S_3 , M_3S_2 and M_1S_5 which were at par with each other. M_1S_2 was significantly superior to all other combinations. M_3S_1 combination registered the lowest nitrogen uptake by crop.

4. 5. 2 Phosphorus content and uptake

The data on phosphorus content and uptake are presented in Table 15. It can be seen from the results that both water regimes and fertilizer levels had significantly influenced the phosphorus content.

The highest mean P content (0.72%) was observed in water regime of M_1 which was significantly superior to other water regimes. The lowest mean phosphorus content (0.64 %) was observed in M_3 . RFD (S_2) recorded the highest mean P content (0.72%) which was significantly superior to all other fertilizer treatments. S_5 recorded the lowest mean P content (0.65%) but it was at par with S_1 , S_3 and S_4 . The interaction effects indicated that M_1S_2 resulted in the highest P content which was significantly superior to all other combinations. M_3S_1 resulted in the lowest P content.

It was evident from the data that phosphorus uptake was significantly influenced by both water regimes and fertilizer levels. Among water regimes, M_1 resulted in the highest mean P uptake (34.6 kg ha^{-1}) which was significantly higher compared to other water regimes. M_3 resulted in the lowest mean P uptake (24.8 kg ha^{-1}). Among the fertilizer treatments, S_2 resulted in the highest mean P uptake (38.3 kg ha^{-1}) followed by S_3 . Both of these were at par with each other and significantly superior to all other fertilizer treatments. The lowest mean P uptake (20.0 kg ha^{-1}) was associated with S_4 . It was the highest with the combination of M_1S_2 , which was

Table 15 : Effect of treatments on Phosphorus content & uptake at harvest stage of rice crop

Phosphorus content (%):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	0.72	0.69	0.58	0.66
S ₂ -RFD	0.82	0.70	0.65	0.72
S ₃ -RFD+50% more N	0.64	0.67	0.69	0.67
S ₄ -Organic manure alone	0.73	0.65	0.63	0.67
S ₅ -50% RFD with 50% organic manure	0.68	0.62	0.66	0.66
Mean	0.72	0.67	0.64	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.02	0.04	0.05	
CD (p=0.05)	0.04	0.08	0.105	

Phosphorus uptake (kg ha⁻¹):

S ₁ -Control	21.1	23.0	15.4	20.0
S ₂ -RFD	52.3	31.4	31.3	38.3
S ₃ -RFD+50% more N	40.3	29.1	33.8	34.4
S ₄ -Organic manure alone	22.9	17.6	19.4	19.9
S ₅ -50% RFD with 50% organic manure	36.0	23.4	24.3	27.9
Mean	34.6	24.9	24.8	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	2.40	2.40	5.15	
CD (p=0.05)	4.71	4.71	10.13	

significantly superior to all other combinations. The lowest P uptake was associated with M_3S_1 combination.

4. 5. 3 Potassium content and uptake

The data on potassium content and uptake are presented in table 16 revealed that potassium content was not significantly influenced by water regimes. But it was significantly influenced by fertilizer levels.

Higher mean K content (1.21%) was registered with S_2 followed by S_3 and S_5 which were at par with each other and significantly superior to other fertilizer treatments. The lowest mean K content (0.82%) was observed in S_4 treatment. K content was the highest with combination of M_2S_2 which was significantly higher compared to some other combinations. The lowest K content was observed in M_1S_4 combination.

Potassium uptake was significantly influenced by water regimes and fertilizer levels. Mean K uptake (54.4 kg ha^{-1}) by crop was significantly higher with M_1 compared to other water regimes. The lowest mean K uptake (41.3 kg ha^{-1}) was associated with water regime of M_3 . Fertilizer level S_2 registered highest mean K uptake (66.6 kg ha^{-1}) followed by S_3 and S_5 , which were at par with each other and significantly superior to other treatments. The lowest mean K uptake (25.8 kg ha^{-1}) was recorded with S_4 treatment.

Among interaction effects, higher K uptake was recorded with M_1S_2 combination followed by M_1S_3 . Both of them were at par with each other.

Table 16 : Effect of treatments on Potassium content & uptake at harvest stage of rice crop

Potassium content (%):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	0.79	0.93	0.88	0.87
S ₂ -RFD	1.28	1.33	1.02	1.21
S ₃ -RFD+50% more N	1.12	1.04	1.18	1.11
S ₄ -Organic manure alone	0.78	0.87	0.82	0.82
S ₅ -50% RFD with 50% organic manure	1.08	1.11	1.11	1.10
Mean	1.01	1.05	1.00	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.05	0.08	0.12	
CD (p=0.05)	NS	0.16	0.24	

Potassium uptake (kg ha⁻¹):

S ₁ -Control	24.2	33.7	24.8	27.5
S ₂ -RFD	88.5	59.3	51.9	66.6
S ₃ -RFD+50% more N	71.1	45.1	59.6	58.6
S ₄ -Organic manure alone	25.8	24.9	26.6	25.8
S ₅ -50% RFD with 50% organic manure	62.5	48.8	43.5	51.5
Mean	54.4	42.3	41.3	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	4.83	5.42	10.53	
CD (p=0.05)	9.46	10.63	20.64	

M_1S_2 was significantly superior to all other combinations. The lowest K uptake was associated with M_3S_1 combination.

4. 5. 4 Zinc content and uptake

The data presented in Table 17 revealed that the highest mean Zn content (34.6ppm) was observed in M_3 followed by M_2 . Both of which were at par with each other and significantly higher to M_1 which recorded the lowest mean Zn uptake (24.6 ppm).

S_2 recorded the highest mean Zn content (33.0 ppm) followed by S_3 and S_1 which were at par with each other and significantly superior to other treatments. The lowest mean Zn content (28.0 ppm) was observed in S_4 treatment.

The data on the interaction effects of water regimes and fertilizer levels revealed that higher Zn content was associated with the combination of M_3S_2 . M_1S_5 combination registered the lowest Zn content.

Among water regimes, M_3 resulted in the highest mean Zn uptake (144.6 g ha⁻¹) followed by M_2 and M_1 which were at par with each other. M_1 recorded the lowest mean Zn uptake (120.1g ha⁻¹).

Among fertilizer levels, S_2 resulted in the highest mean Zn uptake (180.2 g ha⁻¹) followed by S_3 . Both of which were significantly higher compared to other fertilizer treatments. The lowest mean Zn uptake (87.8 g ha⁻¹) was associated with S_4 .

