

172024

ACC. No. 172024

630

RRR/MB

METHANE EMISSION FROM WETLAND RICE FIELDS OF KERALA



By

REENA MATHEW

THESIS

*Submitted in partial fulfilment of the
requirement for the degree of*

Doctor of Philosophy in Agriculture

*Faculty of Agriculture
Kerala Agricultural University*

DEPARTMENT OF AGRONOMY
COLLEGE OF HORTICULTURE
KAU P. O., THRISSUR - 680 656
KERALA, INDIA

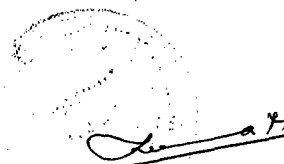
2003

DECLARATION

I hereby declare that this thesis entitled “Methane emission from wetland rice fields of Kerala” is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship, associateship or other similar title, of any other University or Society.

Place : Vellanikkara

Date : 26 - 11 - 2002



REENA MATHEW
(96-21-13)

CERTIFICATE

Certified that this thesis entitled “**Methane emission from wetland rice fields of Kerala**” is a record of research work done independently by Ms. REENA MATHEW, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.



DR. P.V. BALACHANDRAN
Chairman, Advisory Committee &
Associate Director (i/c)
Regional Agricultural Research Station
Pattambi
Kerala Agricultural University

Place : Vellanikkara

Date : 26 - 11 -2002

CERTIFICATE

We, the undersigned members of the Advisory Committee of Ms. REENA MATHEW (96-21-13), a candidate for the degree of Doctor of Philosophy in Agriculture, agree that this thesis entitled "Methane emission from wetland rice fields of Kerala" may be submitted by Ms. REENA MATHEW in partial fulfilment of the requirement for the degree.



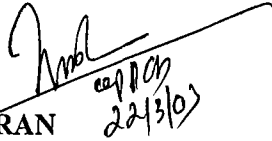
DR. P.V. BALACHANDRAN
Chairman, Advisory Committee &
Associate Director (i/c)
Regional Agricultural Research Station
Pattambi
Kerala Agricultural University



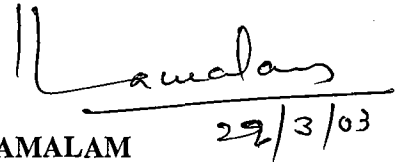
DR. C.T. ABRAHAM
Associate Professor & Head
Department of Agronomy
College of Horticulture
Kerala Agricultural University
Vellanikkara, Thrissur



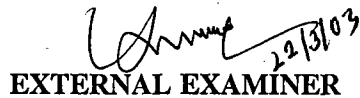
DR. C.S.P. IYER
Head, Centre for Marine Analytical
Reference and Standards
Regional Research Laboratory
Thiruvananthapuram



DR. U. JAIKUMARAN
Associate Professor & Head
Agricultural Research Station
Mannuthy, Thrissur



Smt. N.V. KAMALAM
Former Professor & Head
Radio Tracer Laboratory
College of Horticulture
Kerala Agricultural University
Vellanikkara, Thrissur



EXTERNAL EXAMINER
DR. K. VELASUDHAN
TNAU
COIMBATORE

ACKNOWLEDGEMENT

I wish to place on record my deep sense of gratitude and indebtedness to Dr. P.V. Balachandran, Associate Director (i/c) Regional Agricultural Research Station, Pattambi and Chairman, Advisory Committee for his expert guidance, critical suggestions and constant encouragement throughout the course of the investigation.

My sincere gratitude is expressed to Dr. C.T. Abraham, Associate Professor and Head, Department of Agronomy and member, Advisory Committee, for his valuable suggestions and keen interest during the period of study.

I am greatly obliged to Dr. C.S.P. Iyer, Head, C-MARS, RRL, Thiruvananthapuram and member, Advisory Committee, for his inspiring suggestions and expert guidance during the various stages of the programme.

I owe my gratitude to Dr. U. Jaikumaran, Associate Professor and Head, ARS, Mannuthy, and member, Advisory Committee, for providing the facilities for conducting the field experiment and for his whole hearted co-operation.

With great devotion I express my heartfelt gratitude and affection for Smt. N.V. Kamalam, former Professor & Head, Radio Tracer Laboratory, College of Horticulture for her ever willing help and guidance from the beginning of the investigation.

It is my pleasure to gratefully acknowledge the never ending support and guidance extended to me by Dr. R. Gopinathan, Dr. K.E. Savithri, Dr. Jose Mathew, and Dr. Mercy George, Associate Professors and Dr. A. Latha, Assistant Professor of the Department of Agronomy, College of Horticulture. The co-operation extended by Sri. Govindankutty and Sri. Rajendra Babu is highly appreciated.

I express my sincere gratitude to Dr. N.N. Potty, Professor (Retd.) and former Head, Department of Agronomy, College of Horticulture, Dr. R. Vikraman Nair, Director of Research (i/c), Kerala Agricultural University and former member of my Advisory Committee for critical suggestions and enduring interest during the execution of this work.

I am extremely grateful to Dr. P.A. Wahid, Director of Academic and PG studies, for his expert advice in the interpretation of the data relating to radio tracer experiments.

I am indebted to Dr. P. Sureshkumar, Assistant Professor and Radiological safety officer, Radio Tracer Laboratory for his unfailing support and sincere efforts. I am also thankful to Dr. P. Sreedevi, Associate Professor & Head and Dr. N. Saifuddin, Associate Professor, for their valuable suggestions. The co-operation extended by Smt. Valsala is remembered with gratitude.

I take this opportunity to express my sincere gratitude to Sri. K. Madhavan Nair, Professor (Instrumentation) for the prompt and needful help during the critical stages of the investigation.

I am grateful to Dr. V.K.G. Unnithan, Professor & Head, Department of Agricultural Statistics, College of Horticulture for his suggestions during the statistical analysis.

I very much appreciate the co-operation extended to me by Smt. G. Santhakumari, Professor and Head, Dr. S. Pushkala, Associate Professor, Dr. T.K. Bridgit, Assistant Professor and other staff members of ARS, Chalakudy.

With immense pleasure I recall the timely help and unfailing support received from Dr. B. Vijayalakshmianna, Department of Ocean Development, RRL, Thiruvananthapuram and the co-operation extended by Dr. S. Karthikeyan, Smt. Sindhu and other members of the department.

I also express my gratitude for the valuable help rendered by Dr. Ramadasan Kuttan, Amala Cancer Research Institute for ¹⁴C counting.

I remember with thanks the valuable help rendered by Dr. K.A. Mariam and Dr. C.S. Gopi, Associate Professors and Dr. Betty Bastin, Assistant Professor, Department of Soil Science and Agricultural Chemistry, College of Horticulture and Sri. Rajendra Prasad, Instrumentation Engineer, during the chemical analysis of plant samples.

I express my sincere gratitude to Dr. M.T. Kanakamony and Dr. C.A. Rosamma, Associate Professors and other staff members and labourers of ARS, Mannuthy, for their timely help and sincere efforts.

My heartfelt appreciation and gratitude are extended to Dr. K.P. Visalakhi and Dr. P.K. Sudhadevi, Associate Professors and Dr. Mini Abraham, Assistant Professor for their whole hearted co-operation throughout the period of investigation. I am also thankful to other staff members and labourers of the Water Management Research Unit and Pineapple Research Centre, Vellanikkara.

I am grateful to Dr. A.I. Jose and Dr. P.V. Prabhakaran, former Associate Deans and Dr. A. Sukumara Varma, Associate Dean, College of Horticulture for providing the necessary facilities during the period of investigation.

I am thankful to Kerala Agricultural University for granting me study leave and part time registration facility for this study. The award of contingent grant from CSIR is gratefully acknowledged.

I express my deepest appreciation and gratitude to my friends Dr. Gracy Mathew, Dr. K.M. Durgadevi, Dr. Lency Thomas, Dr. Deepa Thomas, Sri. Lakshmikanthan and Sri. Sajinanath for their unstinted help and encouragement.

I acknowledge with love and gratitude the unfailing support and constant encouragement given to me by my affectionate husband Joseph and son Jerry and daughter Merin. I am indebted to the prayers and blessings of my beloved father, parents-in-law and other family members.

Finally I bow my head to God Almighty for his grace and blessings bestowed upon me for the successful completion of this enduring investigation.



REENA MATHEW

CONTENTS

Chapter No.	Title	Page No.
1.	INTRODUCTION.....	1
2.	REVIEW OF LITERATURE.....	4
3.	MATERIALS AND METHODS.....	22
4.	RESULTS.....	34
5.	DISCUSSION.....	99
6.	SUMMARY AND CONCLUSION.....	111
7.	REFERENCES.....	114

APPENDICES

ABSTRACT

LIST OF TABLES

Sl. No.	Particulars	Page No.
1.	Estimates of methane emission from rice fields of different countries	5
2.	Methods of analysis	27
3.	Chemical constituents of different plant materials on dry weight basis	30
4.	Physico-chemical properties of the soils under study	33
5.	Diurnal variations in methane flux during the different growth stages	35
6.	Diurnal variations in soil and water temperature at different growth stages	37
7.	Methane emission from paddy field as influenced by different sources of organic manure and nitrogen during the first and second crop seasons	39
8.	Soil and plant characters at tillering stage of the first crop season and tillering and booting stages of the second crop season	41-43
9.	Methane emission from paddy field as influenced by the interaction of organic manures and nitrogen fertilisers	45
10.	Effect of different sources of organic manure and nitrogen on height of plants at different growth stages during the first and second crop seasons	47
11.	Effect of different sources of organic manure and nitrogen on the number of tillers per hill during the first and second crop seasons	49
12.	Effect of different sources of organic manure and nitrogen on the root volume at different growth stages during the first and second crop seasons	50
13.	Effect of different sources of organic manure and nitrogen on the fresh weight of roots at different growth stages during the first and second crop seasons	51

Sl. No.	Particulars	Page No.
14.	Effect of different sources of organic manure and nitrogen on the yield contributing characters during the first and second crop seasons	53
15	Grain and straw yields of rice as influenced by different sources of organic manure and nitrogen during the first and second crop seasons	55
16.	Effect of different sources of organic manure and nitrogen on the nitrogen content of plant parts at different growth stages during the first and second crop seasons	56-57
17.	Effect of different sources of organic manure and nitrogen on the phosphorus content of plant parts at different growth stages during the first and second crop seasons	59-60
18.	Effect of different sources of organic manure and nitrogen on the potassium content of plant parts at different growth stages during the first and second crop seasons	61-62
19.	Effect of different sources of organic manure and nitrogen on the calcium content of plant parts at different growth stages during the first and second crop seasons	63-64
20.	Effect of different sources of organic manure and nitrogen on the magnesium content of plant parts at different growth stages during the first and second crop seasons	66-67
21.	Effect of different sources of organic manure and nitrogen on the copper content of plant parts at different growth stages during the first and second crop seasons	68-69
22.	Effect of different sources of organic manure and nitrogen on the zinc content of plant parts at different growth stages during the first and second crop seasons	71-72
23.	Effect of different sources of organic manure and nitrogen on the iron content of plant parts at different growth stages during the first and second crop seasons	73-74
24.	Effect of different sources of organic manure and nitrogen on the manganese content of plant parts at different growth stages during the first and second crop seasons	76-77

Sl. No.	Particulars	Page No.
25.	Organic carbon remaining in soil from the added organic manures	78
26.	Organic carbon remaining in soil as percentage from the added organic manures	79
27.	pH of the soil as influenced by organic manures and presence of crop	82
28.	Organic carbon content of the soil as influenced by organic manures and presence of crop	84
29.	Organic carbon remaining in soils (dpm) from the added rice straw	86
30.	Organic carbon remaining in soils (mg g^{-1}) from the added rice straw	87
31.	Organic carbon remaining in soils as percentage of the added C from rice straw	88
32.	Half life of labelled straw in different soils	90
33.	Correlation coefficient of the percentage of the organic carbon remaining in soil from the added rice straw at different intervals and decay rate constant with soil properties	91
34.	Organic carbon remaining in soils (dpm) from the added daincha	92
35.	Organic carbon remaining in soils (mg g^{-1}) from the added daincha	93
36.	Organic carbon remaining in soils as percentage of the added C from daincha	94
37.	Correlation coefficients between organic carbon remaining at different intervals from the added daincha and soil properties	96
38.	Variation in pH over time (days) due to the incorporation of organic manures in different soils	97

LIST OF FIGURES

Fig. No.	Title	Between Pages
1.	Meteorological data 1998 – 1999	22-23
2.	Meteorological data 1999 – 2000	22-23
3.	Experimental arrangement for methane efflux measurement	23-24
4.	Layout of the field experiment on the effect of organic manures and nitrogen fertilisers on methane emission	25-26
5.	Diurnal and seasonal variations in methane emission during the first and second crop seasons	36-37
6.	Methane efflux at different growth stages during the first and second crop seasons	36-37
7.	Organic carbon remaining in soil as percentage of the added C in rice straw at different intervals after incorporation	79-80
8.	Organic carbon remaining in soil as percentage of the added C from green manures at different intervals after incorporation	80-81
9.	Organic carbon remaining in soil as percentage of the added C in the presence and absence of rice	80-81
10.	Organic carbon remaining as percentage of the added carbon at periodic intervals after incorporation of rice straw and daincha in soil	89-90
11.	Exponential model of decay pattern of rice straw in different soils	90-91
12.	Variation in pH over time (days) due to the incorporation of organic manures in different soils	97-98
13.	Organic carbon remaining in soils at different intervals after incorporation of rice straw and daincha	109-110

LIST OF PLATES

Sl. No.	Title	Between Pages
1.	Perspex box and accessories for collecting air samples from rice fields	23-24
2.	Field experiment on methane emission from rice fields	25-26
3.	Pot culture experiment	28-29

INTRODUCTION

INTRODUCTION

Global warming and the consequent global climatic change has become the most debated, yet unresolved issue of great public interest. Carbon dioxide, chlorofluorocarbons, nitrous oxide and methane in the atmosphere are mainly responsible for global warming due to their green house effect. The world wide concern and awareness to increasing concentrations of green house gases stemmed from the incremental variations observed in the global atmospheric temperature levels and detection of an ozone hole in the stratosphere. Meteorological records show that the temperature rose steadily by 0.3°C to 0.6 °C during the period from 1880 to 1940 and 0.2°C during 1940-1990 (Roy and Prasad, 1991). The climatic models predict a temperature rise of 0.5°C by 2005, 1.5°C by 2050 and 3°C by 2100 (Singh, 1991). The increase in concentration of green house gases is considered to be one of the possible reasons for this increase in temperature.

Methane is recognised as the second important green house gas contributing about 15 to 20 per cent to global warming. The present atmospheric concentration of 1.8 ppmv is more than double its pre-industrial value of 0.8 ppmv (Khalil and Rasmussen, 1987). Although methane has a relatively short atmospheric life time (8 to 12 years), one molecule of methane traps about 32 times more heat than a molecule of carbon dioxide (Dickinson and Cicerone, 1986). Mosier (1998) calculated the Global warming potential of methane as 24.5, relative to carbondioxide.

A wide variety of natural and anthropogenic processes contribute to the production of methane and its emission to the atmosphere. Natural sources include wetlands, lakes, rivers, oceans etc. whereas anthropogenic sources include mining, biomass burning, landfills, ruminants, termites, animal wastes and domestic sewages. The net global annual emission of methane is estimated to be 40 Tg yr⁻¹ (IPCC, 1992) being the balance of various sources and sinks.

Wetland rice fields constitute about 88 per cent of the total rice area in the world (IRRI, 1995) and have been identified as a potent source of methane

production. Earlier reports of global emission from rice fields were alarming but more recent estimates ranged between 20 and 150 Tg yr⁻¹ with an average value of 60 Tg yr⁻¹ (IPCC, 1994). Asian countries were considered as the major contributor of methane emission from wetland rice fields since 90 per cent of the rice area in the world is located in Asia. China and India together occupy 60 per cent of the total harvested rice area in Asia. However, detailed estimations from China revealed a much lower emission rate of 13 to 17 Tg yr⁻¹ (Wang *et al.*, 1994). The reported values for India ranges from 2.7 to 6.4 Tg yr⁻¹ (Parashar *et al.*, 1994).

The variability in the emission rates reported from time to time reveals the necessity for standardisation and further refinements in the procedures for estimation. Large temporal and spatial variability is observed in the methane emission even from similar rice growing situations. Hence more region - specific estimations are needed to arrive at a reliable estimate on methane emission from wetland rice fields. The information on methane emission from rice fields in Kerala is lacking, except for a study conducted by Regional Research Laboratory, Thiruvananthapuram as a part of the Methane Campaign, 1991 co-ordinated by National Physical Laboratory, New Delhi.

The primary substrates used by methanogens are formed in the wetland system during the fermentation of plant debris added to the soil by the incorporation of organic residues or by the release of root exudates from the standing crop. Therefore addition of organic residues in soil can contribute to an enhanced methane emission. But at the same time, organic matter content, the basic soil factor contributing to soil productivity, can be maintained only by the addition of crop residues in the soil. It is all the more important in a tropical climate like ours where organic matter is subjected to quick degradation leading to loss of carbon. Organic residues also serve as important source of micronutrients. Furthermore, incorporating the cereal residues into the soil is considered as a possibility for increasing carbon sink, thereby removing carbondioxide from the atmosphere. This necessitates the management of organic carbon in soil for maintaining its productivity without enhancing the green house gas emissions.

The global annual rice production has to be 600 million tonnes by 2010 to feed the world population as against 473 million tonnes in 1990 (IRRI, 1999).