Table 17 : Effect of treatments on Zn content & uptake at harvest stage of rice crop

Zn content (ppm):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	26.6	30.9	33.9	30.5
S ₂ -RFD	26.0	34.8	38.3	33.0
S ₃ -RFD+50% more N	24.1	35.1	38.0	32.4
S ₄ -Organic manure alone	23.3	29.7	31.1	28.0
S ₅ -50% RFD with 50% organic manure	21.6	32.8	31.6	28.6
Mean	24.6	32.7	34.6	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	1.91	1.88	4.08	
CD (p=0.05)	5.29	3.89	9.29	

Zn uptake (g ha⁻¹):

S ₁ -Control	83.2	104.9	93.4	93.8
S ₂ -RFD	175.8	156.1	208.8	180.2
S ₃ -RFD+50% more N	145.6	153.6	195.4	164.9
S ₄ -Organic manure alone	76.1	84.6	102.7	87.8
S ₅ -50% RFD with 50% organic manure	119.9	140.2	122.8	127.6
Mean	120.1	127.9	144.6	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	18.98	14.61	39.62	
CD (p=0.05)	52.71	30.15	93.44	

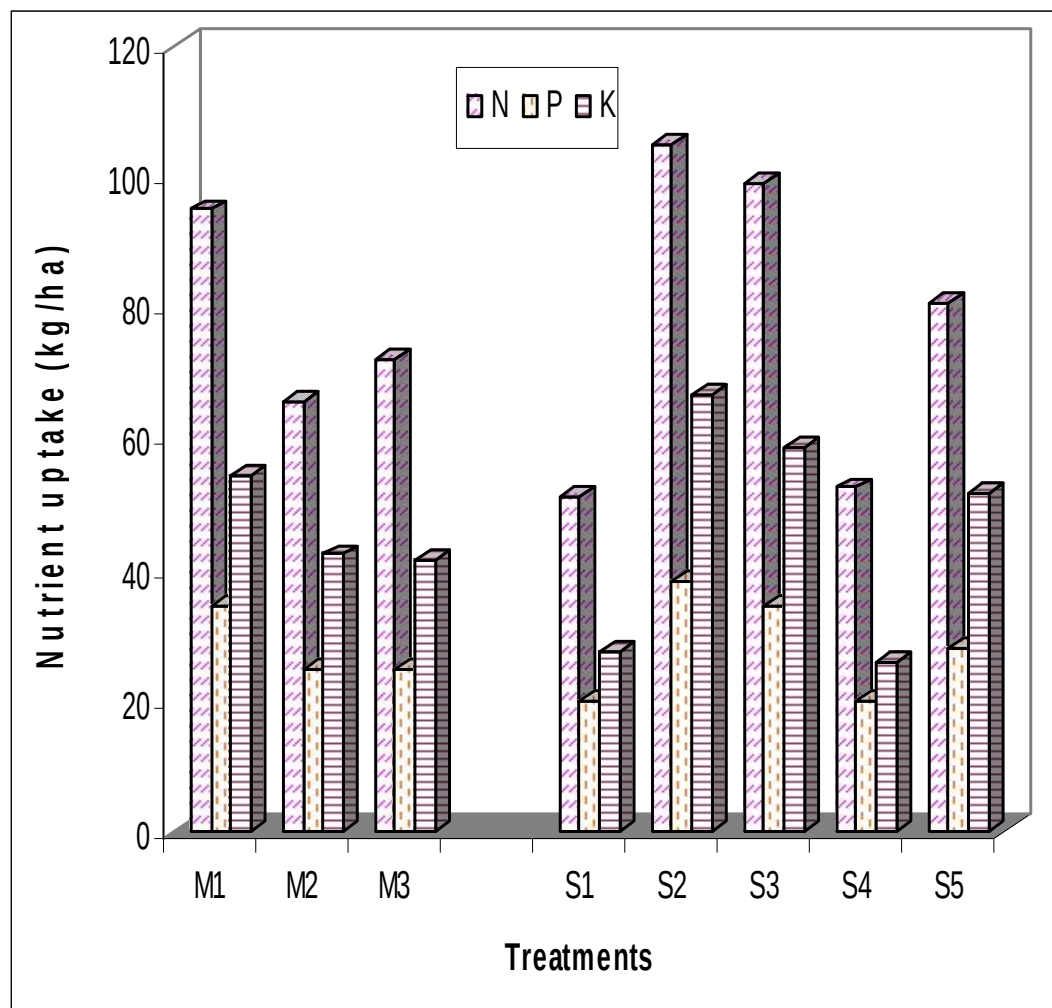


Fig. 10: Influence of nutrient and water management practices on Nutrient uptake

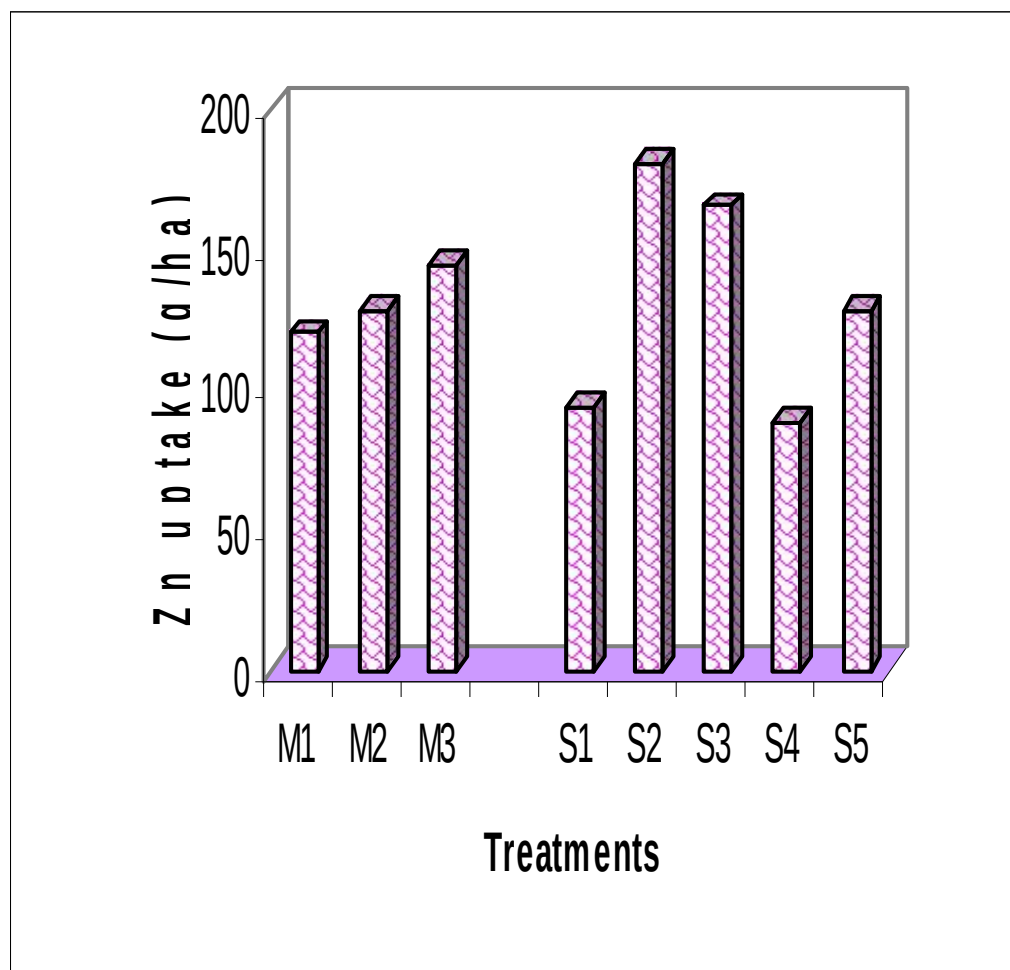


Fig. 11: Influence of nutrient and water management practices on Zn uptake

Zn uptake was highest with the combination of M_3S_2 followed by M_3S_3 and M_1S_2 which were at par with each other. The lowest Zn uptake was associated with M_1S_4 combination.

4.6 AVAILABLE NPK AND ZINC IN POST HARVEST SOIL

The data on available N, P_2O_5 , K_2O and Zn in post harvest soil samples are presented in Tables 18 and 19.

4. 6. 1 Available Nitrogen

The data presented in Table 18, revealed that water regimes, fertilizer levels and their interactions did not significantly influence the available nitrogen in soil after harvest of rice crop. It ranged from 204 kg ha^{-1} (M_2S_5) to 230 kg ha^{-1} (M_2S_1).

Though it was not significant, the mean available nitrogen among water regimes was in the ascending order of $M_2 < M_3 < M_1$. Similarly in case of fertilizer levels, it was in the ascending order of $S_5 < S_3 < S_2 < S_4 < S_1$.

4. 6. 2 Available P_2O_5

The data presented in Table 18 revealed that water regimes significantly influenced the mean available P_2O_5 in soil after harvest of rice crop. The highest mean available P_2O_5 (119 kg ha^{-1}) was observed in M_2 which was on par with that of M_3 and significantly higher to M_1 which recorded lowest mean available P_2O_5 (97 kg ha^{-1}).

Table 18 : Available nitrogen & P_2O_5 in post harvest soil as influenced by nutrient and water management practices

Available nitrogen ($kg\ ha^{-1}$):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M_1)	IW/CPE= 1.0 (M_2)	IW/CPE= 0.75 (M_3)	
S_1 -Control	227	230	221	226
S_2 -RFD	226	209	217	217
S_3 -RFD+50% more N	219	211	212	214
S_4 -Organic manure alone	224	217	214	218