A knowledge about the soil organic matter dynamics in different rice soils is necessary for arriving at suitable mitigation options for controlling methane emission. The factors affecting the decomposition of residues vary with the nature of residue added and also the basic soil properties. The availability of substrates for methanogenesis can be assessed from the rate of decomposition of soil organic material at different stages of crop growth. In this background, the present study was undertaken with the following objectives:

- i) To find out the diurnal and seasonal variations in methane emission from wetland rice fields,
- ii) To find out the variations in methane emission due to different organic manures and inorganic fertilisers,
- iii) To study the degradation pattern of different sources of organic manure in the presence and absence of rice crop,
- iv) To compare the decomposition pattern of rice straw and daincha under anaerobic conditions in different rice soils.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

2.1 METHANE EMISSION FROM WET LAND RICE FIELDS

Extensive research has been carried out during the last decade on methane emission from rice fields. Large variations in the estimated values of methane emission were observed in different rice growing situations probably due to the impact of soil and environmental factors and also due to the region specific crop management practices. Information collected on the areas related to the research project is summarised briefly in this chapter.

2.1.1 Estimates of methane emission from wetland rice fields

There is considerable uncertainty regarding the contribution of wetland rice fields, towards methane emission. Though methane emission was known to occur from rice fields as early as from 1913 (Harrison and Aiyer, 1913) the first comprehensive measurements were reported only in 1980s (Cicerone and Shetter, 1981, Seiler *et al.*, 1984). Earlier, Koyama (1964) had estimated a global emission of 190 Tg yr⁻¹ based on anaerobic incubation of a few paddy soils. In a review of the eleven global budgets published between 1978 and 1988, Khalil and Rasmussen (1990) reported emission rates in the range from 18 to 280 Tg yr⁻¹. The reports of the Intergovernmental Panel on Climate Change in 1992 estimated values between 20 and 100 Tg yr⁻¹ which corresponded to 6 to 29 per cent of the total anthropogenic methane emission. Studies of Bachelet and Neue (1993) have revealed that the methane emission rates from rice areas of Asia were 25 per cent less than the values estimated in the past. The estimated figures from the rice fields of different countries are given in Table 1. The methane campaign during Kharif 1991, involving 15 organisations in India revealed that the methane budget from Indian paddy fields ranged between 2.7 and 6.4 Tg yr⁻¹ with an average value of 4.3 Tg yr⁻¹; the total methane emission from Kerala was reported to be 0.002 Tg yr⁻¹ (Parashar *et al.*, 1994). Sinha (1995) reported a global emission rate of 7.08 Tg yr⁻¹ using the rice biomass – methane relationship methodology. The values for Asia and China were 5.13 and 1.22 Tg yr⁻¹ respectively.

Table 1. Estimates of methane emission from rice fields of different countries (Sass, 1994)

Country	Total area of rice (10^{10}m^2)	Methane emission (Tgy^{-1})
China	32.2	13 – 17
India	42.2	2.4 – 6
Japan	2.3	0.02 – 1.04
Thailand	9.8	0.5 – 8.8
Philippines	3.5	0.3 – 0.7
USA	1.0	0.04 – 0.5

2.1.2 Mechanism of methane production in wetland rice fields

In wetland rice cultivation, the soil is flooded for most of the crop growing season limiting oxygen supply to the soil. Facultative and anaerobic microorganisms proliferate and use up oxidized substrates according to the sequential oxidation reduction order and finally organic matter for their respiration. The final products of anaerobic decomposition are carbon-dioxide and methane. The two major pathways of methane production are reduction of carbondioxide and transmethylation of acetic acid (Neue and Scharpenseel, 1984).

Easily degradable crop residues, weeds and soil organic matter are the major sources of initial methane production. At later growth stages, root exudates and decaying root and plant parts provide important carbon sources for methane production. Several green house and field measurements showed a large CH_4 flux at the later growth stages of rice plants and attributed it to the supply of organic carbon from rice root exudation (Holzapfel - Pschorn *et al.*, 1986, Lindau *et al.*, 1991). Chidthaisong and Watanabe (1997) indicated that the contribution of plant supplied organic material to the formation of methane sharply increases after

flooding. Kaku *et al.* (2000) estimated the contribution of different fractions of a wetland ecosystem such as soil, plant residues and living rice roots to the total methanogenic activity. It was shown that plant residues significantly enhanced methanogenic activity in the first half of the cropping season and rice roots in the latter half.

Methane is produced exclusively by methanogenic bacteria which can metabolise in the strict absence of oxygen and at a redox potential of -150 mV. They are neutrophilic, with an optimum pH range of six to eight. The produced methane is either released into the atmosphere or oxidized as it enters the oxidised zone of the rhizosphere. It is oxidised by methanotrophic bacteria to carbondioxide and water. Hence the amount of methane emitted to the atmosphere is the balance of methane production and oxidation in the soil. Holzapfel – Pschorn *et al.* (1986) observed that only 23 per cent of the produced methane was released into the atmosphere. Sass *et al.* (1991) reported that 58 per cent of methane produced in a Texas rice field was oxidised.

2.1.3 Methane release from the soil to the atmosphere

Methane is released from the rice field to the atmosphere by three processes namely, ebullition, diffusion and plant mediated transport.

Ebullition is a physical process by which the gases escape from the soil in the form of bubbles. Submerged soils can entrap a substantial amount of methane produced in the gaseous form, which is released during soil disturbances like intercultural operations. Field studies indicated that ebullition accounted for less than 10 per cent of the total emission in a season (Holzapfel –Pschorn *et al.*, 1986). Neue *et al.* (1994 a) estimated a value of 20 per cent and Denier van der Gon *et al.* (1996) up to 10 per cent of the total methane emission. However the contribution of ebullition to the total emission would depend on the quantum of methane produced early in the season, since ebullition plays a predominant role only during the initial plant growth stages (Wassmann *et al.*, 1996).

The transport of methane through diffusion occurs across the flooded soil and overlying water of the field to the atmosphere. It is relatively small, to the tune of one to two per cent of the total emission (Butterbach – Bahl *et al.*, 1997). It is dependant on the surface – water concentration of methane, wind speed etc.

Methane transport through rice plants

Presence of a well developed aerenchymatous tissue is a morphological adaptation of wetland plants to flooding. They extend from the leaf parts above water to the root. These tissues with air-filled interspaces supply oxygen to the roots from the atmosphere (Justine and Armstrong, 1987). They also transport gases from the roots to the unsubmerged parts of the plant above water and release these gases to the atmosphere. Aulakh *et al.* (2000) demonstrated the continuity of numerous aerenchyma channels in rice roots showing direct connection with those of the culm.

The emission of methane through rice plants has been reported by several workers. Cicerone and Shetter (1981) proposed that methane emitted from paddy fields to the atmosphere is transported mainly through the rice plant. Ninety per cent of methane emission in a submerged soil was through plant mediated transport (Holzapfel – Pschorn *et al.*, 1986).

Nouchi *et al.* (1990) 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 get released through the micropores in the abaxial epidermis of the leaf sheath. Stomata did not play a major role in methane release. Wang *et al.* (1997) reported that leaves are the major release sites at the early growth stages which suggested the involvement of stomata also. Nodes became important at the later stages of plant growth. Cracks and porous structures were considered to be the possible exchange sites of the aerenchyma of the nodes. Small amounts of emission were detected through panicles also.

The transport of methane through rice plant was considered to be independent of the physiological processes of the plant, since cutting the plants

above the water level (Holzapfel-Pschorn *et al.*, 1986) or darkening or increasing CO₂ in the atmosphere (Seiler *et al.*, 1984) did not significantly affect the methane emission rates. Nouchi *et al.* (1990) also suggested that the methane transport by rice plants did not depend on transpiration. Rice roots could absorb methane without water uptake. The dissolved methane in the water in the root zone was transported and released into the atmosphere by diffusion through root-stem aerenchyma system driven by the methane concentration gradient. Denier van der Gon and Breemen (1993) also reported the transport mechanism to be a diffusion process. Nouchi *et al.* (1994) attempted to quantify the methane emission through a diffusion model considering methane concentration in soil water and conductance of the rice plant. Byrnes *et al.* (1995) proved that methane emission through the rice plants were not affected by water movement. However, Hosono and Nouchi (1997) proposed another pathway of methane transport by mass flow, in which the methane in the gas phase entrapped in the soil could enter into the rice body directly through a part of the stem near the base existing under the soil surface. Chanton *et al.* (1997) demonstrated that although methane transport was predominantly through molecular diffusion, a small component of the emission was subjected to transpiration induced flow also.

2.1.4 Diurnal and seasonal variations in methane emission

Methane fluxes from rice fields showed distinct diurnal and seasonal changes. The diurnal variations observed in the paddy fields of Italy revealed that the minimum flux occurred early in the morning and maximum flux in the afternoon (Sass *et al.*, 1991). In Philippines, methane emission generally increased rapidly after sunrise, peaked early in the afternoon and declined rapidly to a plateau during the night (Neue *et al.*, 1994 b). Wang *et al.* (1994) reported that the pattern and magnitude of diel variations were different for early and late rice. For early rice, the peak values were found in the early afternoon, while for late rice, highest values were generally observed at night. Adhya *et al.* (1994) reported a peak emission rate at noon. Buendia *et al.* (1998) found that the day/night patterns of methane fluxes depended on plant stages but could be superimposed by other factors such as intermittent drainage. Contradictory observations were also

recorded by some workers. Measurements in California (Cicerone *et al.*, 1983) showed that the diurnal variations of methane flux were not significant. Nouchi *et al.* (1994) also reported that the methane flux in the vegetated field did not show any significant variations between morning, afternoon and night. But in the unvegetated field, the flux due to ebullition followed a change similar to that of the global solar radiation.

Seasonal variations in methane efflux were studied by many workers. Nugroho *et al.* (1994) while studying the methane emission from Indonesian paddy fields observed that peak period of emission in rainy season was during the first half of the growth period while it was in the second half for the dry season cultivation.

In Thailand, a relatively lower methane emission was observed in the dry season than in the wet season, due to the very shallow water depth (Katoh *et al.*, 1999). Methane emission showed high correlation coefficient with temperature and low correlation with light intensity (Yang and Chang, 1999). Lu *et al.* (2000a) also pointed out that methane emission patterns differed among rice seasons and were governed by temperature changes. In the same rice field, methane emission increased during the first half of the growing period and decreased during the second half.

2.1.5. Factors influencing methane emission from rice fields

2.1.5.1 Organic amendments

Readily mineralisable organic material is the main source of fermentation products leading finally to methane production. Hence addition of organic amendments can naturally tend to increase methane production. The effect may vary depending upon the quantity and nature of the organic manure added. Yagi and Minami (1990) reported 1.8 to 3.5 fold increase in the methane emission rate due to the application of rice straw @ 6-9 t ha⁻¹. Only a slight increase in methane emission was observed when compost was applied instead of straw. In a pot culture study, rice straw treatment resulted in a six-fold increase in methane

emission rate compared to rice straw compost at 77 days after flooding (Mariko *et al.*, 1991). Wang *et al.* (1992) also found a positive correlation between methane emission and straw application up to 44 t ha⁻¹ in a Crowley silt loam. Field studies conducted at the IRRI by Neue *et al.* (1994a) showed that addition of rice straw @ 5 t ha⁻¹ resulted in a ten fold increase in methane emission as compared to chemical fertilisers only. Nouchi *et al.* (1994) could observe an earlier and higher methane emission in rice straw applied plots. While the methane emission from these plots started 19 to 26 days after flooding, that from the mineral fertiliser plots was detected only from 68 days after flooding. The efflux values were 40 mg m⁻²hr⁻¹ and 5.5 mg m⁻²hr⁻¹ respectively.

Difference in methane emission rates due to different rates of straw application was reported by Kludze and DeLaune (1995). In a laboratory study application of rice straw @ 10g kg soil⁻¹ (22 t ha⁻¹) produced higher values of methane emission than application of 5g kg soil⁻¹ (11g ha⁻¹) in the fallow plots. However, methane emission in the plots with rice decreased at higher rate of application of straw.

Methane emission from rice fields is also influenced by the nature of the organic amendments. Bhat and Beri (1996) observed higher emission rates for wheat straw than rice straw. The higher emission due to the application of green manures in rice field was reported by Denier van der Gon *et al.* (1992). Tragore *et al.* (1999) could observe a much higher efflux for green manure, compared to bio gas residue and beef manure. The values were 52, 20 and 19 times respectively than the plots where chemical fertiliser alone was applied. Agnihotri *et al.* (1999) also reported enhancement of methane flux from paddy soils due to rice straw and bio fertiliser whereas compost of cowdung and leaves did not stimulate methane production. Similar results were obtained by Corton *et al.* (2000) while comparing the effects of rice straw compost and fresh rice straw in paddy fields in the Philippines. Glissmann and Conrad (2000) indicated that the different straw fractions like stem, leaf blade and sheath contributed differently to methane emission and decreased in the order stem > leaf blade > sheath. Addition of rice straw and the fraction of straw affected the fermentation pattern only in the

early phase of degradation, but had no effect on the degradation pathway during the later methanogenic phase.

The time of application of the organic manures also showed profound influence on the methane emission from paddy fields. Liou *et al.* (1999) observed significant effect of chicken manure in the early stage of second crop season in Taiwan and not during the first crop season. Similar results were obtained by Xu *et al.* (2000), where the influence of rice straw on methane emission was exhibited only when it was applied before planting of the current season.

2.1.5.2 Mineral fertilisers

Reports on the effect of mineral fertiliser application on methane production and emission showed inconsistent trends. Generally, fertiliser improves plant growth which may increase emission. Among the fertilisers, the rate and type of N fertiliser considerably influenced the methane emission in flooded rice soils. Lindau *et al.* (1990) reported a lower methane flux in ammonium sulphate and ammonium nitrate added plots compared to urea applied plots. Parashar *et al.* (1991) observed that the methane emission was considerably lower for the fertilisers having sulphate.

Wang *et al.* (1992) conducted a laboratory study with rice soil incubated under anaerobic conditions. The treatments included Nitrogen @ 100, 200 and 300 mg per kg soil as urea, ammonium nitrate and ammonium sulphate and an unfertilized control. Significant difference was observed in the total methane production among the different rates of applied nitrogen. Methane production was significantly increased by urea application compared to the other two fertilisers. The peak value also reached one week earlier in the case of urea. The emission rates were lower than control for ammonium nitrate and ammonium sulphate. Corton *et al.* (2000) also reported lower methane emission when ammonium sulphate was used as the N fertiliser in place of urea.

Contrary to this, Neue *et al.* (1994 c) could not observe any significant difference between urea and ammonium sulphate at different rates and methods of

application. Dunfield *et al.* (1995) also did not observe any difference between urea and ammonium nitrate. However, ammonium sulphate was found to reduce methane emission.

The effect of sulphate in reducing methane production was considered to be due to the better competing ability of sulphate reducers compared to methanogens. This was further explained by Denier van der Gon and Neue (1994) in a study involving green manure + gypsum. The green manure, *Sesbania rostrata* was incorporated one week before transplanting. In the first week after transplanting, the methane emission from green manure treated plots reached a peak value of $4.5 \text{ gm}^{-2}\text{day}^{-1}$. No such peak was observed in gypsum amended plot. After that, both the plots followed the same pattern of emission but with a higher rate for the treatment with green manure alone. The total emission was 55 to 70 per cent lower for the gypsum amended treatment.

2.1.5.3 Environmental factors

Yagi and Minami (1990) and Bhat and Beri (2002) obtained a positive correlation between methane flux and soil temperature. Parashar *et al.* (1991) explained this as due to the decreasing solubility of methane with increase in temperature. The rate of change of methane flux per degree centigrade rise in temperature ranged between 0.1 and $14 \text{ mg m}^{-2}\text{hr}^{-1}$ from place to place.

Seasonal emission rates of methane were positively correlated with accumulated solar radiation. One per cent increase in accumulated solar radiation was accompanied by 1.1 per cent increase in methane emission (Sass *et al.*, 1991). Adhya *et al.* (1994) related the peak at mid day to higher solar radiation and higher soil water temperature. Lee *et al.* (1994) studied the correlation between micrometeorological elements and methane emission rates from rice canopy. The maximum correlation was obtained with soil heat flux. High correlations were also obtained with water and soil temperature, latent heat flux and sensible heat flux. Satpathy *et al.* (1997) also related the diurnal pattern of methane emission to the atmospheric, soil and water temperature. Cai *et al.* (1997) observed an

increase in the methane flux with increase in soil temperature at 5 cm and 10 cm depth before the peak methane flux was reached. However, Lindau (1994) could not obtain any significant positive relation between methane flux and temperature.

2.1.5.4 *Cultivars and growth stages*

Rice plant affects methane emission in three ways. About 60 to 90 per cent of methane produced in the soil system is transported to the atmosphere through the rice plant. Another way is by providing root exudates and decaying roots. Hence crop parameters like tillers, root mass, rooting pattern, total biomass and metabolic activities contribute to methane emission. Rice plants also contribute to a decrease in the methane emission rate by providing oxygen in the rhizosphere. The methanotropic bacteria in the rhizosphere oxidizes methane to CO₂.

There are many reports regarding the varietal differences in methane emission. Parashar *et al.* (1991) reported variation among varieties grown under identical environment and soil parameters in India. Similarly Neue *et al.* (1994 d) found that among the different varieties, methane emission was 30 per cent more in the traditional variety Dular than the new plant type. They attributed this difference in rate to the higher number of tillers and longer roots in the traditional variety. Wang *et al.* (1997) and Aulakh *et al.* (2001) also suggested the positive influence of tiller number on methane transport capacity of the rice plant. Kludze and De Laune (1995), Satpathy *et al.* (1998) and Ding *et al.* (1999) reported differences among the varieties in methane emission while Watanabe *et al.* (1994) observed difference even between the shoots of a single plant. This variation of methane emission between varieties could be attributed to difference in plant size (Sass *et al.*, 1990; Mariko *et al.*, 1991), difference in aerenchymatous cells (Seiler, *et al.*, 1984) and difference in root volume and root fresh weight (Mishra *et al.*, 1997; Yao *et al.*, 2000) and difference in plant lacunal methane concentration (Byrd *et al.*, 2000). Lu *et al.* (2000b) explained that the intercultivar difference in root carbon release was responsible for the intercultivar difference in the dissolved organic carbon in the root zone and consequently in methane flux. Aulakh *et al.* (2001) observed that high above ground dry matter was associated with a large

root system and higher carbon release from roots. About 61 to 83 per cent of the exudate carbon was converted to methane.