S_5 -50% RFD with 50% organic manure	217	204	219	213
Mean	223	214	217	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm $\pm$	7.02	7.21	15.11	
CD (p=0.05)	NS	NS	NS	

Available P_2O_5 ($kg\ ha^{-1}$):

S_1 -Control	91	120	110	107
S_2 -RFD	102	117	117	112
S_3 -RFD+50% more N	96	107	114	106
S_4 -Organic manure alone	107	131	101	113
S_5 -50% RFD with 50% organic manure	92	120	101	107
Mean	97	119	110	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm $\pm$	5.23	4.92	11.11	
CD (p=0.05)	10.23	NS	21.78	

Fertilizer levels did not significantly influence the available P_2O_5 in post harvest soil.

The interaction effects indicated that M_2S_4 resulted in the highest available P_2O_5 ($131.00 \text{ kg ha}^{-1}$) closely followed by M_2S_5 and M_2S_1 which were at par with each other. M_2S_4 was significantly superior to other combinations. The lowest available P_2O_5 (91.67 kg ha^{-1}) was registered in M_1S_1 .

4. 6. 3 Available K_2O

The data presented in Table 19 revealed that water regimes, fertilizer levels and their interactions did not significantly influence the available K_2O in soil after harvest of rice crop. It ranged 438 kg ha^{-1} with M_1S_3 to 469 kg ha^{-1} with M_3S_5 .

Though it was not significant, the available K_2O among water regimes was in the ascending order of $M_1 < M_2 < M_3$ whereas the trend among fertilizer levels $S_3 < S_1 < S_2 < S_4 < S_5$.

4. 6. 4 Available Zinc

The data presented in Table 19 revealed that available Zn in soil after harvest of rice crop was significantly influenced by water regimes, fertilizer levels and their interactions.

Table 19 : Available K₂O & Zn in post harvest soil as influenced by nutrient and water management practices

Available K₂O (kg ha⁻¹):

Fertilizer levels	Water regime			Mean
	Continuous flooding (M ₁)	IW/CPE= 1.0 (M ₂)	IW/CPE= 0.75 (M ₃)	
S ₁ -Control	451	449	451	450
S ₂ -RFD	450	449	453	450
S ₃ -RFD+50% more N	438	439	466	448
S ₄ -Organic manure alone	449	451	466	455
S ₅ -50% RFD with 50% organic manure	441	458	469	456
Mean	446	449	461	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	7.93	6.92	16.73	
CD (p=0.05)	NS	NS	NS	

Available Zn (ppm):

S ₁ -Control	16.5	12.9	12.2	13.9
S ₂ -RFD	14.5	12.5	11.9	12.9
S ₃ -RFD+50% more N	13.5	11.1	12.9	12.5
S ₄ -Organic manure alone	15.9	12.8	12.8	13.8
S ₅ -50% RFD with 50% organic manure	13.8	12.1	13.1	13.0
Mean	14.8	12.3	12.6	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm ±	0.19	0.65	0.64	
CD (p=0.05)	0.37	1.29	1.25	

Among the water regimes, M_1 resulted in the highest mean Zn availability (14.8 ppm) which was significantly higher compared to other water regimes. The lowest mean Zn availability (12.3 ppm) was associated with M_2 .