However, Satpathy *et al.* (1997) could not observe any significant influence of plant parameters like aerial biomass, root biomass and grain and straw yields on methane flux from the rice field. Shin and Yun (2000) also failed to get any significant correlation between root distribution and canopy dry matter weight and methane emission.

Methane emission from a rice field was also found to vary with the growth stages. The flux showed two peaks during the growing season in Italy and Spain, a first maximum before tillering and a second maximum during the reproductive stage (Seiler *et al.*, 1984; Holzapfel – Pschorn and Seiler, 1986). Shutz *et al.*, (1989) observed three seasonal maxima, the first shortly after flooding, the second during vegetative growth stage and the third during grain filling and maturity. Similarly, Neue *et al.* (1994 b) also could observe three distinct seasonal maxima of emission, shortly after flooding, during late vegetative period and the third and highest during grain filling and maturity stages.

In Indonesian rice fields, emission rates were higher during the first half of the growth period, in contrast to that in temperate regions (Nugroho *et al.*, 1994). Nugroho *et al.* (1996) observed a broad peak 6 to 7 weeks after transplanting during the rainy season. But two distinct sharp peaks were observed during the dry season, three and six weeks respectively after transplanting. In Punjab, Bhat and Beri (1996) observed two peaks, first at 33 days after transplanting and second 75 days after transplanting. The emission was maximum in the first half of the growth period.

Jia *et al.* (2001) observed a higher methane emission at tillering stage than at panicle initiation stage and attributed this to the lower rhizospheric CH₄ oxidation and more effective transport through rice at tillering stage.

2.1.5.5 *Water regimes*

Water management practices can influence the quantum of methane production, since the conditions for methanogenesis are created only in a continuously flooded field. Liang and Yang (1994) opined that methane emission could be reduced by 15-59 per cent with intermittent irrigations. Husin *et al.* (1995) studied the effect of continuous flooding, intermittent irrigation and saturated soil in Indonesian wetlands. Continuous flooding resulted in a higher methane flux followed by intermittent irrigation. Lowest emission was observed under saturated conditions. Singh *et al.* (1996) suggested that the methane output could be reduced by lowering the submergence level in rice paddies. Lu *et al.* (2000a) observed that the local practice of mid season drainage reduced methane emission by 44 per cent as compared to continuous flooding. The emission could be further reduced by 30 per cent by adopting intermittent irrigation. Jain *et al.* (2000) could obtain 22 per cent reduction in methane emission in New Delhi due to intermittent irrigation compared to continuous flooding. The water regime of the fallow period between two rice seasons also influenced the methane emission (Trolldenier, 1995). A higher and earlier methane emission was observed from a rice crop following wet fallow compared to rice following dry fallow.

2.1.5.6 *Soil characters*

The complex interaction between soil properties and microbial fermentation is not clearly understood. However, the soil properties identified to influence methane emission include texture and clay mineralogy, pH, organic carbon content, redox potential and salinity. Neue *et al.* (1994 e) observed positive correlation between methane production and organic carbon content of more than two per cent. Wassman *et al.* (1998) also obtained positive correlation for the content of organic carbon and organic nitrogen with methane production over eight weeks. Methane emission was higher in a sandy soil than in a clayey soil with the same organic carbon content. The clay colloids form complexes with organic matter making it less degradable. Clay soils may also entrap more methane, thus increasing the probability of oxidation. Singh *et al.* (1997) assigned

the differences in methane emission between a vertisol and inceptisol to the difference in soil texture.

Soil Eh influenced methane flux from rice soils in two ways. It directly determined the amount of methane production in the soil and it also initiated morphological and physiological changes in rice plant that affect gas exchange between soil and atmosphere. Wang *et al.* (1993) estimated the critical soil Eh for initiation of methane production to be -150 mV to -160 mV. Masscheleyen *et al.* (1993) also observed that a soil Eh value of -150 mV was optimum for methane production. Methane emission was found to decrease with increase in redox potential. Kludze *et al.*, (1993) observed that methane production and emission rate increased sharply with decreasing soil Eh from -200 to -300 mV. Cai *et al.* (1997) could not obtain any significant relation between methane flux and soil Eh.

Methanogens are generally considered to be neutrophilic, the optimum pH range being 6 to 8. Parashar *et al.* (1991) observed maximum emission at pH 8.2 and found the range of 7.5 to 8.5 most favourable. In tropical flooded situations, methane production may start hours after flooding in alkaline and calcareous soils, two to three weeks after flooding in neutral soils and more than five weeks after flooding in acidic soils. Wetland soils with acidic reaction and high Kaolinitic clay content and high bulk density produced less methane (Neue *et al.*, 1990).

Salinity of the soil is another factor inhibiting methane emission. Patel and Roth (1979) reported the inhibitory action of sodium chloride at high concentrations. Denier van der Gon and Neue (1995) showed that the addition of salt to the rice field caused a reduction in methane emission by 25 per cent.

2.1.5.7 Chemicals used in rice cultivation

Several pesticides, herbicides and nitrification inhibitors were studied for their effect on methanogenesis and methanotrophy, since these chemicals influence microbial processes. Bronson and Mosier (1991) found that encapsulated calcium carbide was very effective in reducing gaseous emissions from flooded rice fields. In Australia, application of nitrapyrin and wax coated calcium carbide

significantly reduced methane emission from dry seeded flooded rice fields (Keerthisinghe *et al.*, 1993). Kumaraswamy *et al.* (1998) showed that applications of carbofuran at low rates resulted in significantly lower methane emissions from flooded rice fields by increasing the oxidation of methane.

2.2 DECOMPOSITION PATTERN OF ORGANIC MANURES IN SOIL

Crop residue decomposition is an important factor in organic matter stabilisation since the degradation products are incorporated into various soil organic matter pools. Decomposition of plant materials occurs in several steps involving both physical and chemical transformations. In general, water soluble carbon fractions are degraded first (Knapp *et al.*, 1983) followed by structural polysaccharides like cellulose, hemicellulose (Harper and Lynch, 1981) and then lignin, which decomposes at a much slower rate (Herman *et al.*, 1977). The basic feature of organic matter decomposition in soil is that the added C and N are never completely mineralised but are partly retained in forms having varying degrees of biodegradability and turnover times. Added organic materials are finally converted to substances identical to the natural humic compounds.

Decomposition was described approximately by two first order reactions, the first a rapid breakdown of easily decomposable components and the second a much slower decay of stabilised residues and turn over products. According to Sinha *et al.* (1977), the decomposition of organic carbon was controlled by two simultaneously occurring super imposed first order kinetic reactions. Hence the concentration of substrate was the most important factor controlling C mineralisation. The rate of C mineralisation or potentially mineralisable C could be expressed by the equation $dc/dt = -kC$, which on integration became $\log (C_0 - C_t) = \log C_0 - \frac{kt}{2.303}$. The addition of organic materials significantly increased the potentially mineralisable carbon. The magnitude of increase was different in different soils. Yadav *et al.* (1989) and Prasad and Sinha (1996) also employed the same equation for arriving at the carbon mineralisation potential and half time of mineralisation.

2.2.1 Rate of decomposition of organic manures

The rate of decomposition of residues has been studied using labelled plant materials and radiotracer techniques. Fuhr and Sauerbeck (1968) observed that about 30 to 39 per cent of the added labelled carbon was retained in soil after one year. Jenkinson (1977) reported that 12 per cent of the initial labelled carbon remained in the soil after 10 years. About 40 to 51 per cent of the added ^{14}C was lost within 34 days (Amato and Ladd, 1980) and 32 per cent within 10 days (Cerri and Jenkinson, 1981). Saini *et al.* (1984) observed highest decomposition during the first eight days after incubation for stubbles and four days for roots of wheat and rice straw and Brassica. About 9 to 16 per cent of the substrate carbon was mineralized during 72 days. Azam *et al.* (1985) observed that only 20 to 30 per cent of added C was left in soil after one year under temperate climates. Sarmah and Bordoloi (1994) observed maximum evolution of carbon dioxide during the first week of incubation. Higher the amount of organic matter added, higher was the evolution.

2.2.2 Effect of nature of the crop residue on decomposition

The chemical composition of the added residue was found to affect the initial decomposition rate. N, S lignin, water soluble C and other nutrients were important (Herman *et al.*, 1977). Ghidey *et al.* (1985) suggested temperature, moisture and initial C : N ratio of the residue to be the main factors that affected decomposition. According to Janzen and Kucey (1988), the extent of carbon mineralisation was positively correlated with the N content of crop residues, S content, cellulose and hemicellulose content. The positive influence of nitrogen content of the residue in deciding the total amount of C mineralised under aerobic conditions was further stressed by Ajwa and Tatabai (1994). In an incubation experiment, Vanlauwe *et al.* (1996) showed that the residue C mineralisation at 40 per cent water holding capacity was significantly correlated with residue lignin content, C : N ratio and polyphenol : N ratio. Martens (2000) opined that the carbon remaining in the soil following decomposition could be related to the specific phenolic acid content of the residue.

However, the effect of crop residue on soil organic matter content was largely dependant on the amount of residue added rather than the type of the residue or the degree of decomposition (Sauerbeck, 1968). The percentage of labelled carbon retained became very similar after one year. As soon as the most readily decomposable compounds disappeared further decomposition of the residues proceeded at approximately the same rate for the different residues.

2.2.3 Decomposition in different soils

Jenkinson (1977) indicated that the rates of decay were not substantially influenced by soil properties except in extreme acidic conditions. Sauerbeck and Gonzales (1977) also observed similar processes of plant residue decomposition in different soils. However Malik and Haider (1977) reported that the rate of decomposition of labelled plant material differed in three soils and was influenced by the chemical and microbiological properties of the soil. The presence of salts was found to depress the rate of decomposition (El-Shakweer *et al.*, 1977).

Cerri and Jenkinson (1981) reported that the decomposition of aerobically incubated rye grass was faster in a near-neutral soil than in an acid soil. About 52 per cent was evolved as CO₂ in the neutral soil while that from acidic soil was 40 per cent. Mandal and Gupta (1981) studied the transformation of ¹⁴C labelled wheat and berseem plant material in four different soils under green house conditions. They observed that the rate of mineralisation and total C mineralised followed a similar trend in all the soils. Decomposition was higher for the first ten days, then decreased sharply and became steady after 70 days. During the period of peak decomposition, Lateritic soil showed a higher decomposition rate. The lowest rate was shown in black soils, due to higher clay, higher CEC and low available N. Diane *et al.* (1983) also reported that the initial rate of decomposition of the added substrate was more rapid in alkaline than in acid soil. van Veen *et al.* (1985) observed higher decomposition in a sandy loam soil, twice as fast as in a clayey soil.

Amato *et al.* (1987) observed that the decomposition of plant materials in soils was negatively correlated with clay content. No relationship was observed with pH and soil organic C and N. Alvarez *et al.* (1991) did not observe differences in decomposition rate of straw in soils with different bulk densities.

Amato and Ladd (1992) demonstrated that decomposition of ^{14}C labelled glucose and its incorporation into microbial biomass were directly correlated with soil clay contents and cation exchange capacity of soils. Decomposition was faster in the soil of lower clay content. In the case of legume materials, more total organic ^{14}C residue was retained in mildly acidic soils than in neutral to alkaline soils. Ladd *et al.* (1995) observed 1.6 times faster decomposition in a sandy loam soil compared to clayey soil in the first two days. Thereafter only a marginal difference in the decomposition rate existed between the soils up to 101 days.

2.2.4 Effect of the standing crop on decomposition of plant residues

There are many reports on the inhibitory and stimulatory effect of living plants on the organic matter decomposition.

Fuhr and Sauerbeck, as early as in 1968, reported that the decomposition of labelled plant material was markedly lowered in the presence of small grain crops compared to root crops or fallow. Shields and Paul (1973) and Jenkinson (1977) confirmed this. During laboratory experiments under controlled conditions, Reid and Goss (1982) and Sparling *et al.* (1982) observed that when ^{14}C labelled plant material was decomposed in soil planted with maize, rye grass, wheat or barley, $^{14}\text{CO}_2$ release from the soil was reduced compared to bare soil controls. Bek (1994) also observed a decreased rate of mineralisation of ^{14}C labelled straw in the soil planted with rape compared to unplanted soil. He attributed this reduction to the competition between plants and microorganism for mineral N. In contrast, Helal and Sauerbeck (1984) reported a stimulatory effect of living roots on soil organic matter decomposition. Sallih and Bottner (1988) demonstrated that the presence of plants suppressed the decomposition of newly incorporated ^{14}C labelled plant material during the first 200 days of decomposition and stimulated

the mineralisation of ^{14}C in the soil during the later stage compared to bare soil. Cheng and Coleman (1990) studied the effect of roots on soil organic matter mineralisation. Living roots had a stimulatory effect on soil organic matter decomposition due to the higher microbial activity induced by the roots. This stimulatory effect was reduced by the application of fertiliser.

2.2.5 Effect of management practices on straw decomposition

Incorporating the straw hastened its decomposition only in the first 15 days, thereafter the decomposition rate was similar to that of straw retained on the soil surface (Cogle *et al.*, 1989). A comparison of mineralisation of straw in soil incubated at two moisture regimes namely, 60 per cent water holding capacity and standing water revealed that the mineralisation estimated as CO_2 evolution was lowest for the soil with the standing water (Senapati and Behera, 2000). The net residue carbon mineralisation was lower in flooded systems compared to non-flooded conditions (Devevre and Horwath, 2000). The C mineralised in flooded soil was mainly from labile pools and secondarily from recalcitrant pools like cellulose and lignin, depending on temperature. Agricultural measures applied in a soil induced a higher efficiency of soil microbial community with respect to substrate use for growth (Fliessbach *et al.*, 2000).

2.2.6 Priming action of added organic materials

Datta and Goswami (1962) opined that the native organic matter began to decompose consequent to the decomposition of added organic material. This 'priming effect' lasted as long as the plant residue contributed a major part of the decomposing mass. Sorensen (1975) attributed this effect to the increased biological activity of special group of micro organisms or enzymes produced in soil during decomposition of added organic materials. The positive priming effect had also been reported by Raina and Goswami, 1988. The magnitude of priming effect varied significantly with the type of material added and the type of soil.

MATERIALS AND METHODS

MATERIALS AND METHODS

The following four experiments were undertaken to generate the data needed for fulfilling the objectives of the research project. The first two were field experiments, while the third one was a pot culture study and the fourth was an incubation study:

- i) Diurnal and seasonal variations in methane emission from rice fields,
- ii) Effect of different organic manures and inorganic fertilisers on the methane flux from rice fields,
- iii) Decomposition pattern of different organic manures in the presence and absence of rice in Lateritic soil,
- iv) Decomposition pattern of rice straw and daincha in selected rice soils of Kerala

3.1 LOCATION

The first two experiments were conducted at the Agricultural Research Station, Mannuthy. The station is located at 10° 31'N latitude and 76° 13'E longitude and at an altitude of 40.29 MSL. The soil of the area is Lateritic sandy clay loam belonging to the oxisol group. It is acidic in reaction with a pH value of 6.0. The average organic carbon content is 0.46 per cent, available P 44 kg ha⁻¹ and available K 71.0 kg ha⁻¹. The third and fourth experiments were conducted under green house conditions at the Radio Tracer Laboratory of the College of Horticulture, Vellanikkara.