Higher mean available Zn (13.9 ppm) was observed in control plots (S_1) closely followed by S_4 , S_5 and S_2 . S_1 was significantly higher to S_3 which recorded the lowest mean available Zn (12.5 ppm).

Available Zn was highest with M_1S_1 followed by M_1S_4 and M_1S_2 which were at par with each other. M_1S_1 was significantly superior to other combinations except M_1S_4 . The lowest available Zn associated with M_2S_3 .

4.7 WATER USE EFFICIENCY

The data on water use efficiency is presented in Table 20 and Fig. 12. It is evident from the data that water use efficiency was significantly influenced by water regimes, fertilizer levels and their interactions.

Among water regimes, M_3 resulted in the highest mean water use efficiency ($13.79 \text{ kg ha}^{-1}\text{mm}^{-1}$) which was significantly higher compared to other water regimes. The lowest mean water use efficiency ($6.68 \text{ kg ha}^{-1}\text{mm}^{-1}$) was associated with M_1 .

The highest mean water use efficiency ($12.40 \text{ kg ha}^{-1}\text{mm}^{-1}$) was observed in fertilizer level of S_3 followed by S_2 and S_5 . They were at par with

each other and were significantly superior to other treatments. The lowest mean water use efficiency ($7.50 \text{ kg ha}^{-1}\text{mm}^{-1}$) was recorded in S_4 treatment.

Water use efficiency was also significantly influenced by the interaction effect of water regimes and fertilizer levels. It was the highest with the combination of M_3S_3 closely followed by M_3S_2 and M_3S_5 . They were at par with each other and were significantly superior to other combinations. The lowest water use efficiency was recorded in combination with M_1S_1 .

Table 20 : Water use efficiency ($\text{kg ha}^{-1} \text{mm}^{-1}$) of rice crop as influenced by nutrient and water management practices

Fertilizer levels	Water regime			Mean
	Continuous flooding (M_1)	IW/CPE= 1.0 (M_2)	IW/CPE= 0.75 (M_3)	
S_1 -Control	4.49	8.79	9.42	7.57
S_2 -RFD	8.61	12.28	16.02	12.30
S_3 -RFD+50% more N	7.89	11.86	17.46	12.40
S_4 -Organic manure alone	4.58	7.26	10.67	7.50
S_5 -50% RFD with 50% organic manure	7.82	9.47	15.41	10.90
Mean	6.68	9.93	13.79	
	Water regime(M)	Fertilizer level(S)	Mx S	
SEm $\pm$	0.60	0.73	1.33	
CD (p=0.05)	1.18	1.44	2.60	

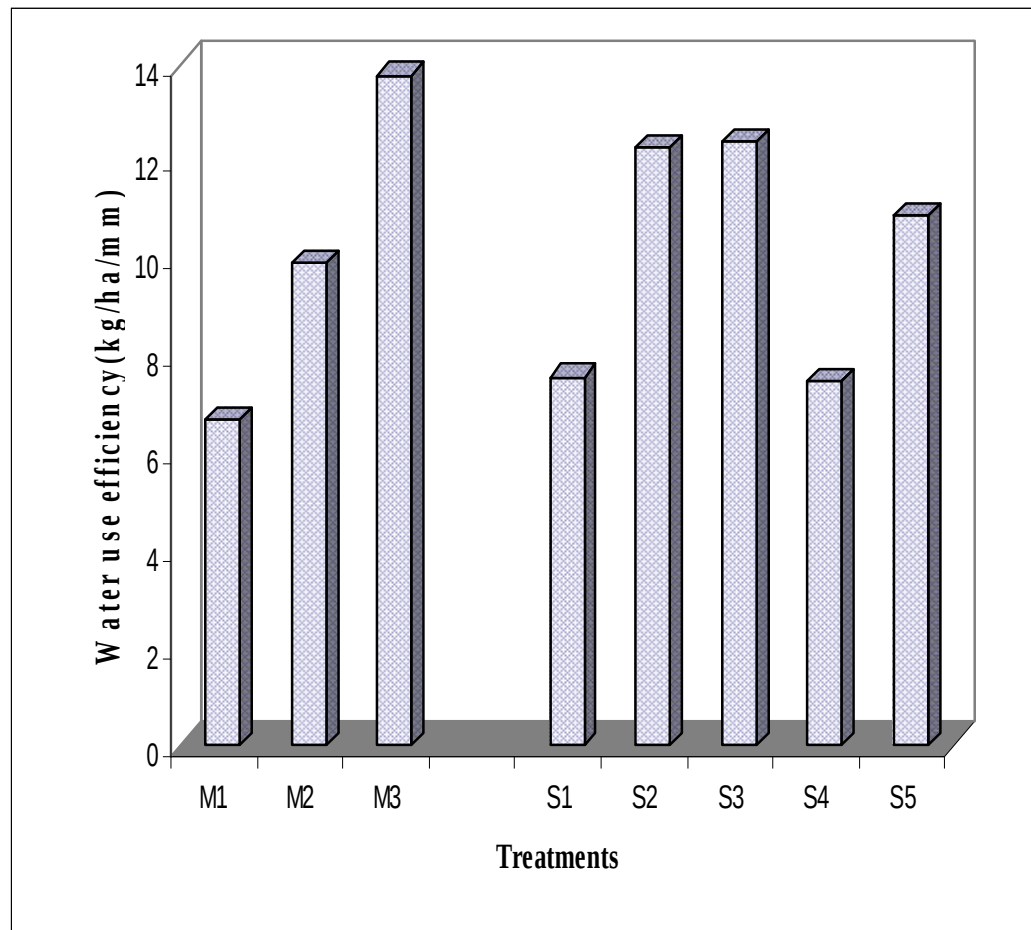


Fig. 12: Water use efficiency of rice crop as Influenced by nutrient and water management practices

CHAPTER V

DISCUSSION

Influence of nutrient and water management practices on methane emission from rice field, yield variation of rice crop and uptake of nutrients by rice crop were studied. The results obtained are discussed in this chapter in the light of available literature. The major trends of variations have been discussed rather than the individual variations.

Methane emission rates increased with accelerating rates in the morning, and reached a maximum during early afternoon (12.30 pm-2.30pm). Then followed by a rapid decrease during the evening (Table 2 and Figure 3). This distinct diurnal pattern was observed over a period of 10 hours (7.30am to 5.30pm). The diurnal variation would be a function of the methane concentration in soil solution. The diffusion coefficient is temperature dependent and changes significantly during the day time. This diurnal pattern was similar to those observed by Wang *et al.* (1999a), Satpathy *et al.* (1997) and Sass and Fisher (1994).