3.2 CLIMATE AND WEATHER

The experimental area enjoys a typical humid tropical climate. The weekly average values of the different weather elements during the period of the field experiments are presented in Appendices 1 and 2. Rainfall and evaporation are given as total weekly values while all the other meteorological parameters are

Fig. 1. Meteorological data 1998 - 1999

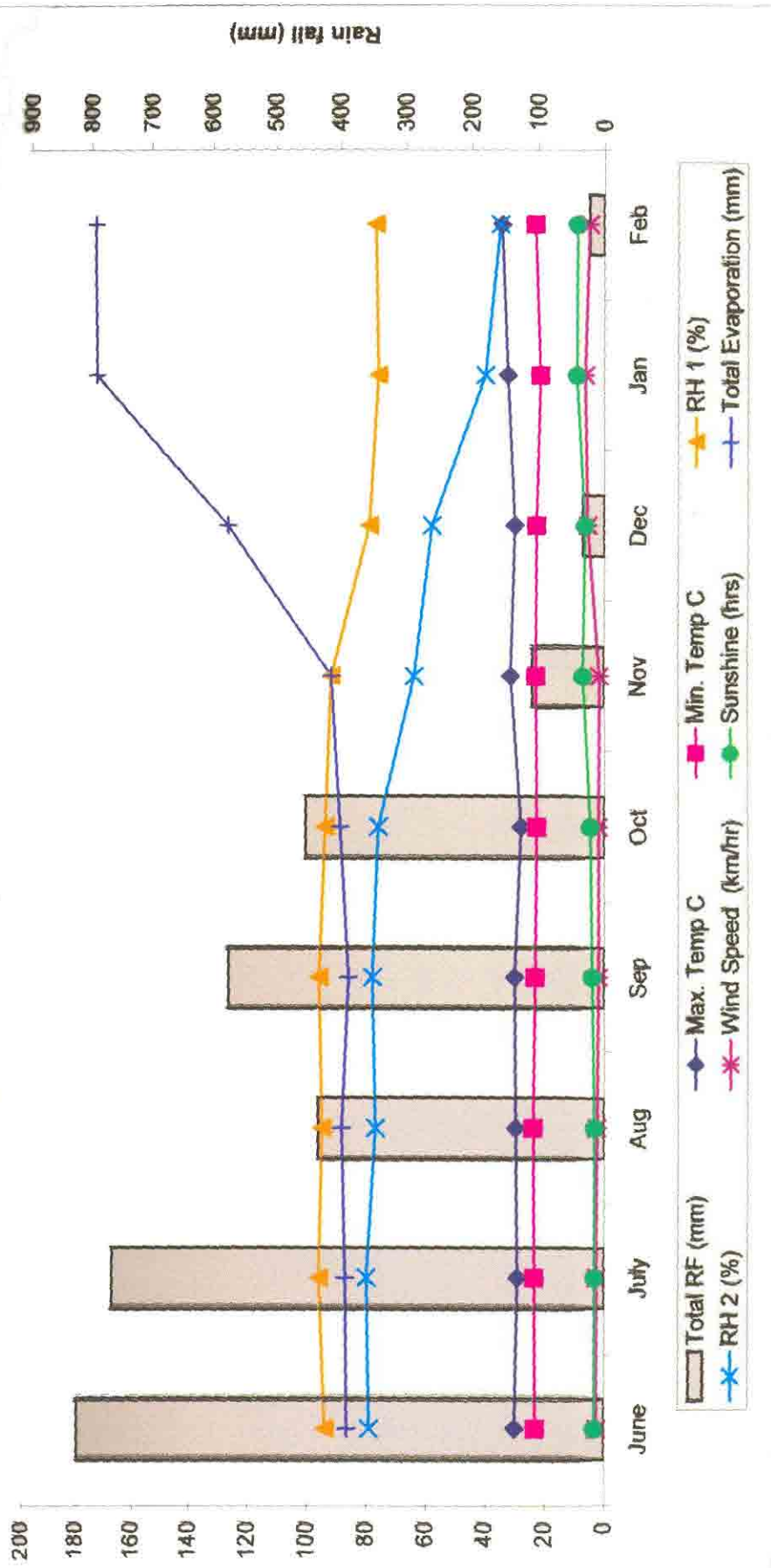
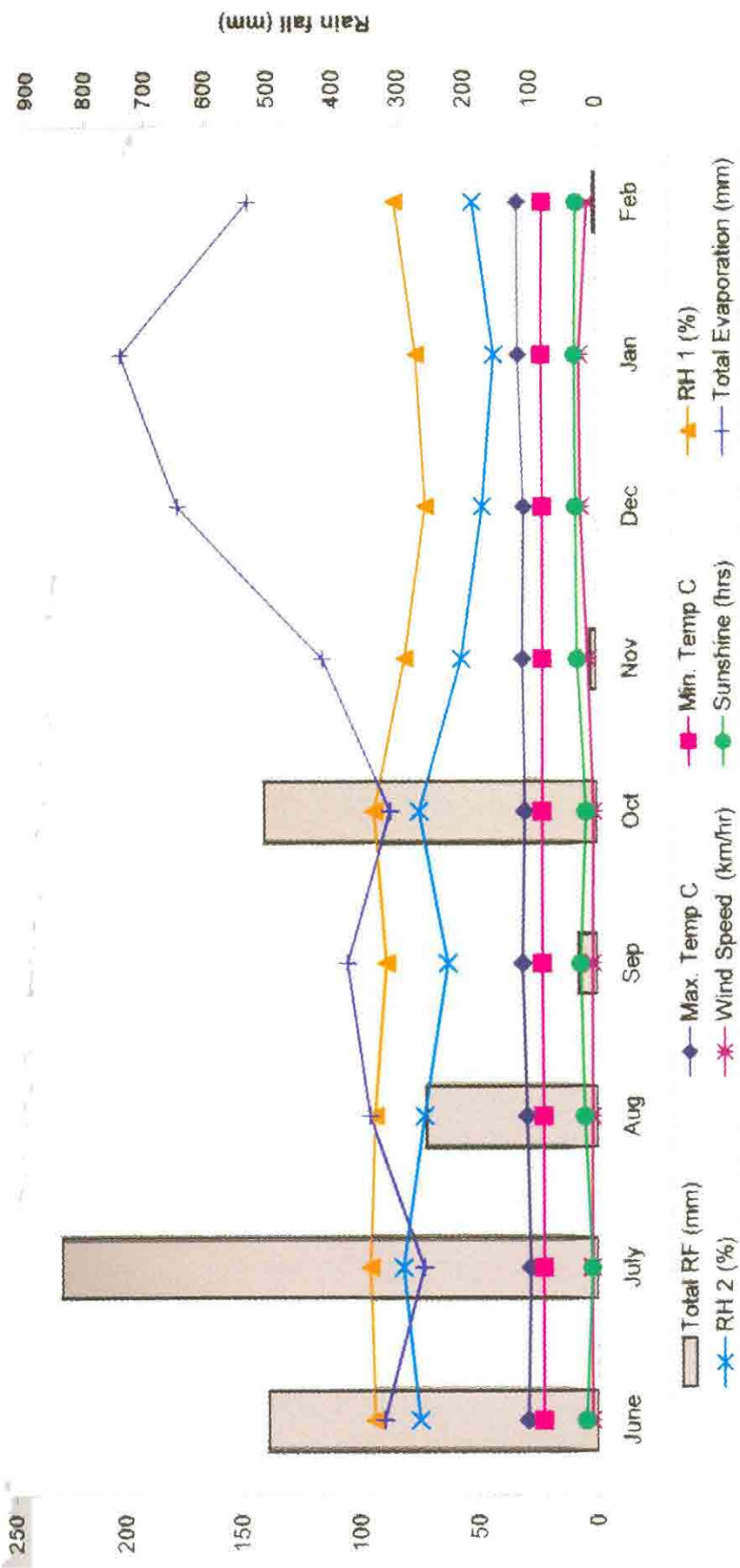


Fig. 2. Meteorological data 1999 - 2000



furnished as weekly means. The graphical representation of monthly average values are given in Fig. 1 and 2.

3.3 FIELD EXPERIMENT I - DIURNAL AND SEASONAL VARIATIONS IN METHANE EMISSION FROM RICE FIELDS

This experiment was aimed at studying the diurnal variations in methane emission at various stages of growth of rice during different seasons. The experiment was conducted at the Agricultural Research Station, Mannuthy during the first and second crop seasons of 1998-99. The methane flux was measured at tillering, panicle initiation, booting, flowering and maturity stages of the rice variety Kanchana from a field managed at uniform package of practices. Estimations of methane were done in the morning (8 to 10 am), noon (12 to 2 pm) and evening (4 to 6 pm).

Methodology

The methane efflux from paddy fields was studied using closed chamber technique. This technique was adapted from the Methane Campaign 1991, which was co-ordinated by the National Physical Laboratory, New Delhi (Anon., 1992). The air in the sampling site was trapped using a perspex box of size 52 × 32 × 70 cm and with one side open. The open end would rest in a U shaped channel mounted on the top of an aluminum base. The aluminum base was fixed in the soil at the sampling site well in advance so that minimum disturbance was caused to the soil during sampling. The U shaped channel on the aluminum base could hold water which isolated the air inside the chamber from the outside atmosphere (Fig. 3).

A battery operated air circulation pump (pulse pump) with a flow rate of 1.5 litres per minute was connected to the chamber with polythene tubings through a three way stop cock (Fig. 3 and Plate 1). This arrangement was used for mixing the air inside the chamber and also to draw air sample in special 250 ml glass sampling bottles having two way stop cock at both ends. The perspex box used in the experiment could enclose 10 hills of rice planted at spacing of



Plate 1. Perspex box and accessories for collecting air samples
from rice fields

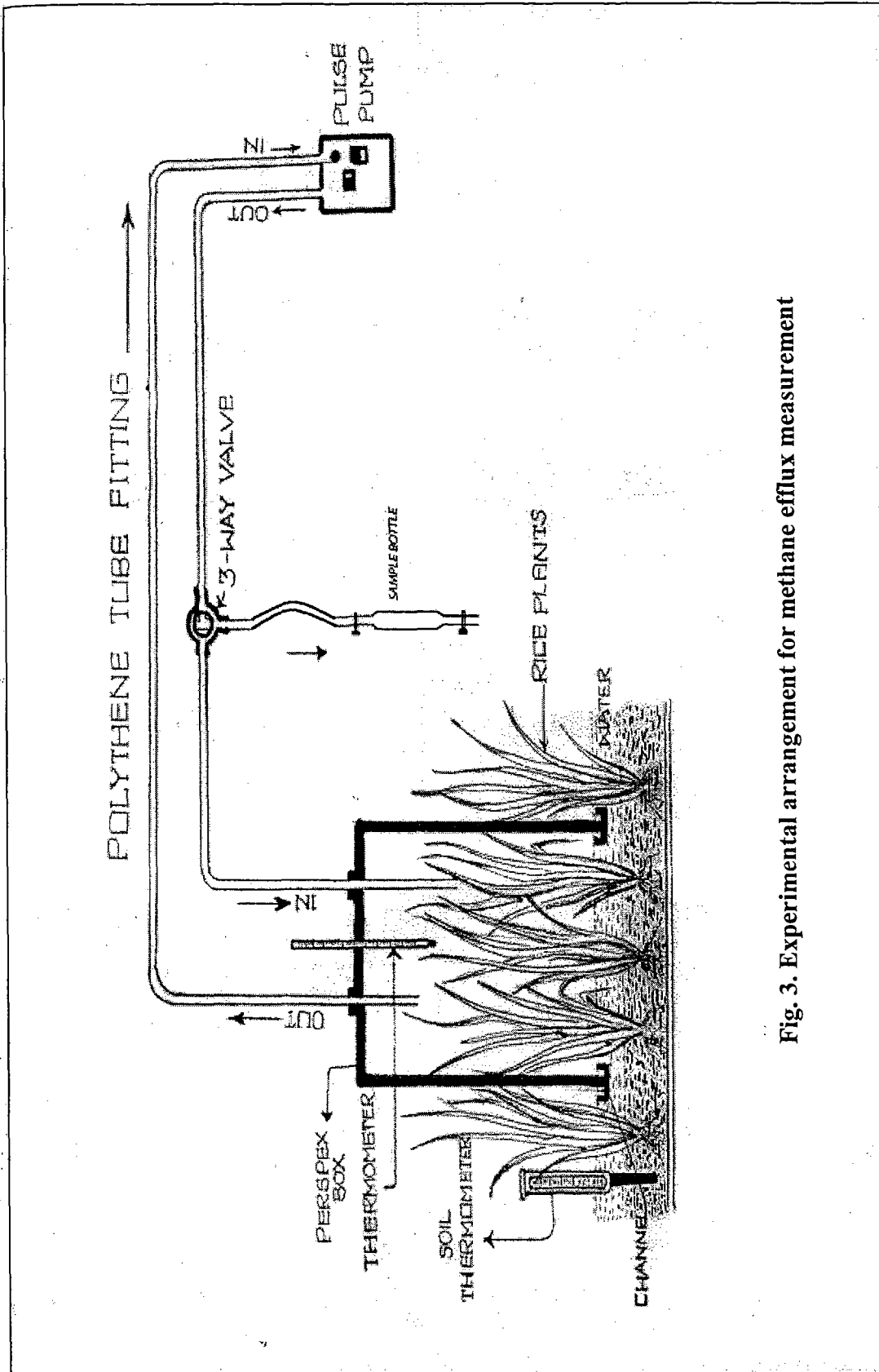


Fig. 3. Experimental arrangement for methane efflux measurement

15 × 10 cm. After placing the chamber on the aluminum base, air samples were collected at 0, 15 and 30 minutes from the same site. The level of water and temperature inside the chamber were measured during each sampling for calculating the chamber air volume at STP. The chamber was removed from the sampling site after 30 minutes. Samples were collected from three locations at a time.

The air samples were analysed for methane at the Regional Research Laboratory, Thiruvananthapuram. It was done by gas chromatograph (Nucon 5765 – AIMIL Ltd.) equipped with FID and a column of molecular sieve 5 A (60-80 mesh). The column, detector and injector temperatures were maintained at 80, 120 and 120°C respectively. Nitrogen was used as the carrier gas, hydrogen as the fuel gas and oxygen as the oxidant with flow rates of 30 psi for nitrogen and 10 psi for hydrogen and oxygen. Five millilitre sample was introduced into the gas chromatograph using a gas tight syringe. The retention time of methane was 1.1 – 1.4 minutes. Calibrations were done using 1.6 ppm methane in Nitrogen supplied by National Physical Laboratory, New Delhi. Zero air was used as the secondary standard. The methane content in each sample was estimated from the peak in the chromatogram. The methane flux F ($\text{mg m}^{-2}\text{hr}^{-1}$) was calculated from the temporal increase of methane concentration inside the chamber per time from the following equation.

$$F = \frac{K \times 273 \times V \times 60 \times dc}{(273 + T) \times A \times dt}$$

where

K - The constant for conversion of methane concentration from the volume to the weight (0.714).

T - Air temperature within the chamber

V - Volume of air in the chamber above water (m^3)

A - Surface area covered by the chamber (m^2)

dc/dt - Change in methane concentration ($\mu\text{L L}^{-1}$) per unit of time (minutes)

3.4 FIELD EXPERIMENT II - EFFECT OF DIFFERENT ORGANIC AND INORGANIC FERTILISERS ON THE METHANE FLUX FROM RICE FIELDS.

The experiment was laid out at Agronomic Research Station, Mannuthy, during the year 1999 - 2000.

3.4.1 Technical programme

Treatments

Number of treatment combinations - 12

A. Sources of organic manures

- i) Rice straw
- ii) Glyricidia
- iii) Farm Yard Manure (FYM)
- iv) Control

B. Sources of N fertiliser

- i) Urea
- ii) Factomphos
- iii) Control

Design - RBD

Replication - 3

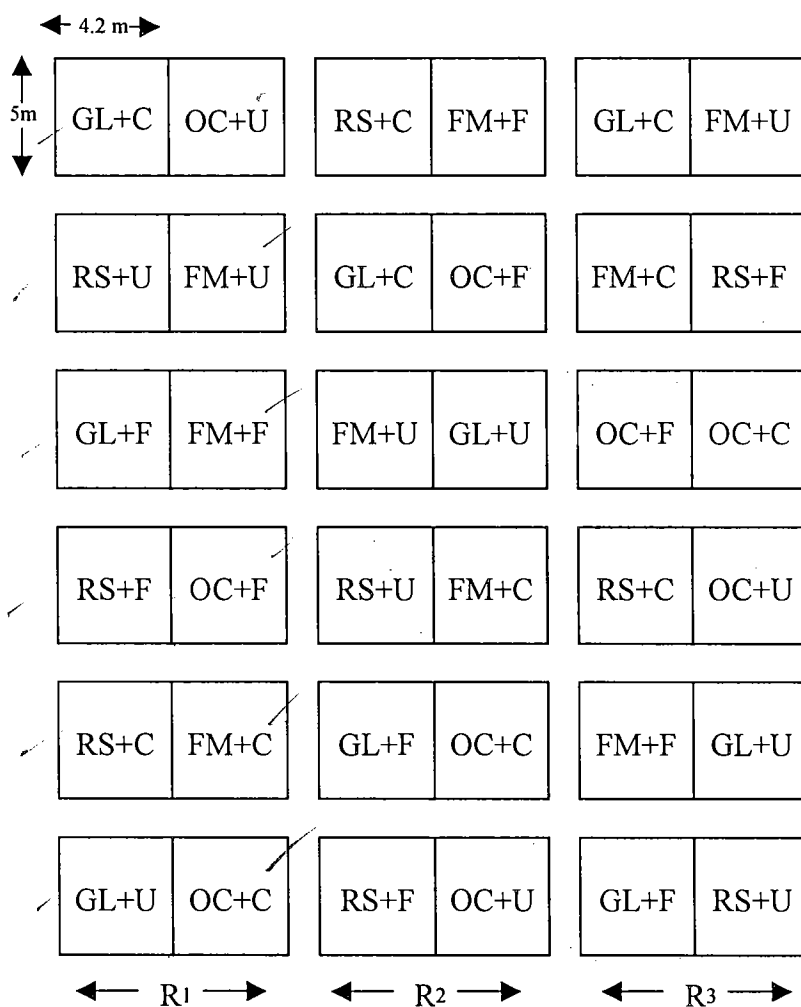
Plot size - 21 m²

The layout of the experiment is given in Fig. 4. The organic manures were applied @ 5t ha⁻¹ one week prior to planting. Twenty days old seedlings of variety Kanchana were planted @ 2 seedling/hill at a spacing of 15 × 10 cm. Kanchana is a short duration, photo insensitive and red kernelled variety having medium stature and medium tillering habit. The grains are long and bold. A fertiliser dose of 70:35:35 kg ha⁻¹ was given to the crop as per Package of Practices Recommendation of Kerala Agricultural University (KAU, 1996). The nitrogen fertilisers used were urea and factomphos in accordance with the treatments. Superphosphate was used as the phosphorus fertiliser in all the plots except where



Plate 2. Field experiment on methane emission from rice fields

Fig. 4. Layout of the field experiment on the effect of organic manures and nitrogen fertilisers on methane emission from rice fields



Organic manures

RS - Rice straw
 GL - Glyricidia
 FM - Farmacyard manure
 OC - Control

N fertiliser

U - Urea
 F - Factomphos
 C - Control

factomphos was applied. The source of potassium in all the plots was muriate of potash.