Soil, water and air temperatures reached a maximum in the early afternoon when CH₄ emission was the highest (Table 3 and Figure 4). CH₄ emission was influenced by many factors such as solar radiation, atmospheric, soil and water temperatures (Sass *et al.*, 1991).

Water regimes significantly influenced CH_4 emission at various growth stages of rice plants (Table 4, 5, 6, 7). The highest CH_4 emission was observed in water regime of continuous flooding followed by irrigation given at $\text{IW/CPE} = 1.0$. The lowest CH_4 emission was observed when irrigation was given at $\text{IW/CPE} = 0.75$. It was observed that with the advancement of growth stages there was increase in CH_4 emission up to flowering. At tillering stage, CH_4 emission was low compared with other growth stages. After irrigation there was a considerable enhancement in CH_4 emission when compared with before irrigation, especially in intermittently flooded plots.

At panicle initiation stage, CH_4 emission was more than that of tillering stage. But it was less than that of flowering stage. At this stage also, there was increased CH_4 emission after irrigation in drier water regimes.

At flowering stage, CH_4 emission was maximum compared with other growth stages. However, at maturity stage, CH_4 emission was minimum compared with other growth stages. The reason being, as the growth advanced, the increment in biomass production prompted high rates of CH_4 emission (Sinha, 1995).

Flooding the soil generally creates anaerobic condition favorable for CH_4 production and emission. But under intermittent irrigation, it may not be possible to create anaerobic condition as observed under flooding and hence there was a minimum emission of CH_4 from rice field. The pattern of CH_4 emission due to seasonal variation also was similar to that of pattern followed in stage-wise

emission (Table 9). There was significant reduction in seasonal CH₄ emission to an extent of 25 and 40 percent in the treatments of IW/CPE=1.0 and IW/CPE=0.75, respectively over continuous flooding. Higher production and emission of CH₄ under flooded conditions, is brought out by methanogenic bacteria that can metabolize only in the strict absence of free oxygen, coupled with alkaline condition of the flooded soil which also contributes to CH₄ emission (Neue, 1993 and Minami 1994).

A net decrease of CH₄ emission to an extent of 28% was observed by Jain *et al.* (2000) by applying intermittent irrigation. Thus, flood water regime can have a strong influence on CH₄ emission rates from rice fields (Minami, 1994, Wang *et al.*, 2000 and Wassmann *et al.*, 2000b).

The results further showed that seasonal CH₄ emission was also significantly influenced by fertilizer levels (Table 8). RFD treatment recorded highest seasonal CH₄ emission which was significantly superior to all other treatments, followed by 50% RFD+ 50% organic manure and organic manure alone and both of these were at par with each other and were significantly higher to control treatment. The higher CH₄ emission is known to occur due to application of chemical fertilizers. Similarly, Lindau *et al.* (1991) reported that CH₄ emission increased as the application rate of urea- N was increased. Seasonal CH₄ emission increased by 74% following application of RFD as compared to control treatment (Table 9). It was observed that seasonal flux of

CH₄ increased by 45% and 54%, respectively following application of organic manure alone and 50% RFD+ 50% organic manure.

The least amount of CH₄ t⁻¹ grain yield was recorded in control treatment followed by RFD treatment. Lower amount of CH₄ t⁻¹ grain yield was recorded in 50% RFD+ 50% organic manure compared to the organic manure alone.

RFD treated plots always recorded more biomass production (Appendix IV) than other treatments. The increase in CH₄ emission by rice crop in response to heavy fertilization would be a function of increased biomass production. Since methane is produced in rhizosphere from organic carbon released by the plant, a higher above ground biomass would potentially release more organic carbon (Sinha, 1995).

CH₄ emission from plots treated with 50% RFD+ 50% organic manure was less than that of RFD treated plots. The reduction in CH₄ emission may be due to less biomass production than RFD treated plots. When compared to plots treated with organic manure alone, plots treated with 50% RFD+ 50% organic manure recorded more CH₄ emission. The increase of CH₄ emission may be due to more biomass production from plots treated with 50% RFD+ 50% organic manure than plots treated with organic manure alone. Similar results were reported by (Cicerone *et al.* 1983 and Sinha, 1995), where in they clearly showed the dependence of CH₄ emission on biomass.

When compared to sole organic manure more CH₄ emission was observed than control plots, may be due to the increase of readily mineralizable carbon

content in soil. The mineralizable carbon in the organic carbon content of the organic amendment was one of the principal factors affecting CH₄ emission from flooded soils (Yagi and Minami, 1990).

Interaction effects also influenced the seasonal CH₄ emission (Table 8). When compared with seasonal flux and grain yield (Table 11), less amount of CH₄ t⁻¹ grain yield was recorded in combinations of M₂S₁, M₃S₁ and M₃S₂. But M₂S₁ and M₃S₁ recorded lower grain yield than M₃S₂. Therefore M₃S₂ (water regime of IW/CPE=0.75+RFD fertilizer level) can be recommended as a suitable mitigation practice. In this combination, CH₄ emission was reduced by 38% over M₁S₂ (continuous flooding +RFD) combination. These results corroborate the finding of Wang et al. (2000) and Lu *et al.* (2000).

CH₄ emission steadily increased over the cropping season (Table 10, Fig. 5 & 6). Maximum methane emission was observed at the flowering stage. Similar seasonal pattern was observed by Holzapfel-pschorn *et al.* (1986).

The variation in methane emission during the vegetative period may be due to the gradual increase in biomass production, reaching the maximum by flowering. The higher CH₄ emission between the maximum tillering and PI (ground growth period) can also be attributed to disturbance of wetland soil by cultural practices, which favours soil trapped methane to escape to atmosphere through ebullition (Nue, 1993 and Wassmann and Martius, 1997). After flowering however, the rate of CH₄ emission decreases significantly. Since the rate of photosynthesis declines after the commencement of grain development,

the supply of current assimilates for methane production would also decrease (Sinha, 1995), resulting in decreased CH₄ emission at maturity stage. These results suggest that it is important to evaluate the integrative effects of water management and fertilizer application for mitigating greenhouse effect caused by methane emission in order to attenuate the global warming contributed by rice paddy fields.

The results further (Table 12) indicated that grain and straw yield were significantly influenced by water regimes, fertilizer levels and their interactions.

Among the water regimes, both grain and straw yields were higher with continuously flooded plots and lower with water regimes of IW/CPE=1.0 and IW/CPE=0.75. This variation in rice crop obviously is due to more favourable conditions brought about in soil environment for plant growth through continuous flooding. Continuous flooding was a cause to supply adequate water for soil solution which could obviously increase nutrient availability and subsequent enhanced nutrient uptake. Such results were earlier reported by Parihar (2004).

Intermittent irrigation limits water availability for optimum crop growth. Water stress at any growth stage reduces rice yield. A soil moisture content of - 50 kPa (slightly above field capacity) may reduce rice grain yield by about 20-25% compared to continuously flooded treatment (De Datta, 1981).

Higher grain and straw yields were registered with RFD (S_2) followed by RFD + 50% more N (S_3). Significant increase in grain and straw yields with more inorganic fertilizer could be attributed to increased dry matter and root growth. The highest NPK rate of application was contributed to increase N, P and K uptake, grain and straw yields (Sudha and Chandini, 2002).

There was significant increase in grain and straw yields due to application of 50% RFD+ 50% organic manure over other fertilizer levels (S_4 and S_1). The increased availability of both macro and micronutrients from FYM resulted in relatively higher yields. This might be due to accelerated mineralization of organic sources in the presence of inorganic fertilizers (urea) due to stimulatory effect of urea on microbes (Chakraborty and Mandal, 1988).

Among all the interactions, higher grain and straw yield were associated with combinations of M_1S_2 followed by M_1S_3 and M_1S_5 over other combinations. This can be attributed to increased availability of nutrients and moisture due to combined effect of continuous flooding with RFD, RFD+50% more N and 50% RFD+ 50% organic manure. These results are in agreement with observation of Jadhav and Dahiphale (2005).

The results (Table 13) revealed that number of tillers and panicles were significantly influenced by water regimes, fertilizer levels and their interactions.

Higher number of tillers and panicles were observed in continuously flooded plots than intermittently irrigated plots. This variation might be quite

reasonable to emphasize that adequate moisture condition was the reason for increase in availability of nutrients for enhancing plant growth. Lower number of tillers and panicles were observed in intermittently irrigated plots may be due to water stress effect caused on plant growth. This trend is in agreement with findings of Patra (2000).

Among the fertilizer levels, number of tillers and panicles were higher in plots treated with RFD, RFD+50% more N and 50% RFD+ 50% organic manure over organic manure alone and control plots. This trend could also be attributed to more nutrient availability for better plant growth. Similar trend was reported by Pandey *et al.* (2000) and Rammohan *et al.* (2000).

Among interactions, combination of continuous flooding with RFD +50% more N was found to be superior over other combinations. This could be attributed to the combined favourable effects of water regime and fertilizer levels on soil fertility and plant growth. These results are in agreement with observation of Jadhav and Dahiphale (2005).

Content of N, P and Zn in plants (Table 14, 15, 16 and 17) was significantly influenced by water regimes, whereas K content was not significantly influenced by water regimes. Among the water regimes, higher N and P contents were observed in continuously flooded plots over other water regimes. This can be attributed to the increased N and P availability under anaerobic condition. Soil submergence is known to influence the availability of $\text{NH}_4\text{-N}$ and phosphorus (Patra, 2000). Higher Zn content was observed in water

regimes of IW/CPE=1.0 and IW/CPE=0.75 over the continuously flooded plots. The availability of Zn decreases due to submergence and by the formation of insoluble compounds of Zn as ZnS and ZnCO₃. These results are in accordance with report of Mythili *et al.* (2003).

Fertilizer levels of RFD and RFD+ 50% more N recorded higher NPK and Zn content in the plant over other treatments. The higher level of inorganic fertilizer application significantly increased the nutrient availability and root growth contributing to higher nutrient content in the plant. These observations corroborate the findings of Sudha and Chandini (2002).

Among the interaction effects, Higher NPK contents were associated with combinations of M₁S₂ and M₁S₃ which might be due to combined favourable impact of moisture availability and soil fertility. These observations are in accordance with the report of Jadhav and Dahiphale (2005).

Higher Zn content was associated with combination of driest water regime (IW/CPE=0.75) and RFD+ 50% more N. This could be due to the increase in the availability of Zn under oxidized soil condition.

Uptake of NPK and Zn by rice crop (Table 14, 15, 16 and 17) was significantly influenced by water regimes. Among the water regimes, higher N, P and K uptake were observed in continuously flooded plots. It was obvious from the data that these variations were brought about due to significant differences in crop yield and plant nutrient content. The highest NPK uptake

with continuous flooding might be due to the optimum soil environment leading to better root growth and nutrient absorption. The findings of De Datta (1981) and Patra (2000) lend support to the present findings.

Higher Zn uptake was observed in driest water regime (IW/CPE=0.75) over other water regimes. This variation may be due to the increase in Zn availability under oxidized soil condition as discussed above.

Fertilizer levels of RFD and RFD+ 50% more N recorded higher NPK and Zn uptake over other treatments. Higher level of inorganic fertilizer application significantly increased the root growth and nutrient availability and ultimately the nutrient uptake. These results are in accordance with report of Sudha and Chandini (2002).

Among interaction effects, higher uptake of NPK was recorded with combination of M_1S_2 and M_1S_3 . The highest Zn uptake was observed in combinations of drier water regimes of IW/CPE=1.0 and IW/CPE=0.75 with RFD fertilizer level.

Available P_2O_5 and Zn in post harvest soil (Table 18 and 19) were significantly influenced by water regime whereas available N and K did not show any such trend.

Among the water regimes, higher available P_2O_5 was observed in drier water regimes of IW/CPE=1.0 and IW/CPE=0.75 over the continuously flooded plots. This variation may be due to higher P uptake by plants from continuously

flooded plots (Table 15). Higher Zn availability was reported with continuously flooded plots compared to other water regimes. This variation may be due to lower Zn uptake by plants from continuously flooded plots (Table 17).

Fertilizer levels did not significantly influence the available N, P_2O_5 and K_2O . Among the fertilizer levels, control plots (S_1) resulted in highest Zn availability may be due to lower Zn uptake from control plots.

The interaction effects indicated that combination of water regime of IW/CPE= 1.0 and organic manure alone resulted in highest available P_2O_5 . This trend may be due to lower P uptake from this treatment. Available Zn was highest in combination of continuous flooding + control plot.