During the first crop season (June to September) sampling for methane could be done during the maximum tillering stage only, due to the non functioning of the gas chromatograph. Biometric observations like plant height, number of tillers per hill, dry weight of plant and root, root volume etc. were recorded at different stages. The yield contributing characters such as number of productive tillers per m², number of spikelets per panicle, percentage of filled grains per panicle and 1000 grain weight were recorded at the time of maturity.

The height of plants were measured from the base of the culm to the tip of the longest leaf. The dry weight of plant and root were recorded after drying in the oven at the 65 – 70°C. For collecting the root samples, incisions were made to a depth of 25 cm using an iron chisel on all the four sides of the hill at a distance of half of the spacing from the base of the hill. The entire plant was scooped out along with the bulk soil. The roots were washed in running tap water by keeping in a 2 mm sized wire mesh sieve. All the soil particles were removed and the roots separated from the plant. The root pieces in the wire mesh also were added to it. After taking the fresh weight and root volume, the root samples were dried in oven at 65 – 70°C for taking the dry weight. The root volume was found out by water displacement method.

Plant and soil samples were collected for chemical analyses and the methods of analysis are indicated in Table 2.

The experiment was repeated with the same layout during the second crop season (October to January) also. Methane efflux were monitored during tillering, booting, flowering and maturity stages.

Table 2. Methods of analysis

I. Plant chemical analysis

Sl. No.	Nutrient	Method	Reference
1.	Nitrogen	Microkjeldahl digestion and distillation method	Piper, 1942
2.	Phosphorus	Diacid extract estimated colorimetrically in a spectronic 20 spectrophotometer by Vanadomolybdo phosphoric yellow colour method	„
3.	Potassium	Diacid extract using flame photometer	„
4.	Calcium & Magnesium	Diacid extract using AAS	„
5.	Iron, Mn, Zn, Cu	Diacid extract using AAS	„
II. Soil chemical analysis			
1.	Organic carbon	Walkely – Black titration method	Jackson, 1958
2.	Available P	Bray I extract Ascorbic acid reduced molybdo phosphoric blue colour method using spectrophotometer	Watanabe and Olsen, 1965
3.	Available K	Neutral Normal Ammonium acetate extract using flame photometer.	Jackson, 1958
4.	Available Zn & Mn	0.1 N HCl extract and AAS	Sims and Johnson, 1991

3.5 POT CULTURE EXPERIMENT - DECOMPOSITION PATTERN OF DIFFERENT ORGANIC MANURES IN THE PRESENCE AND ABSENCE OF RICE IN LATERITIC SOIL

The experiment included labelling of the plant materials with ^{14}C , incorporation in the soil in the pots and periodic sampling for ^{14}C counting.

3.5.1 Technical programme

Treatments

Number of treatments - 10

A. Sources of organic manure

i) Rice straw

ii) Daincha

iii) Sunhemp

iv) Glyricidia

v) Control

B. Crop

i) With rice

ii) Without rice

Design - CRD

Replication - 3

Method employed - Radio tracer technique

3.5.2 ^{14}C labelling

Labelling of the organic manures with ^{14}C was done by keeping the plants in a chamber containing $^{14}\text{CO}_2$ which was generated by reacting dilute HCl with labelled sodium carbonate ($\text{Na}_2^{14}\text{CO}_3$). Sodium carbonate was kept inside the chamber in a petridish. An arrangement similar to the intravenous fluid administration system was provided to pour dilute HCl to the petridish. The plants were kept in polythene cover inside the chamber. After keeping the plants and the petridish inside the chamber, the door of the chamber was closed tightly and dilute HCl was supplied to the petridish in a regulated flow. Care was taken so that the



Plate 3. Pot culture experiment

soil and the polythene covers were not contaminated. The plants were exposed to $^{14}\text{CO}_2$ for 30 minutes and then removed from the chamber. They were allowed to grow for 20 days before incorporation.

3.5.3 Pot culture

The soil used for the pot culture study was collected from the rice field of the Agricultural Research Station, Mannuthy where the field experiment 3.4 was conducted. Soil was taken up to a depth of 0 to 30 cm, air dried, powdered and passed through a 2 mm sieve. Plastic buckets provided with narrow polythene tubes for draining water as and when required were used for the experiment. Each bucket was filled with 6 kg soil. ^{14}C labelled plant material was chopped into small pieces of less than 0.5 mm length and mixed with this soil. Sufficient quantity of the fresh material was added so as to supply dry material @ one per cent of the weight of the soil. The specific activity and the nutrient composition of the plant materials are given in Table 3.

Twenty day's old seeding of the rice variety Jyothi were planted on the 30th day after in corporation of organic material. It is a short duration, photo insensitive and red kernelled variety with high tillering capacity. The variety is adapted to all region of Kerala. Four hills of two seedlings each were planted in each bucket. The water level in each pot was maintained at 2 cm. Fertilisers were given in the pots planted with rice as per Package of Practices Recommendation (KAU, 1996) in three equal splits as basal, at active tillering stage and at panicle initiation stage. The experiment was continued for 240 days with two crops of rice.

3.5.4 Soil analysis and ^{14}C counting

Soil samples were taken from each treatments at 15 days intervals using a half inch PVC pipe of 15 cm length modified to from a wet soil auger. Soil samples were collected from the entire depth of the soil in the bucket. pH, organic carbon and ^{14}C content were estimated. The samples used for organic C determination was sieved through a 0.5 mm sieve for removing the undecomposed

Table 3. Chemical constituents of different plant materials on dry weight basis

Plant material	Organic Carbon (%)	N (%)	C : N ratio	P (%)	K (%)	Zn (ppm)	Mn (ppm)	Fe (ppm)	Specific activity KBq g ⁻¹ C
Rice straw	37.7	0.73	51 : 1	0.10	1.10	90	671	1500	1.50
Daincha	36.0	2.75	13 : 1	0.48	2.50	40	130	1375	2.08
Sunhemp	38.0	2.41	16 : 1	0.22	1.80	50	200	1500	1.30
Glyricidia	36.3	3.30	11 : 1	0.38	2.30	30	40	1750	2.75

plant material remaining in the soil. For the ^{14}C counting the soil samples were dried at 70°C without sieving and powdered well using a mortar and pestle. A fixed quantity (0.5 g) of this soil sample was subjected to combustion in the Biological Material Oxidiser (OX – 500 - R.J. Harvey Instrument Corporation, USA) and the CO_2 liberated was trapped in a toluene based scintillation cocktail (PPO – 3.9 g; POPOP – 0.1 g; Ethanolamine – 25 ml; Methanol – 225 ml and Toluene – 750 ml). The ^{14}C content was estimated by counting in a liquid Scintillation Counter (Wallac 1409, Finland). Soil samples from each pot were analysed for soil nutrient content after the harvest of each crop.

3.6 INCUBATION STUDY - DECOMPOSITION PATTERN OF RICE STRAW AND DAINCHA IN SELECTED RICE SOILS OF KERALA

3.6.1 Technical programme

Treatments

Number of treatments - 21

A. Soil types

- i) Lateritic
- ii) Chittoor black
- iii) Pokkali
- iv) Onattukara
- v) Karappadam
- vi) Kole
- vii) Kari

B. Organic manures

- i) Rice straw
- ii) Daincha
- iii) Control

Design - CRD

Replication - 3

Method employed - Radio tracer technique

The location and physico-chemical properties of the soils used in this study are presented in Table 4. Ten gram samples of each soil after passing through a 2 mm sieve were taken in 100 ml screw cap plastic bottles and mixed with sufficient quantity of ^{14}C labelled rice straw or daincha so as to supply 0.1 g dry material ie. organic manure @ one per cent of the weight of soil. The plant materials were labelled as per the procedure outlined in section 3.5.2. The specific activity of the rice straw and daincha were 13.25 KBq g^{-1}C and 3.0 KBq g^{-1}C respectively. Each treatment was replicated thrice. Another set of soils without any organic manure addition was kept as control. The control and treatment samples were submerged by adding 10 ml ordinary water. The Chittoor black and Kari soils needed 15 ml water to have the required submergence. Different sets of treatments were kept for periodic sampling. The bottles were closed tightly and kept at room temperature.

Estimations were made at 2, 4, 6, 8 and 10 days after incubation and then at 15 days interval up to 115 days. The soil samples at each sampling date were dried at 70°C , powdered and ^{14}C content was determined after combustion in the Biological Material Oxidiser and subsequent counting in Liquid Scintillation Counter as in the pot culture experiment.

3.7 STATISTICAL ANALYSIS

Statistical analysis of the data was done according to the design adopted for each experiment using the Analysis of Variance Technique (Panse and Sukhatme, 1978). Computation of data was done using the programme MSTATC.

Table 4. Physico-chemical properties of the soils under study

Soil	Location	Sand (%)	Silt (%)	Clay (%)	OC (%)	Available P (Kg ha ⁻¹)	Available K (Kg ha ⁻¹)	Available Mn (Kg ha ⁻¹)	Available Zn (Kg ha ⁻¹)	Available Fe (Kg ha ⁻¹)	pH
Lacteritic	Mannuthy	76.0	4.4	18.7	0.38	44.4	38.8	5.2	7.5	186.6	5.05
Chittoor black	Eruthiempathy	8.7	29.3	62.9	0.66	55.2	675.0	15.2	6.7	52.6	7.62
Pokkali	Vyttila	62.4	4.0	32.3	0.53	131.8	103.0	4.1	3.4	124.3	3.80
Onattukara	Kayamkulam	66.0	12.1	28.1	0.55	134.0	109.0	4.4	5.6	132.2	5.34
Karappadam	Moncompu	34.9	26.7	42.7	1.48	18.7	297.2	10.4	8.9	672.0	4.60
Kole	Venkitangu	25.6	21.4	55.5	2.10	41.3	513.7	8.1	3.4	356.9	4.05
Kari	Karumadi	59.3	12.2	32.7	1.05	14.3	568.9	9.1	11.2	2016.0	3.19

RESULTS

RESULTS

The results of the experiments conducted on methane emission from rice fields of Lateritic soils, decomposition pattern of different organic manures in the presence and absence of rice crop and the decomposition pattern of rice straw and daincha in different rice soils of Kerala are presented in this chapter.

4.1 FIELD EXPERIMENT I - DIURNAL AND SEASONAL VARIATIONS IN METHANE EMISSION FROM RICE FIELDS

4.1.1 Methane emission from rice fields

The experiment was conducted during the first and second crop seasons of 1998-99. Estimations on methane emission were done at tillering, panicle initiation, booting, flowering and maturity stages. During the second crop season, methane flux could be estimated only up to the booting stage since the concentrations of methane in the samples collected at the flowering and maturity stages were almost the same as that of the ambient air.

4.1.1.1 *First crop season*

The location wise and mean data on the methane flux during the first crop season at different growth stages are given in Table 5. It was observed that the methane emission was maximum in the evening at all stages of growth except at tillering and booting. The mean values of the rate of methane emission averaged over the growth stages decreased from morning to noon and then increased in the evening (Fig. 5). A similar trend was observed at flowering and maturity stages. But at the tillering stage the values decreased from morning to evening while a reverse trend was observed at the panicle initiation stage. At the booting stage, the rate of emission increased from morning to noon and then decreased in the evening. The observations at the three locations did not show any uniformity in the pattern of methane emission with respect to the three times of measurement. The individual values of methane emission at the three location in the same field ranged from $0.13 \text{ mg m}^{-2} \text{ hr}^{-1}$ to $1.50 \text{ mg m}^{-2} \text{ hr}^{-1}$ during the tillering stage, 0.66 to

Table 5. Diurnal variations in methane flux ($\text{mg m}^{-2} \text{hr}^{-1}$) during the different growth stages

Growth stages	Morning				Noon				Evening				Mean
	Ch I	Ch II	Ch III	Mean	Ch I	Ch II	Ch III	Mean	Ch I	Ch II	Ch III	Mean	
Tillering	0.29	1.21	1.50	1.00	0.80	0.13	0.69	0.54	0.36	0.46	0.39	0.40	0.65
Panicle initiation	0.72	0.66	0.87	0.75	1.04	0.85	0.82	0.90	0.99	0.91	0.94	0.95	0.87
Booting	1.41	2.61	1.88	1.97	3.08	2.17	3.92	3.06	3.11	3.05	2.15	2.77	2.60
Flowering	1.48	3.73	2.97	2.73	2.17	1.89	2.13	2.06	3.32	3.56	2.07	2.98	2.59
Maturity	3.00	2.99	1.48	2.49	1.49	1.31	1.15	1.32	2.12	2.74	2.71	2.52	2.11
Mean				1.79				1.57				1.92	
ii) Second crop season													
Tillering	0.78	2.41	1.69	1.62	2.95	4.87	3.91	3.91	3.88	6.11	5.51	5.17	3.57
Panicle initiation	1.61	1.70	2.23	1.85	5.51	3.76	4.61	4.63	2.24	3.20	2.97	2.80	3.09
Booting	4.94	6.62	5.10	5.55	3.80	2.10	2.36	2.84	3.70	2.83	3.02	3.18	3.86
Mean				3.01				2.27				3.98	

Ch - Channel

1.04 mg m⁻² hr⁻¹ during the panicle initiation stage, 1.41 to 3.92 mg m⁻² hr⁻¹ during the booting stage, 1.48 to 3.73 mg m⁻² hr⁻¹ during the flowering stage and 1.15 to 2.99 mg m⁻² hr⁻¹ during the maturity stage.

A graphical representation of the mean values for the different stages averaged over the time of measurement is presented in Fig. 6. The methane flux increased from 0.6 mg m⁻² hr⁻¹ at the tillering stage to 0.87 mg m⁻² hr⁻¹ at the panicle initiation stage. The rate of emission rose to 2.60 mg m⁻² hr⁻¹ at the booting stage, levelled off during flowering and declined again during the maturity stage.

4.1.1.2 *Second crop season*

The mean values of rate of methane emission during the second crop season showed a diurnal pattern similar to the first crop season (Table 5 and Fig. 5). But this was not reflected in the methane flux pattern at the different stages. The mean values of methane efflux during the tillering stage was found to increase from morning to evening through noon. The highest emission rate of 5.17 mg m⁻² hr⁻¹ obtained in the evening was approximately 3.5 times more than that of the flux in the morning. During the panicle initiation stage the values increased from morning to noon and then decreased in the evening. Contrary to this, the emission rate was lowest during noon at booting. The highest value was obtained in the morning in all locations, at booting stage.

The average values of methane emission during the tillering, panicle initiation and booting stages were 3.57, 3.09 and 3.86 mg m⁻² hr⁻¹ respectively. The values remained more or less the same during the different growth stages. It was also observed that the rate of emission was higher than that of the first crop season (Fig. 6).

4.1.2 **Diurnal variations in soil and water temperature**

The variations in soil and water temperature during the first and second crop seasons are presented in Table 6.

Fig. 5. Diurnal and seasonal variations in methane emission during the first and second crop seasons

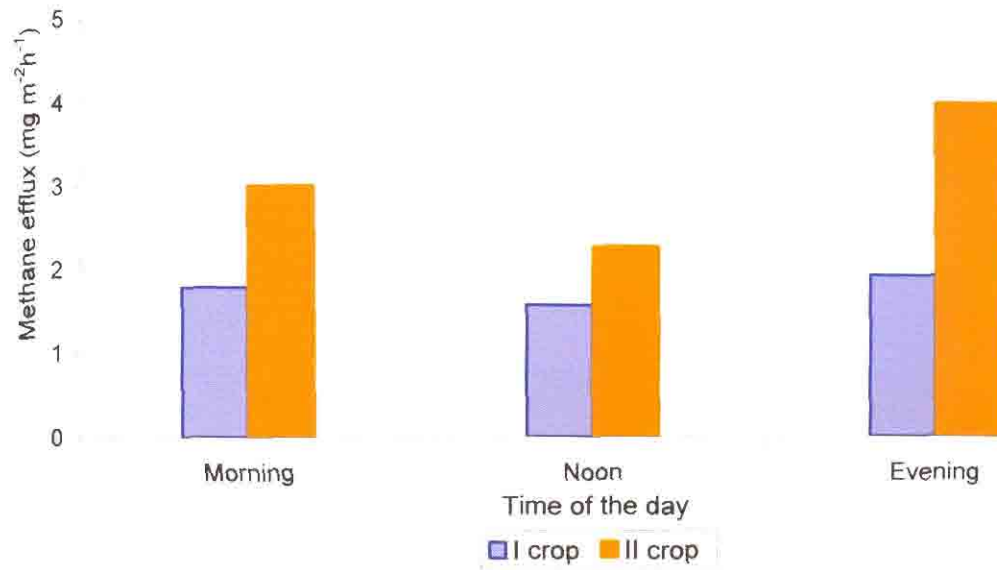


Fig. 6. Methane efflux (mg m⁻²h⁻¹) at different growth stages during the first and second crop seasons

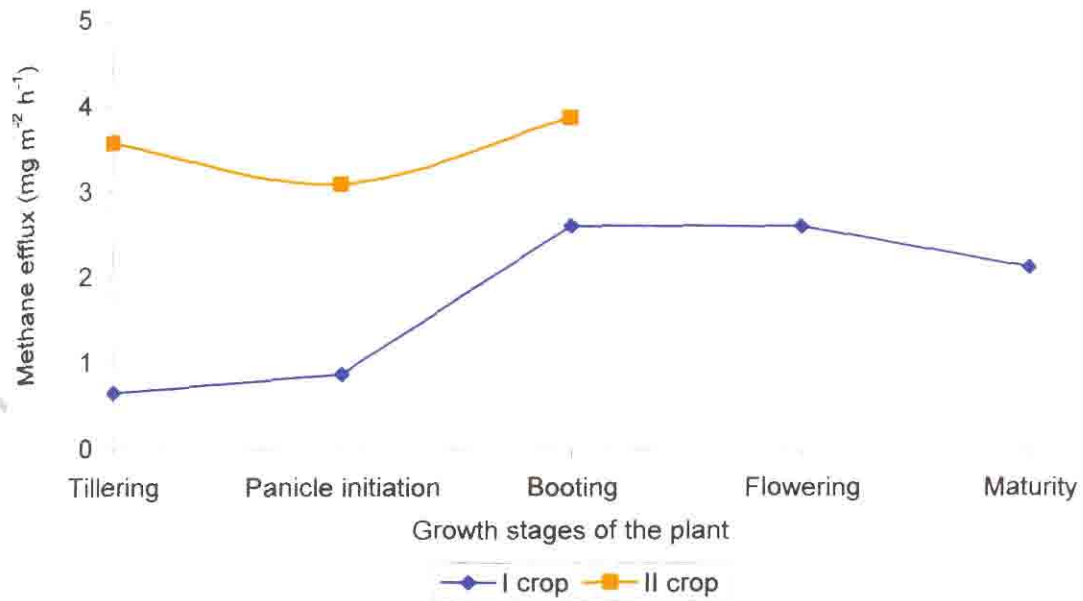


Table 6. Diurnal variations in soil and water temperature at different growth stages

i) First crop season

Growth stages	Soil temperature at 5 cm depth (°C)			Water temperature (°C)			Redox potential (mV)	Organic Carbon (%)	pH
	Morning	Noon	Evening	Morning	Noon	Evening			
Tillering	26.1	27.7	27.7	26.2	27.1	27.2	-90	0.38	6.1
Panicle initiation	25.5	27.7	27.7	27.6	30.0	30.1	-100	0.37	6.0
Booting	26.6	28.8	30.0	28.1	32.1	30.5	-150	0.38	6.1
Flowering	25.5	27.7	28.8	27.5	31.2	31.1	-80	0.40	6.2
Maturity	25.5	26.6	27.7	27.3	29.0	29.3	+10	0.40	6.5

ii) Second crop season

Tillering	26.6	32.2	33.3	25.1	29.5	28.3	-100	0.41	6.2
Panicle initiation	25.5	26.6	27.2	27.5	29.1	28.4	+51	0.40	6.0
Booting	24.4	30.5	28.8	26.0	32.0	30.2	+50	0.42	6.3
Flowering	24.4	27.2	27.8	26.2	27.3	27.5	-	-	-
Maturity	21.1	24.4	24.4	-	-	-	-	-	-

4.1.2.1 *First crop season*

The soil temperature at 5 cm depth and the water temperature fluctuated between morning, noon and evening. The soil temperature was higher at noon and evening than in the morning. It was also observed that the soil temperature was generally higher in the evening than at noon, except at tillering and panicle initiation stages during the first crop season.