The results showed that the variation in water use efficiency (Table 20) was significant among water regimes, fertilizer levels and their inter actions. Among water regimes, the highest water use efficiency was recorded with water regime of IW/CPE=0.75. This trend in rice crop obviously was due to application of less amount water compared to the other water regimes. Similar results were given by Lourduraj and Bayan (1999).

Fertilizer levels of RFD+ 50% more N, RFD and 50% RFD+50% organic manure recorded higher water use efficiency over the other treatments because of higher grain yield recorded in these plots. Similar trend was reported by Jadhav and Dahiphale (2005).

Water use efficiency was higher with the combinations of water regime of IW/CPE=0.75 with RFD+50% more N, RFD and 50% RFD+50% organic manure.

CHAPTER VI

SUMMARY

A field experiment on “Influence of management practices on the methane emission in rice field” was conducted at the Directorate of Rice Research, Rajendranagar, Hyderabad on clay soil during *rabi* season of 2005-2006 to find out the influence of nutrient and water management practices on methane emission from rice field and to suggest mitigation options, yield variation of rice crop and uptake of NPK by rice crop. The salient features of the findings made and conclusions drawn are presented below.

1. A distinct diurnal pattern of methane efflux was observed over a period of 10 hours (7.30am to 5.30pm) at tillering stage of rice crop.
2. Water regimes significantly influenced CH₄ emission at different growth stages of rice crop. Among the water regimes, irrigations at IW/CPE=0.75 and IW/CPE=1.0 were superior as compared to continuous flooding as they showed reduction in methane emission. There was reduction in seasonal CH₄ emission to an extent of 25% and 40% in treatments of IW/CPE= 1.0 and IW/CPE= 0.75, respectively over continuous flooding.
3. It was observed that with the advancement of growth stages there was increase in CH₄ emission up to flowering. At flowering stage, CH₄ emission was maximum compared with other growth stages. However, at maturity stage, CH₄ emission was minimum coupled with other growth stages.

4. After irrigation, there was a considerable enhancement in CH_4 emission when compared with before irrigation, especially in intermittently flooded plots. Water regime of $\text{IW/CPE} = 0.75$ recorded least amount of $\text{CH}_4 \text{ t}^{-1}$ of grain yield (1.28kg) compared with other water regimes.
5. RFD treatment recorded the highest seasonal CH_4 emission which was significantly superior to all other treatments followed by 50% RFD+ 50% organic manure and organic manure alone. Both of these were at par with each other and were significantly superior to control treatment. Among fertilizer levels, least amount of seasonal $\text{CH}_4 \text{ t}^{-1}$ of grain yield (1.49kg) was recorded with RFD treatment compared with other treatments.
6. Among interaction effects, least amount of seasonal $\text{CH}_4 \text{ t}^{-1}$ of grain yield (1.49kg) was recorded with combination of $\text{IW/CPE} = 0.75$ + RFD treatment.
7. Among the water regimes, continuously flooded plots recorded a significant influence over drier water regimes in registering better growth parameters (biomass production and number of tillers hill^{-1}), yield attributes (number of tillers hill^{-1}), grain and straw yields.
8. Higher grain and straw yields were registered with RFD treatment followed by RFD+ 50% more N. There was significant increase in grain and straw yields due to application of 50% RFD+ 50% organic manure over organic manure alone and control treatment.
9. Higher N and P contents of plant were observed in continuously flooded plots over other water regimes. However, higher Zn content was recorded in water regimes of $\text{IW/CPE} = 1.0$ and $\text{IW/CPE} = 0.75$ over the

continuously flooded plots. Higher plant content of NPK and Zn was associated with fertilizer levels of RFD and RFD+50% more N.

10. Uptake of NPK by rice crop was higher in continuously flooded plots over drier water regimes. However, higher Zn uptake was observed in the driest water regime (IW/CPE=0.75) over other water regimes. Fertilizer levels of RFD and RFD+50% more N recorded higher NPK and Zn uptake over other treatments.

11. With regard to nutrient status of the soil after harvest of the crop, higher available P_2O_5 was recorded in drier water regimes over the continuously flooded plots. However, higher Zn status was reported with continuously flooded plots.

12. The highest water use efficiency was recorded with the driest water regime (IW/CPE=0.75) over other water regimes. Water use efficiency was higher with fertilizer levels of RFD+50% more N, RFD and 50% RFD+ 50% organic manure.

Finally, it was concluded that the combination of IW/CPE=0.75 +RFD treatment can be recommended as a suitable mitigation option owing to its least amount of seasonal CH_4 t^{-1} of grain yield (1.29kg).

Maximum grain yield and higher NPK uptake could be obtained with the combination of continuous flooding+ RFD treatment. However higher Zn uptake can be obtained with combination of IW/CPE=0.75 +RFD treatment.

Combination of IW/CPE=0.75 +RFD with 50% more N treatment can be followed to obtain maximum water use efficiency ($17.46 \text{ kg ha}^{-1} \text{ mm}^{-1}$).

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Appendix I

Weekly mean meteorological data during crop growth period (January – May, 2006)