The temperature of the water above the soil was always higher than that of the soil. However the temperature at noon and in the evening were almost similar. While the soil temperature fluctuated within one to two degree Celsius between morning and noon, the rise in water temperature from morning to noon was to the tune of two to four degree Celsius.

4.1.2.2 *Second crop season*

During the booting, flowering and maturity stages of the second crop season, the soil temperature at 5 cm depth in the morning was lower than that of the first crop season. This period coincided with the low night temperatures. The diel pattern in soil and water temperatures were similar to that of the first crop season.

4.2 FIELD EXPERIMENT II - EFFECT OF DIFFERENT ORGANIC MANURES AND INORGANIC FERTILISERS ON THE METHANE FLUX FROM RICE FIELDS.

The results of the experiment to find out the effect of different sources of organic manure and sources of nitrogen are given in Table 7. It was observed that the methane emission was significantly influenced by the type of organic manure added before planting and also the source of nitrogen fertiliser applied.

4.2.1 Effect of different sources of organic manure

During the first crop season at tillering stage, the highest emission rate of $5.51 \text{ mg m}^{-2} \text{ hr}^{-1}$ was recorded when rice straw was used as the source of organic

Table 7. Methane emission from paddy field as influenced by different sources of organic manure and nitrogen during the first and second crop seasons

Sources of organic manure	Methane efflux (mg m ⁻² hr ⁻¹)		
	First crop season	Second crop season	
	Tillering	Tillering	Booting
Rice straw	5.51 ^a	1.09 ^a	6.02 ^a
Glyricidia	5.30 ^a	0.61 ^b	4.29 ^b
Farm yard manure	3.02 ^b	0.65 ^b	2.63 ^c
Control	2.73 ^c	0.40 ^c	1.01 ^d
CD (0.05)	0.63	0.16	1.23
Sources of N			
Urea	4.98 ^a	0.95 ^a	4.84 ^a
Factomphos	5.05 ^a	0.45 ^c	3.39 ^b
Control	3.09 ^b	0.67 ^b	2.24 ^c
CD (0.05)	0.55	0.14	1.06

manure. This was on par with the incorporation of glyricidia ($5.30 \text{ mg m}^{-2}\text{hr}^{-1}$). Though the farm yard manure application resulted in a significantly lower level of methane emission compared to the other two sources it was significantly higher than the control.

During the second crop season, rice straw incorporation brought about a higher methane efflux which was significantly higher than glyricidia and farm yard manure application at tillering and booting stages. The emission rate recorded for glyricidia and farm yard manure were almost the same at tillering stage while that for farm yard manure was significantly lower to glyricidia at the booting stage. The treatments without organic manure addition recorded the lowest values of 0.40 and $1.01 \text{ mg m}^{-2} \text{ hr}^{-1}$ respectively at tillering and booting stages. The methane flux could not be estimated at flowering and maturity stages since all the samples recorded values similar to ambient air.

Soil characteristics like organic carbon content, redox potential and soil temperature at 5 cm depth were not significantly influenced by the sources of organic manure (Table 8). Similarly biometric parameters like plant height, number of tillers, dry weight of the plant, root volume and fresh weight of root were not significantly influenced by the treatments at any of the stages except booting stage of the second crop season. The plant height at booting stage was significantly lower in control.

4.2.2 Effect of different sources of nitrogen

Application of nitrogenous fertiliser significantly influenced the methane emission rate during tillering stage of the first crop season and booting stage of the second crop season. The effect of the two sources of nitrogen namely, urea and factomphos were on par during the tillering stage of the first crop. However, urea recorded significantly higher emission rate during the tillering and booting stages of the second season. Though the methane efflux following the application of factomphos during the tillering stage in first crop season and at the booting stage during the second crop season were significantly higher than that of control,

Table 8a. Soil and plant characters at tillering stage during the first crop season

Sources of organic manure	Soil characters				Plant characters					
	Soil temperature at 5 cm (°C)	Redox potential (mV)	pH	OC (%)	Plant height (cm)	No. of tillers hill ⁻¹	Dry matter hill ⁻¹ (g)	Root volume hill ⁻¹ (ml)	Fresh weight of roots hill ⁻¹ (g)	
Rice straw	28.5	-72.2	5.7	0.43	47.4	6.1	4.9	2.0	1.6	
Glycicidia	28.9	-95.6	5.9	0.44	46.4	6.0	4.8	1.8	1.5	
Farm yard manure	28.5	-166.6	6.0	0.51	47.1	6.2	4.9	1.8	1.4	
Control	28.5	-140.0	5.8	0.44	46.3	6.0	4.8	2.1	1.2	
CD (0.05)				NS	NS	NS	NS	NS	NS	
Sources of N										
Urea	29.4	-100	5.8	0.45	47.0	5.8	4.8	2.1	1.5	
Factomphos	28.6	-130.6	5.8	0.46	48.2	6.4	4.9	2.1	1.6	
Control	27.8	-128.3	5.8	0.45	45.2	5.9	4.9	1.7	1.4	
CD (0.05)				NS	2.1	NS	NS	0.3	NS	

Contd....

Table 8b. Soil and plant characters at tillering stage during the second crop season

Sources of organic manure	Soil characters				Plant characters					
	Soil temperature at 5 cm (°C)	Redox potential (mV)	pH	OC (%)	Plant height (cm)	No. of tillers hill ⁻¹	Dry matter hill ⁻¹ (g)	Root volume hill ⁻¹ (ml)	Fresh weight of roots hill ⁻¹ (g)	
Rice straw	29.1	13.3	6.6	0.53	28.8	6.6	3.5	2.3	2.0	
Glycidia	28.7	-43.4	6.6	0.58	29.7	7.3	3.6	2.4	2.0	
Farm yard manure	30.2	13.4	6.6	0.56	28.8	7.2	3.6	2.8	2.2	
Control	29.4	38.8	6.6	0.56	28.3	6.7	3.5	2.5	2.0	
CD (0.05)				NS	NS	NS	NS	NS	NS	
Sources of N										
Urea	29.1	30.8	6.6	0.54	29.6	7.2	3.5	2.4	2.0	
Factomphos	28.7	73.3	6.6	0.58	29.4	7.2	3.6	2.7	2.2	
Control	30.1	-33.3	6.6	0.56	27.7	6.6	3.5	2.4	1.9	
CD (0.05)				NS	1.4	NS	NS	NS	NS	

Contd...

Table 8c. Soil and plant characters at booting stage during the second crop season

Sources of organic manure	Soil characters				Plant characters					
	Soil temperature at 5 cm (°C)	Redox potential (mV)	pH	Organic carbon (%)	Plant height (cm)	No. of tillers hill ⁻¹	Dry matter hill ⁻¹ (g)	Root volume hill ⁻¹ (ml)	Root weight hill ⁻¹ (g)	
Rice straw	24.8	-35.5	6.58	0.50	62.7	11.4	7.3	4.5	3.9	
Glyricidia	24.7	-57.7	6.59	0.52	61.7	12.4	8.1	5.3	4.8	
Farm yard manure	26.3	-77.7	6.64	0.56	60.9	11.8	7.9	5.3	4.4	
Control	24.6	-31.1	6.58	0.50	58.8	10.8	7.2	5.1	4.3	
CD (0.05)				NS	1.9	NS	NS	NS	NS	
Sources of N										
Urea	24.5	-63.2	6.60	0.50	61.8	12.7	7.9	4.9	4.2	
Factomphos	25.4	-56.6	6.61	0.50	63.3	13.7	8.4	5.5	4.7	
Control	25.3	-32.2	6.59	0.55	58.1	8.3	6.6	4.7	4.1	
CD (0.05)				NS	1.4	1.1	0.66	0.7	NS	

the emission was lower than the control during the tillering stage of the second crop season. Among the plant characters studied in relation to methane emission, only plant height was found to be significantly influenced by the application of nitrogen during all the three stages of methane estimation. The root volume per hill was also significantly affected by the application of nitrogen during tillering stage of first crop and booting stage of second crop (Table 8).

4.2.3 Effect of organic manure × nitrogen interaction on methane emission

The data showing the interaction effect of organic manure and nitrogen sources on rate of methane emission are presented in Table 9. Significant influence of the interaction was observed during first and second crop seasons.

4.2.3.1 At tillering during the first crop

Within each organic manure treatment, application of nitrogen resulted in significantly higher methane emission rate. The effect of urea and factomphos was comparable in all the organic manure treatments except rice straw incorporation where the effect of factomphos was significantly higher than urea.

4.2.3.2 At tillering during the second crop

As in the first crop season, higher and significant positive influence was shown by urea, compared to factomphos and control in rice straw incorporated plots. Neither urea nor factomphos could influence the methane flux in the glyricidia plots or the plots without organic manure. In the plots where farm yard manure was applied, the control treatment without nitrogen recorded the highest methane flux.

4.2.3.3 At booting stage during the second crop

The application of nitrogen contributed to higher methane emission only in the rice straw and glyricidia incorporated treatments. The values of methane flux were on par between urea and factomphos in the FYM applied plots. However, in

Table 9. Methane emission from paddy field as influenced by the interaction of organic manures and nitrogen fertilisers

i) First crop season – Tillering

Sources of N	Sources of organic manure			
	Straw	Glyricidia	Farm yard manure	Control
Urea	6.03	6.45	3.70	3.75
Factomphos	7.84	5.82	4.08	2.45
Control	2.65	3.64	1.28	2.00
CD (0.05) OM × N	1.09			

ii) Second crop season – Tillering

Source of N	Straw	Glyricidia	Farm yard manure	Control
Urea	2.09	0.70	0.64	0.39
Factomphos	0.60	0.52	0.27	0.41
Control	0.60	0.63	1.05	0.42
CD (0.05) OM × N	0.27			

iii) Second crop season – Booting

Source of N	Straw	Glyricidia	Farm yard manure	Control
Urea	7.84	6.85	2.92	1.75
Factomphos	7.01	3.44	2.04	1.06
Control	3.21	2.58	2.95	0.22
CD (0.05) OM × N	2.13			

the plots where glyricidia was incorporated, urea application resulted in a significantly higher methane emission rate than factomphos.

4.2.4 Seasonal variation in methane emission

A comparison of the data on methane emission during the tillering stage of first and second crop seasons showed that the emission rate in all the treatments was higher during the first crop season (Table 7). This is at variance to the previous experiment where a higher emission rate was observed during the second crop season (Table 5).

The methane flux increased from tillering to booting stage during the second crop season. A two to seven fold increase was observed depending on the treatments. The magnitude of increase was more in the organic manure applied treatments.

Samples were collected for estimating the methane flux at flowering and maturity stages of the second crop season. The values corresponded to that of ambient air and the flux could not be worked out.

4.2.5 Methane emission in relation to soil and plant parameters.

Correlation coefficients were worked out between the methane emission at the three stages and soil characters like soil temperature at 5 cm depth, redox potential and plant characters such as height, number of tillers, dry weight, root volume and fresh root weight. Significant positive correlations were obtained between methane efflux at booting stage of the second crop and plant height ($r^2 = 0.61$).

4.2.6 Effect of different sources of organic manure and nitrogen on the biometric characters

4.2.6.1 *Height of plants*

The data on the height of plants during the first and second crop seasons are shown in Table 10. Though there was a progressive increase in height from

Table 10. Effect of different sources of organic manure and nitrogen on height of plants (cm) at different growth stages during the first and second crop seasons

Sources of organic manure	First crop season			Second crop season		
	Tillering	Panicle initiation	Maturity	Tillering	Panicle initiation	Maturity
Rice straw	47.4	77.4	92.4	28.8	57.3	66.5
Glyricidia	46.4	75.3	91.5	29.7	58.7	65.6
Farm yard manure	47.1	75.2	91.8	28.8	57.3	63.7
Control	46.3	74.2	90.2	28.3	54.5	60.7
CD (0.05)	NS	NS	NS	NS	2.5	1.9
Sources of N						
Urea	47.0	77.4	91.6	29.6	59.2	65.0
Factomphos	48.2	77.4	93.7	29.4	60.2	66.1
Control	45.2	71.8	89.2	27.7	51.4	61.2
CD (0.05)	2.1	3.4	2.2	1.4	2.1	1.7

tillering to maturity during the first crop season, it was not influenced by the application of organic manure as well as the different sources of organic manure. During the second crop season also the height of plants at tillering was not affected significantly by the sources of organic manure. But at the panicle initiation and maturity stages the height recorded for the three sources of organic manure was at par and were significantly higher than the treatment without organic manure.

The height of plants at tillering, panicle initiation and maturity were significantly influenced by the nitrogen levels during the first crop season. The height of plants in the control was significantly lower than that supplied with urea and factomphos which were on par. A similar result was obtained during the second crop season also, regarding the height of plants at tillering, panicle initiation and maturity.

4.2.6.2 Number of tillers per hill

The number of tillers per hill during the first and second crop seasons were not significantly influenced by the application of different sources of organic manure (Table 11). During the first crop season, the number of tillers increased from tillering to flowering stage and then declined at maturity. However, during the second crop season, the number of tillers increased only up to panicle initiation stage and thereafter declined both at flowering and maturity stages.

It could be observed that the application of N or the sources of nitrogen did not significantly influence the number of tillers at any of the stages during the first crop season. But significant difference was observed in the number of tillers per hill due to the application of N during the second crop season at all stages except tillering stage.

4.2.6.3 Root volume and fresh root weight per hill

The data on root volume and fresh root weight of rice at different growth stages during the first and second crop seasons are given in Tables 12 and 13.

Table 11. Effect of different sources of organic manure and nitrogen on the number of tillers per hill during the first and second crop seasons

Sources of organic manure	First crop season				Second crop season			
	Tillering	Panicle initiation	Flowering	Maturity	Tillering	Panicle initiation	Flowering	Maturity
Rice straw	6.1	7.3	8.1	6.1	6.6	11.4	9.0	8.0
Glyricidia	6.0	7.3	8.4	6.5	7.3	12.4	9.2	8.7
Farm yard manure	6.2	7.0	8.5	6.2	7.2	11.8	8.7	7.8
Control	6.0	6.7	8.2	6.2	6.7	10.8	8.4	8.0
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sources of N								
Urea	5.8	7.2	8.3	6.5	7.2	12.7	10.0	8.6
Factomphos	6.4	7.4	8.8	6.1	7.2	13.7	9.7	8.6
Control	5.9	6.6	7.9	6.1	6.6	8.3	6.9	7.2
CD (0.05)	NS	NS	NS	NS	NS	1.1	1.2	0.9

Table 12. Effect of different sources of organic manure and nitrogen on the root volume (ml hill⁻¹) at different growth stages during the first and second crop seasons

Sources of organic manure	First crop season			Second crop season		
	Tillering	Panicle initiation	Flowering	Tillering	Panicle initiation	Flowering
Rice straw	2.0	4.0	3.2	2.3	4.5	3.3
Glyricidia	1.8	3.6	2.9	2.4	5.3	4.0
Farm yard manure	1.8	3.6	2.9	2.8	5.3	3.9
Control	2.1	4.4	2.5	2.5	5.1	3.9
CD (0.05)	NS	NS	NS	NS	NS	NS
Sources of N						
Urea	2.1	4.2	3.1	2.4	4.9	3.8
Factomphos	2.1	3.9	2.6	2.7	5.5	4.0
Control	1.7	3.6	2.9	2.4	4.7	3.4
CD (0.05)	0.3	NS	NS	NS	0.7	NS

Table 13. Effect of different sources of organic manure and nitrogen on the fresh weight of roots (g) at different growth stages during the first and second crop seasons

Sources of organic manure	First crop season			Second crop season		
	Tillering	Panicle initiation	Flowering	Tillering	Panicle initiation	Flowering
Rice straw	1.6	3.6	2.1	2.0	3.9	2.8
Glyricidia	1.5	3.1	1.9	2.0	4.8	3.2
Farm yard manure	1.4	2.9	1.9	2.2	4.4	3.2
Control	1.2	3.9	1.5	2.0	4.3	3.1
CD (0.05)	NS	NS	NS	NS	NS	NS
Sources of N						
Urea	1.5	3.8	1.9	2.0	4.2	3.0
Factomphos	1.7	3.3	1.6	2.2	4.7	3.4
Control	1.4	3.0	2.1	1.9	4.1	2.8
CD (0.05)	0.2	0.6	NS	NS	NS	NS

A decreasing trend was observed for the fresh root weight and root volume as the plant advanced from panicle initiation to flowering stage. Application of organic manures did not significantly affect the root volume in both seasons. There was a decrease in the root volume from panicle initiation to flowering stage (25 per cent) which was observed for both seasons.