Standard Week	Period	Temperature ($^{\circ}\text{C}$)		R.H. (%)		Rainfall (mm)	Rainy days	Sun Shine (hrs.)	Wind Speed (km/hr)	Evaporation (mm)	Mean Temp ($^{\circ}\text{C}$)
		Max.	Min.	I	II						
1	Jan. 01- 07	27.2	11.1	88.6	34.9	0.0	0	9.3	2.4	2.4	19.2
2	Jan. 08- 14	29.4	14.6	91.6	38.7	0.0	0	8.9	2.1	2.4	22.0
3	Jan. 15- 21	32.0	13.7	85.6	24.0	0.0	0	9.7	2.2	2.8	22.9
4	Jan. 22- 28	29.8	10.6	79.0	19.6	0.0	0	10.1	2.2	2.9	20.2
5	Jan.29-Feb.04	29.8	11.9	80.6	25.7	0.0	0	10.0	2.9	3.1	20.9
6	Feb.05- 11	30.7	12.2	82.9	22.0	0.0	0	10.1	2.9	3.2	21.5
7	Feb.12- 18	33.1	14.3	79.7	20.9	0.0	0	10.2	2.5	3.5	23.7
8	Feb.19- 25	35.5	15.4	75.6	19.6	0.0	0	10.3	3.2	4.6	25.5
9	Feb.26-Mar.04	34.9	18.3	80.0	30.6	58.0	1	9.6	4.6	5.7	26.6
10	Mar.05- 11	31.7	20.9	92.7	49.0	30.0	3	7.6	4.3	3.6	26.3
11	Mar.12- 18	31.7	20.1	87.0	35.4	0.0	0	8.9	3.0	3.8	26.0
12	Mar.19- 25	34.4	18.2	76.7	23.4	0.0	0	9.0	2.9	4.6	26.3
13	Mar.26- Apr.01	36.6	22.0	68.6	23.7	0.0	0	8.7	2.4	5.4	29.3
14	Apr.02- 08	38.2	22.8	70.3	20.9	0.4	0	8.6	2.0	5.9	30.5
15	Apr.09- 15	38.4	23.5	80.3	29.4	1.0	0	8.4	3.1	6.1	31.0
16	Apr.16- 22	33.9	22.3	87.4	41.4	38.9	2	8.0	3.1	5.0	28.1
17	Apr.23- 29	38.4	23.7	54.9	24.0	0.0	0	10.2	2.5	6.8	31.1
18	Apr.30-May 06	38.5	24.9	59.0	29.7	0.0	0	9.3	3.8	6.5	31.7
19	May 07- 13	40.0	24.5	55.6	22.6	0.4	0	10.4	3.7	7.6	32.3
20	May14 - 20	39.8	26.7	61.7	25.4	0.0	0	10.2	4.4	8.7	33.3
21	May21 - 27	36.3	25.3	73.7	51.4	39.2	2	8.6	6.1	7.0	30.8
22	May28- Jun. 03	33.8	25.0	78.7	53.7	0.0	0	7.1	4.7	4.8	29.4

Appendix II

CALENDAR OF OPERATIONS

<u>Date</u>	<u>Operation</u>
12.01.2006	- Nursery Sowing
06.02.2006	- First Ploughing
08.02.2006	- 2 nd Ploughing
12.02.2006	- Land Leveling
12.02.2006	- Layout
13.02.2006	- Basal dose of fertilizer Application and Transplanting
24.02.2006	- Insecticide (granules) Application
01.03.2006	- Insecticide Spraying (Monocrotopos)
12.03.2006	- First Topdressing
06.04.2006	- Insecticide Spraying (Monocrotopos)
07.04.2006	- 2 nd Topdressing
29.05.2006	- Harvesting and Threshing

Appendix III

Application of Irrigation water

Date	Continuous flooding		IW/CPE = 1.0		IW/CPE = 0.75	
	Time (mins.)	Depth (mm)	Time (mins.)	Depth (mm)	Time (mins.)	Depth (mm)
25.02.06	60	25.0	-	-	-	-
27.02.06	-	-	90	30.5	70	22.9
28.02.06	60	25.0	-	-	-	-
02.03.06	60	25.0	-	-	-	-
13.03.06	60	25.0	-	-	-	-
16.03.06	60	25.0	-	-	-	-
17.03.06	-	-	90	30.5	70	22.9
18.03.06	60	25.0	-	-	-	-
21.03.06	60	25.0	-	-	-	-
23.03.06	-	-	90	31.5	70	23.6
24.03.06	60	25.0	-	-	-	-
27.03.06	60	25.0	-	-	-	-
28.03.06	-	-	80	25.4	60	19.1
31.03.06	60	25.0	-	-	-	-
03.04.06	60	25.0	90	33.1	70	24.8
06.04.06	60	25.0	-	-	-	-
10.04.06	60	25.0	120	44.3	90	33.2
13.04.06	60	25.0	-	-	-	-
16.04.06	60	25.0	-	-	-	-
21.04.06	60	25.0	-	-	-	-
24.04.06	60	25.0	105	36.8	80	27.6
26.04.06	60	25.0	-	-	-	-
29.04.06	60	25.0	100	34.4	75	25.8
02.05.06	60	25.0	-	-	-	-
04.05.06	60	25.0	100	33..2	75	24.9
06.05.06	60	25.0	-	-	-	-
08.05.06	60	25.0	-	-	-	-
09.05.06	-	-	90	31.7	70	23.8
10.05.06	60	25.0	-	-	-	-
13.05.06	60	25.0	100	33.6	75	25.2
15.05.06	60	25.0	-	-	-	-
Total		650.0		365.0		273.8

Appendix IV

Plant biomass content at different growth stages

Treatment	Tillering stage				PI stage				Flowering stage			
	28 DAT		33 DAT		48 DAT		50 DAT		69 DAT		71 DAT	
	FW (g)	TPV (ml)	FW (g)	TPV (ml)	FW (g)	TPV (ml)	FW (g)	TPV (ml)	FW (g)	TPV (ml)	FW (g)	TPV (ml)
M ₁ S ₁	15.3	24	24.2	30	35.0	74	58.2	86	73.2	144	76.5	136
M ₁ S ₂	31.8	45	34.5	48	104.3	172	126.7	198	266.5	392	238.0	324
M ₁ S ₄	20.5	32	28.3	34	59.1	84	62.1	98	116.9	210	124.2	216
M ₁ S ₅	29.4	40	32.1	42	84.0	148	96.5	167	180.9	320	197.1	298
M ₂ S ₁	11.6	25	13.8	29	22.1	52	38.4	58	70.2	130	74.3	126
M ₂ S ₂	21.7	42	26.4	52	43.4	84	52.6	108	97.1	215	100.8	224
M ₂ S ₄	6.2	29	10.8	31	32.4	60	41.7	72	65.8	158	87.5	115
M ₂ S ₅	15.1	31	18.3	40	42.2	72	47.8	85	82.9	210	90.6	184
M ₃ S ₁	7.8	22	12.8	28	32.2	42	35.0	51	48.6	135	84.2	108
M ₃ S ₂	18.3	35	20.2	39	53.0	75	58.3	96	104.9	235	175.0	240
M ₃ S ₄	12.7	27	15.8	33	36.1	58	39.5	64	48.2	104	57.1	98
M ₃ S ₅	14.2	34	16.7	37	40.0	72	49.4	84	98.5	188	160.5	169

FW – Fresh weight per hill

S₁– Control

TPV – Total plant volume per hill

S₂– RFD

manure

M₁ – Continuous flooding

M₂ – IW/CPE = 1.0

M₃ – IW/CPE = 0.75

S₄ – Organic manure only

S₅ – 50% RFD+ 50% organic