As in the case of root volume, a decrease in root weight was observed from panicle initiation to the flowering stage, 42 per cent during the first crop season and 28 per cent during the second crop season. Significant variation was not observed between the three sources of organic manure.

The N fertilised plots recorded a significantly higher root volume at panicle initiation stage during the second crop season and root weight at panicle initiation during the first crop season. The sources of N had no significant influence on the root volume and root weight at the other stages of growth during the two seasons.

4.2.7 Effect of different sources of organic manure and nitrogen on the yield contributing characters

The number of productive tillers per m², thousand grain weight and percentage of filled grains per panicle were not significantly influenced by the application of different sources of organic manure during the first and second crop seasons (Table 14). However, the number of spikelets per panicle and length of panicle were positively and significantly influenced by the incorporation of organic manures during the second crop season.

Significant variations were not noticed among the yield contributing characters due to the different nitrogen sources during the first crop season. During the second crop season, the number of panicles per m² was found to be influenced significantly by the sources of nitrogen. The control treatment without nitrogen produced significantly lower number of panicles. The other characters were not significantly influenced by the nitrogen sources during the second crop season also.

Table 14. Effect of different sources of organic manure and nitrogen on the yield contributing characters during the first and second crop seasons

Sources of organic manure	First crop season					Second crop season				
	No. of panicles m ⁻²	No. of spikelets panicle ⁻¹	Percentage of filled grains panicle ⁻¹	1000 gwt (g)	Panicle length (cm)	No. of panicles m ⁻²	No. of spikelets panicle ⁻¹	Percentage of filled grains panicle ⁻¹	1000 gwt (g)	Panicle length (cm)
Rice straw	382	104	85.5	30.1	20.4	480	63	85.2	27.1	17.5
Glycidia	403	98	83.9	29.8	20.4	505	68	81.8	26.8	17.7
Farm yard manure	402	97	85.6	30.9	20.5	482	64	84.7	27.1	17.3
Control	391	99	86.0	30.1	20.4	458	57	87.0	27.1	16.6
CD (0.05)	NS	NS	NS	NS	NS	NS	5.8	NS	NS	0.66
Sources of N										
Urea	406	98	86.0	30.4	20.2	514	64	83.6	27.2	17.3
Factomphos	392	98	84.0	30.0	20.4	498	64	85.0	27.3	17.4
Control	384	102	85.7	30.3	20.6	431	61	85.5	26.5	17.1
CD (0.05)	NS	NS	NS	NS	NS	43	NS	NS	NS	NS

4.2.8 Effect of different sources of organic manure and nitrogen on grain yield and straw yield of rice

The grain and straw yields obtained during the first and second crop seasons are presented in Table 15. The yields were higher during the first crop season than that of the second crop season. The influence of organic manures on the grain yield was seen only during the second crop season, and the treatment without organic manure recorded significantly lower grain yield. The straw yield was not significantly influenced by organic manures during both seasons.

Significant variation was not detected between the yields due to the nitrogen sources during the first crop season. But there was significant difference in grain and straw yields between the nitrogen sources in the second crop season. Factomphos application recorded significantly higher grain and straw yields than control and on par with urea application.

4.2.9 Effect of different sources of organic manure and nitrogen on the nutrient contents of plant parts

4.2.9.1 Nitrogen

The sources of organic manure did not produce any significant influence on the N content of plant parts at the different growth stages during both the seasons except root at tillering and plant at panicle initiation in the first crop season. In the early growth stages, the plant showed a higher content than root. The contents of both plant and root decreased towards the later stages during both the seasons. The grain showed a higher content than straw at maturity stage (Table 16).

The nitrogen content of rice plant at different growth stages were not significantly influenced by the sources of N except at tillering during the first crop season.

Table 15. Grain and straw yields (kg ha^{-1}) of rice as influenced by different sources of organic manure and nitrogen during the first and second crop seasons

Sources of organic manure	First crop season		Second crop season	
	Grain yield	Straw yield	Grain yield	Straw yield
Rice straw	5673	3444	3977	2884
Glyricidia	5454	3426	4021	3016
Farm yard manure	5376	3016	4021	2430
Control	5586	3016	3575	2369
CD (0.05)	NS	NS	271	NS
Sources of N				
Urea	5559	3260	4257	2981
Factomphos	5498	3225	4335	3094
Control	5507	3199	3094	1958
CD (0.05)	NS	NS	236	502

Table 16 a. Effect of different sources of organic manure and nitrogen on the nitrogen content (%) of plant parts at different growth stages during the first crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	1.74	1.11	2.21	1.02	0.89	0.89	0.78	1.04
Glyricidia	1.84	1.01	1.85	1.15	0.69	0.82	0.68	0.99
Farm yard manure	1.98	1.37	1.37	1.09	0.87	0.82	0.51	0.92
Control	1.65	0.85	1.36	1.10	0.80	0.68	0.76	0.92
CD (0.05)	NS	0.2	0.5	NS	NS	NS	NS	NS
Sources of N								
Urea	1.65	1.04	1.92	1.27	0.81	0.84	0.57	1.02
Factomphos	2.30	1.19	1.49	1.01	0.81	0.70	0.82	1.05
Control	1.46	1.03	1.68	1.00	0.81	0.87	0.67	0.85
CD (0.05)	0.60	NS	NS	NS	NS	NS	NS	NS

Contd.....

4.2.9.2 Phosphorus

The phosphorus content in the plant showed a decreasing trend from tillering to flowering in both seasons. The content was higher in the grain than in straw at maturity. The phosphorus content was not significantly influenced by the application or sources of organic manure (Table 17). The phosphorus content of the rice plant was not found to be influenced by the sources of N neither at different stages nor during the different seasons.

4.2.9.3 Potassium

The potassium content of the plant at panicle initiation stage during both first and second crop seasons were significantly influenced by the sources of organic manure (Table 18). Significant influence of organic manure application was also observed for the content of potassium in the root at the panicle initiation and flowering stages during the second crop season. A higher content of potassium was observed for the treatment with straw among the sources of organic manure.

Among the sources of nitrogen, though not significant, a higher potassium content in the plant was recorded by control in all the stages during the second crop season and in the earlier stages during the first crop season. Grain showed a lower content than straw at maturity stage.

4.2.9.4 Calcium

The calcium content of plant parts in both first and second crop seasons were not influenced significantly by the sources of organic manure. However significant difference in content due to N sources was observed at maturity in the second crop season. The content was higher for urea compared to control and on par with factomphos (Table 19).

The percentage of calcium in the plant showed an increase from tillering to maturity during both seasons. The values increased progressively from 423 ppm to

Table 17 a. Effect of different sources of organic manure and nitrogen on the phosphorus content (%) of plant parts at different growth stages during the first crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	0.39	0.28	0.27	0.31	0.19	0.18	0.07	0.24
Glyricidia	0.40	0.30	0.28	0.33	0.21	0.19	0.09	0.30
Farm yard manure	0.39	0.31	0.27	0.35	0.18	0.20	0.09	0.25
Control	0.38	0.28	0.26	0.30	0.19	0.17	0.09	0.22
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sources of N								
Urea	0.38	0.29	0.27	0.31	0.19	0.18	0.09	0.25
Factomphos	0.40	0.30	0.28	0.32	0.20	0.17	0.09	0.24
Control	0.39	0.28	0.27	0.35	0.18	0.20	0.08	0.26
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Contd...

Table 17 b. Effect of different sources of organic manure and nitrogen on the phosphorus content (%) of plant parts at different growth stages during the second crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	0.39	0.27	0.27	0.20	0.22	0.20	0.06	0.43
Glyricidia	0.37	0.30	0.28	0.21	0.18	0.18	0.07	0.34
Farm yard manure	0.35	0.32	0.26	0.24	0.30	0.20	0.08	0.35
Control	0.34	0.26	0.27	0.18	0.21	0.18	0.05	0.31
CD (0.05)	NS	NS	NS	0.04	NS	NS	NS	NS
Sources of N								
Urea	0.389	0.331	0.281	0.204	0.24	0.22	0.06	0.35
Factomphos	0.359	0.278	0.276	0.211	0.22	0.18	0.07	0.38
Control	0.351	0.260	0.266	0.211	0.22	0.18	0.06	0.35
CD (0.05)	NS	NS	NS	0.04	NS	NS	NS	NS

Table 18 a. Effect of different sources of organic manure and nitrogen on the potassium content (%) of plant parts at different growth stages during the first crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	2.95	0.65	1.65	0.21	1.30	0.14	1.55	0.14
Glyricidia	2.98	0.55	1.58	0.19	1.38	0.13	1.38	0.13
Farm yard manure	2.60	0.57	1.45	0.17	1.30	0.16	1.18	0.13
Control	2.55	0.50	1.38	0.17	1.35	0.14	1.27	0.12
CD (0.05)	NS	NS	0.17	NS	NS	NS	NS	NS
Sources of N								
Urea	2.63	0.55	1.51	0.19	1.37	0.14	1.47	0.13
Factomphos	2.79	0.55	1.49	0.17	1.26	0.13	1.11	0.13
Control	2.90	0.60	1.55	0.19	1.36	0.16	1.45	0.13
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Contd...

Table 18 b. Effect of different sources of organic manure and nitrogen on the potassium content (%) of plant parts at different growth stages during the second crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	2.80	1.08	3.05	0.30	1.52	0.29	1.80	0.26
Glyricidia	2.52	0.90	2.73	0.27	1.30	0.25	1.95	0.23
Farm yard manure	2.20	1.18	2.53	0.23	1.37	0.21	1.65	0.22
Control	2.17	0.85	2.30	0.26	1.42	0.23	1.92	0.23
CD (0.05)	NS	NS	0.47	0.037	NS	0.012	NS	NS
Sources of N								
Urea	2.30	1.05	2.50	0.24	1.40	0.22	1.60	0.24
Factomphos	2.36	0.97	2.57	0.25	1.37	0.23	1.91	0.23
Control	2.60	0.99	2.89	0.30	1.42	0.28	1.97	0.23
CD (0.05)	NS	NS	NS	0.03	NS	0.01	NS	NS

Table 19 a. Effect of different sources of organic manure and nitrogen on the calcium content (ppm) of plant parts at different growth stages during the first crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	395.5	29.0	654.0	61.5	937.8	36.3	3218.7	114.5
Glyricidia	518.7	31.7	712.0	55.5	895.0	37.5	4141.2	111.2
Farm yard manure	375.2	30.2	763.7	67.7	1028.8	40.2	3481.2	107.0
Control	401.7	30.0	705.3	80.5	1273.3	35.8	3468.7	101.7
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sources of N								
Urea	376.5	28.4	634.5	57.5	1142.6	37.7	3481.2	105.9
Factomphos	488.7	33.9	747.9	61.5	979.5	40.4	3353.7	111.6
Control	403.0	28.4	743.9	79.9	979.1	34.3	3898.7	108.2
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Contd...

Table 19 b. Effect of different sources of organic manure and nitrogen on the calcium content (ppm) of plant parts at different growth stages during the second crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Root
Rice straw	575.7	99.8	468.5	51.5	584.0	54.7	5590.0	64.5
Glyricidia	622.0	102.5	463.5	52.2	5050	53.8	4391.2	76.5
Farm yard manure	674.8	100.3	489.7	51.3	520.8	44.8	3740.0	70.7
Control	611.5	68.7	445.8	51.5	667.8	43.5	4977.5	74.7
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sources of N								
Urea	827.3	93.0	485.2	49.7	552.2	49.0	5681.2	66.1
Factomphos	549.1	94.4	513.6	46.1	668.4	42.7	4450.0	73.6
Control	486.6	91.1	401.8	59.0	488.1	55.9	3892.5	75.0
CD (0.05)	NS	NS	NS	8.5	NS	10.4	1270.0	NS

3577 ppm. A decrease in the content was observed in root from panicle initiation to flowering.

A higher calcium content was estimated in the plant and root during the tillering stage of the second crop season than the first crop season. However it was lower during the panicle initiation stage and flowering stage.

4.2.9.5 Magnesium

During the first crop season the Mg content showed an increase from tillering to flowering but decreased at the time of maturity. But this trend was reversed during the second crop season. The content in root at tillering and panicle initiation and the content in plant during maturity were significantly influenced by the organic manures during the second crop season. During the first crop season, the contents of root at panicle initiation and flowering alone were significantly influenced by the treatments. The content of magnesium in the plant parts was generally higher for farm yard manure or control (Table 20).

As in the case of calcium, the magnesium content at maturity was significantly higher in urea and factomphos in comparison with control during the second crop season.

Grain content accounted for 40 per cent of the total Mg content in the plant during the first crop season and 37 per cent during the second crop season. It was observed that the content of Mg increased from 0.22 per cent at tillering to 0.36 per cent at maturity during the first crop season. However the values decreased from 0.25 at tillering to 0.16 at panicle initiation and flowering and then increased to 0.20 at maturity.

4.2.9.6 Copper

The different sources of organic manure or different sources of nitrogen did not produce any significant influence on the copper content of rice at any of the growth stages during both seasons (Table 21). The grain recorded a higher copper content than the straw. Similarly root recorded a higher concentration than

Table 20 a. Effect of different sources of organic manure and nitrogen on the magnesium content (ppm) of plant parts at different growth stages during the first crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	1853.7	716.3	2512.5	1590.0	4265.0	618.7	2958.7	2268.7
Glyricidia	2491.2	803.7	2828.7	1331.2	4456.2	640.0	4300.0	2683.7
Farm yard manure	2135.0	902.5	2585.0	2066.2	4422.5	791.2	3587.5	2822.5
Control	2333.7	902.5	3037.5	2472.5	4521.2	640.0	3737.5	2237.5
CD (0.05)	NS	NS	NS	563.8	NS	117.4	NS	NS
Sources of N								
Urea	2050.0	906.2	2592.5	1959.0	4768.7	668.7	3575.0	2368.7
Factomphos	2275.0	845.0	2761.2	1686.0	4480.0	723.7	3913.7	2443.7
Control	2286.0	742.5	2870.0	1950.0	4000.0	625.0	3448.7	2697.5
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Contd...

Table 20 b. Effect of different sources of organic manure and nitrogen on the magnesium content (ppm) of plant parts at different growth stages during the second crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Root
Rice straw	2652.5	1825.0	1508.7	878.7	877.5	422.5	1743.7	1112.5
Glyricidia	2508.7	1962.5	1727.5	1041.2	1096.2	628.7	1778.7	1318.7
Farm yard manure	2378.7	2593.7	1381.3	1033.7	1871.2	737.5	2215.0	1256.2
Control	2437.5	1271.2	1343.7	858.7	1300.0	508.7	2533.7	1147.5
CD (0.05)	NS	655.7	NS	151.6	NS	NS	460.0	NS
Sources of N								
Urea	2865.0	2106.2	1428.7	982.5	1476.2	623.7	2225.0	1126.2
Factomphos	2537.5	2053.7	1707.5	925.0	1323.7	496.2	2362.5	1225.0
Control	2080.0	1580.0	1333.7	951.2	1057.5	603.7	1615.0	1275.0
CD (0.05)	NS	NS	NS	NS	NS	NS	397.0	NS

Table 21 a. Effect of different sources of organic manure and nitrogen on the copper content (ppm) of plant parts at different growth stages during the first crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	9.5	21.5	5.3	21.5	29.5	38.7	4.3	5.7
Glyricidia	10.3	23.8	5.8	18.5	27.0	32.5	5.3	6.7
Farm yard manure	9.5	24.3	5.5	23.5	36.5	41.3	6.7	7.3
Control	8.7	20.7	5.8	26.2	32.0	33.7	6.2	6.3
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sources of N								
Urea	10.5	21.0	5.2	26.3	37.1	38.1	6.6	7.0
Factomphos	8.9	25.6	6.0	22.2	34.3	34.4	5.1	6.1
Control	9.1	21.1	5.6	18.8	22.4	37.1	5.1	6.4
CD (0.05)	NS	3.5	NS	NS	NS	NS	NS	NS

Contd...

the above ground part at all the stages. The content was higher during the second crop season.

The copper content in the plant decreased from tillering to panicle initiation and then increased at flowering and again decreased during maturity. The grain recorded a slightly higher values than straw at maturity.

4.2.9.7 Zinc

During both seasons, the zinc content in the plant at tillering decreased by panicle initiation and then increased by flowering. It again decreased at the maturity stage. The content in the grain was lower than that in the straw. The concentration in the root which was always higher than the plant except at flowering, also showed a trend similar to that in the plant (Table 22). No significant influence of organic manures or nitrogen was found in the zinc content of any of the plant parts at any of the growth stages in both seasons.

The concentration of zinc both in plant and root were lower in the treatments supplied with factomphos compared to urea during the first crop season, though not significant and consistent. This trend was however, manifested only in the case of root during the second crop season.

4.2.9.8 Iron

The iron content in the above ground part of the plant remained almost same during the different growth stages in the first crop season (Table 23). Root showed a very high content compared to leaves. Grain recorded very low values in both seasons. The content of iron in the above ground part decreased from tillering to flowering and remained almost same at maturity. The different sources of organic manure or nitrogen did not produce any significant influence on the content of iron in the plant.

Table 22 a. Effect of different sources of organic manure and nitrogen on the zinc content (ppm) of plant parts at different growth stages during the first crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	36.3	52.7	22.5	51.3	52.8	44.5	36.8	17.7
Glyricidia	40.7	50.7	25.7	71.2	36.2	40.2	40.2	20.0
Farm yard manure	41.5	53.8	25.7	68.0	50.5	46.8	36.8	18.5
Control	39.3	57.7	21.8	63.7	42.2	32.2	43.2	16.2
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sources of N								
Urea	40.1	62.6	23.3	66.3	46.9	44.6	40.9	17.1
Factomphos	37.8	48.3	25.0	61.2	38.0	38.9	34.8	20.0
Control	40.5	49.9	23.5	63.1	51.4	39.2	42.1	17.1
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Contd...

Table 22 b. Effect of different sources of organic manure and nitrogen on the zinc content (ppm) of plant parts at different growth stages during the second crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Root
Rice straw	43.7	191.8	13.8	196.0	30.0	124.2	24.0	11.0
Glyricidia	34.0	133.3	21.5	193.7	35.3	158.8	26.0	12.5
Farm yard manure	31.0	215.3	13.8	216.5	40.5	276.8	32.0	13.3
Control	37.8	163.5	22.5	202.2	38.7	144.5	32.2	11.7
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sources of N								
Urea	40.5	208.0	15.4	187.9	40.4	118.0	36.4	11.7
Factomphos	38.8	174.9	20.9	152.0	33.6	147.9	23.4	12.5
Control	30.6	145.1	17.5	266.4	34.4	152.4	25.9	12.1
CD (0.05)	NS	NS	NS	104.1	NS	NS	NS	NS

Table 23 a. Effect of different sources of organic manure and nitrogen on the iron content (ppm) of plant parts at different growth stages during the first crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	4760	294500	4600	333200	5000	141200	4150	410
Glyricidia	4840	263600	4380	383100	4520	142300	4690	430
Farm yard manure	4820	325000	4560	441900	5070	157200	6070	390
Control	4500	244300	4510	385400	3350	133200	5090	360
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sources of N								
Urea	4370	286600	4280	350300	4350	137300	4080	390
Factomphos	5190	288100	5240	376900	4540	138200	5080	390
Control	4630	270800	4010	430600	4560	155300	5840	410
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Contd...

4.2.9.9 *Manganese*

During the first crop season, significant influence of organic manure in the content of Mn was observed only in root at tillering. The Mn content increased from tillering to maturity stage. The content in plant and root at tillering, root at panicle initiation and straw at maturity was significantly influenced by organic manure in the second crop season. Values lower than the first crop season were recorded in the parts at all the stages except tillering (Table 24). The treatments receiving nitrogen fertilisers recorded significantly higher manganese content in straw at maturity stage during first crop season.

4.3 POT CULTURE EXPERIMENT - DECOMPOSITION PATTERN OF DIFFERENT ORGANIC MANURES IN THE PRESENCE AND ABSENCE OF RICE IN LATERITIC SOIL

In this experiment, ^{14}C labelled organic manures namely, rice straw, daincha, sunhemp and glyricidia were incorporated with soil kept in pots. The aim was to study the decomposition pattern of the different crop residues in the presence and absence of rice plants. Rice seedlings of variety Jyothi (20 days old) were planted in the pots 30 days after incorporation of crop residue. The decomposition pattern was studied based on the ^{14}C remaining in the soil from the added material at each sampling.

4.3.1 Decomposition of organic manures

The data on the organic carbon remaining in the soil from the added material in each treatment at different intervals are presented in Table 25. The percentage of the added carbon remaining at each time are presented in Table 26.

4.3.1.1 *Straw*

It was observed that the mineralisation of organic carbon in the straw started just after the incorporation in soil. About 15 per cent of the carbon was lost by five days after incorporation. The organic carbon remaining in soil was found to decrease as days advanced and reached almost fifty per cent at 30 days after

Table 24 a. Effect of different sources of organic manure and nitrogen on the manganese content (ppm) of plant parts at different growth stages during the first crop season

Sources of organic manure	Tillering		Panicle initiation		Flowering		Maturity	
	Plant	Root	Plant	Root	Plant	Root	Plant	Grain
Rice straw	256.5	135.5	283.7	182.7	763.5	123.0	5532.5	160.3
Glyricidia	252.5	129.5	249.2	181.2	753.5	113.2	4832.5	162.0
Farm yard manure	225.5	140.5	267.8	207.8	830.0	112.7	4870.0	158.2
Control	249.0	104.3	338.2	209.0	898.5	104.8	4932.5	145.2
CD (0.05)	NS	24.11	NS	NS	NS	NS	NS	NS
Sources of N								
Urea	239.5	123.4	262.7	191.4	858.0	113.9	5590.0	152.4
Factomphos	264.6	138.8	268.1	211.0	784.5	113.2	5075.0	152.6
Control	233.5	120.3	323.2	183.1	791.5	113.1	4462.5	164.2
CD (0.05)	NS	NS	NS	NS	NS	NS	609.0	NS

Contd...

Table 25. Organic carbon remaining in soil from the added organic manures

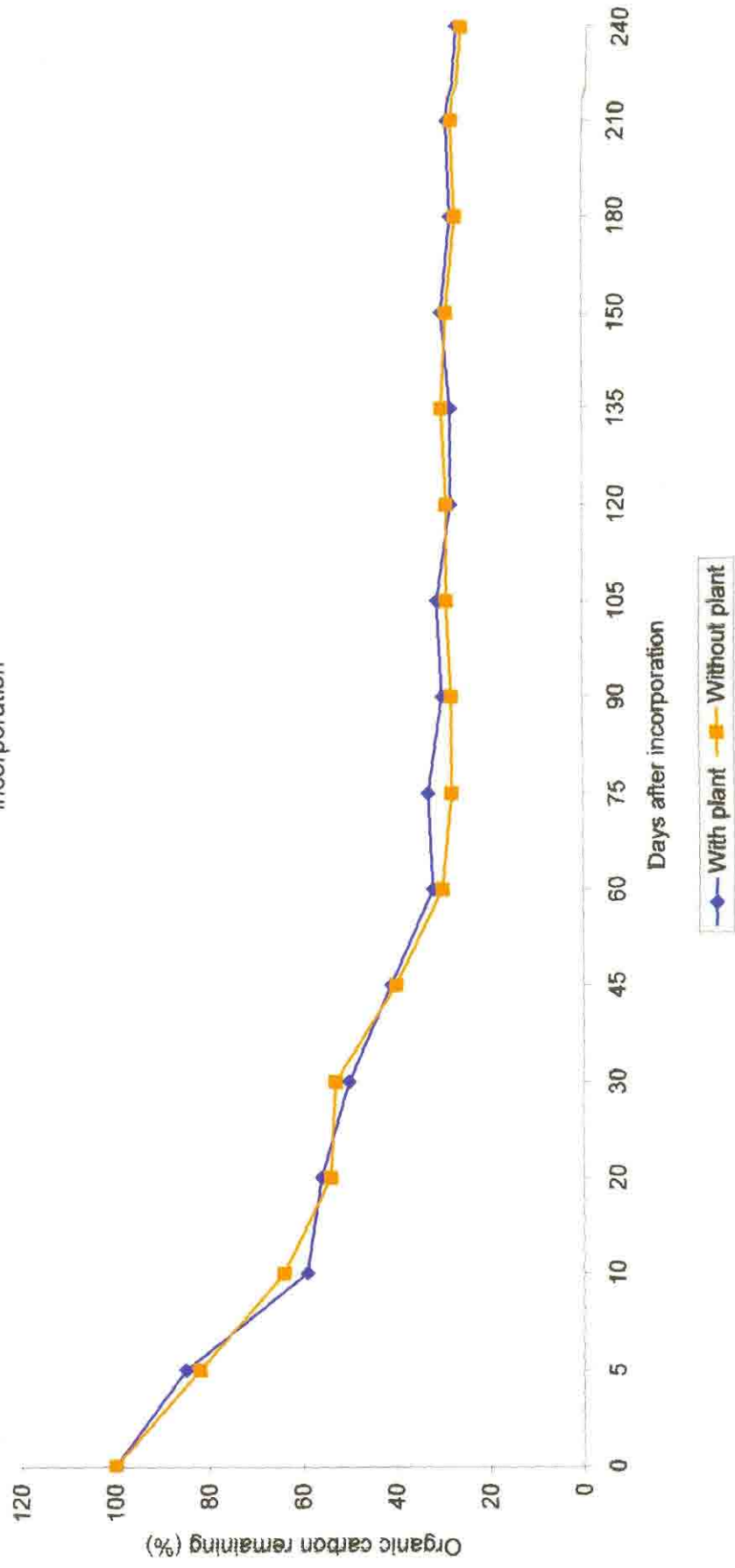
Days after incorporation	Rice straw				Daincha			
	With rice		Without rice		With rice		Without rice	
	dpm	mg g soil ⁻¹	dpm	mg g soil ⁻¹	dpm	mg g soil ⁻¹	dpm	mg g soil ⁻¹
5	289	3.21	281	3.12	230	1.84	228	1.82
10	200	2.22	216	2.40	165	1.32	164	1.32
20	193	2.14	184	2.04	101	0.81	122	0.98
30	171	1.90	182	2.02	92	0.74	78	0.63
45	139	1.54	136	1.52	74	0.59	80	0.64
60	111	1.23	104	1.16	86	0.69	69	0.55
75	114	1.27	96	1.07	82	0.66	70	0.56
90	104	1.15	94	1.05	-	-	-	-
105	106	1.18	98	1.09	-	-	-	-
120	96	1.07	99	1.10	-	-	-	-
135	97	1.08	102	1.13	-	-	-	-
150	104	1.15	99	1.10	-	-	-	-
180	96	1.06	94	1.04	-	-	-	-
210	99	1.10	95	1.06	-	-	-	-
240	95	1.06	94	1.04	-	-	-	-
	Sunhemp				Glyricidia			
5	187	2.40	185	2.37	244	1.48	230	1.39
10	146	1.87	142	1.82	159	0.96	152	0.92
20	119	1.53	85	1.09	131	0.79	122	0.74
30	89	1.15	88	1.14	90	0.54	91	0.55
45	45	0.58	53	0.68	82	0.50	78	0.47
60	41	0.52	52	0.66	75	0.45	72	0.44
75	50	0.64	53	0.68	46	0.28	61	0.37

	Straw	Daincha	Sunhemp	Glyricidia
¹⁴ C dpm added g soil ⁻¹ :	340	450	296	600
Organic carbon added (mg g soil ⁻¹) :	3.77	3.60	3.80	3.63

Table 26. Organic carbon remaining in soil as percentage from the added organic manures

Days after incorporation	Rice straw		Daincha	
	With rice	Without rice	With rice	Without rice
5	85	82	51	50
10	59	64	36	36
20	56	54	22	27
30	50	53	20	17
45	41	40	16	17
60	32	30	18	15
75	33	28	18	15
90	30	28	-	-
105	31	29	-	-
120	28	29	-	-
135	28	30	-	-
150	30	29	-	-
180	28	27	-	-
210	29	28	-	-
240	28	27	-	-
	Sunhemp		Glyricidia	
5	63	62	40	38
10	49	48	26	25
20	40	28	21	20
30	30	30	14	15
45	15	18	13	13
60	14	17	13	12
75	16	17	7	7

Fig. 7. Organic carbon remaining in soil as percentage of the added C in rice straw at different intervals after incorporation



incorporation. This initial rapid declining phase was followed by an almost steady phase of decomposition from 120 days onwards. A very similar trend was observed in the pots without rice (Fig. 7 and 9). As the organic carbon content did not show much variation up to 240 days, the estimation was discontinued thereafter.

4.3.1.2 *Daincha*

The organic carbon in daincha mineralised at a much higher rate at the initial stages. Only fifty per cent of the added carbon remained in the soil after two days. After 75 days, 80 to 85 per cent of added organic carbon was lost. This slow decline phase was initiated from 30 days onwards. No significant difference was observed between the pattern of organic carbon mineralisation in the presence or absence of crop (Fig. 8 and 9).

4.3.1.3 *Sunhemp*

The decomposition process of sunhemp in soil was found to be intermediate between that of straw and daincha. About 50 per cent of the organic carbon was retained 10 days after incorporation in both the treatments with and without crop. The amount of organic carbon remaining in the pots with crop reached almost a stable value of $0.64 \text{ mg g soil}^{-1}$ at 75 days which corresponded to 16 per cent of the added carbon. The corresponding values in the unplanted treatments were $0.68 \text{ mg g soil}^{-1}$ and 17 per cent of the added organic carbon (Fig. 8 and 9).

4.3.1.4 *Glyricidia*

Glyricidia exhibited the fastest rate of decay among the four crop residues incorporated. Only 38 to 40 per cent of the carbon was retained at five days after incorporation. It declined to 25 per cent at 10 days. At 30 days after incorporation the retained carbon was 14 per cent of the added material. This showed that the initial decay rate of 75 per cent in 10 days had slowed down to 12 per cent in 20 days. After 60 days, a sudden decline from 13 per cent to 7 per cent was observed

Fig. 8. Organic carbon remaining in soil as percentage of the added C from green manures at different intervals after incorporation

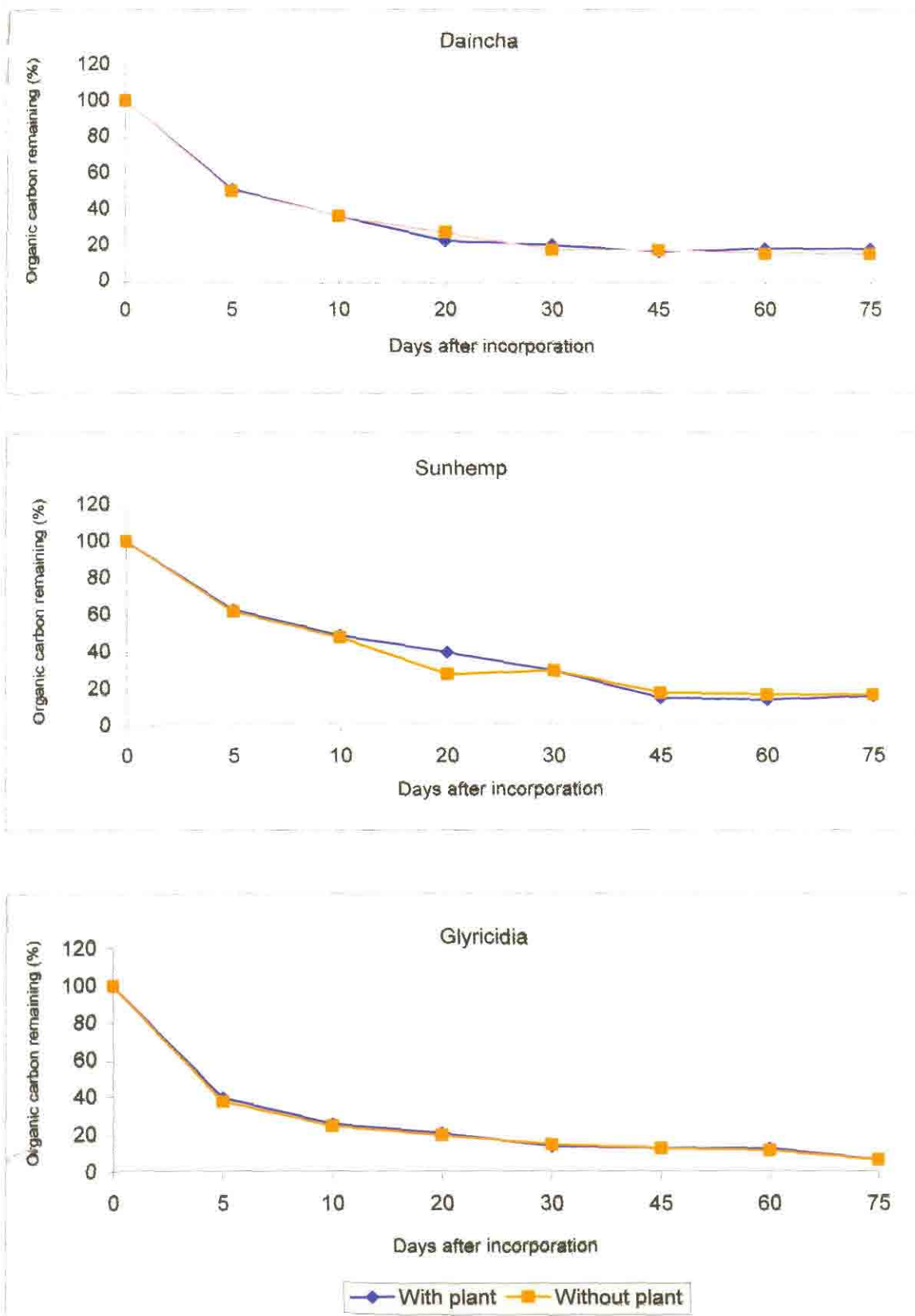
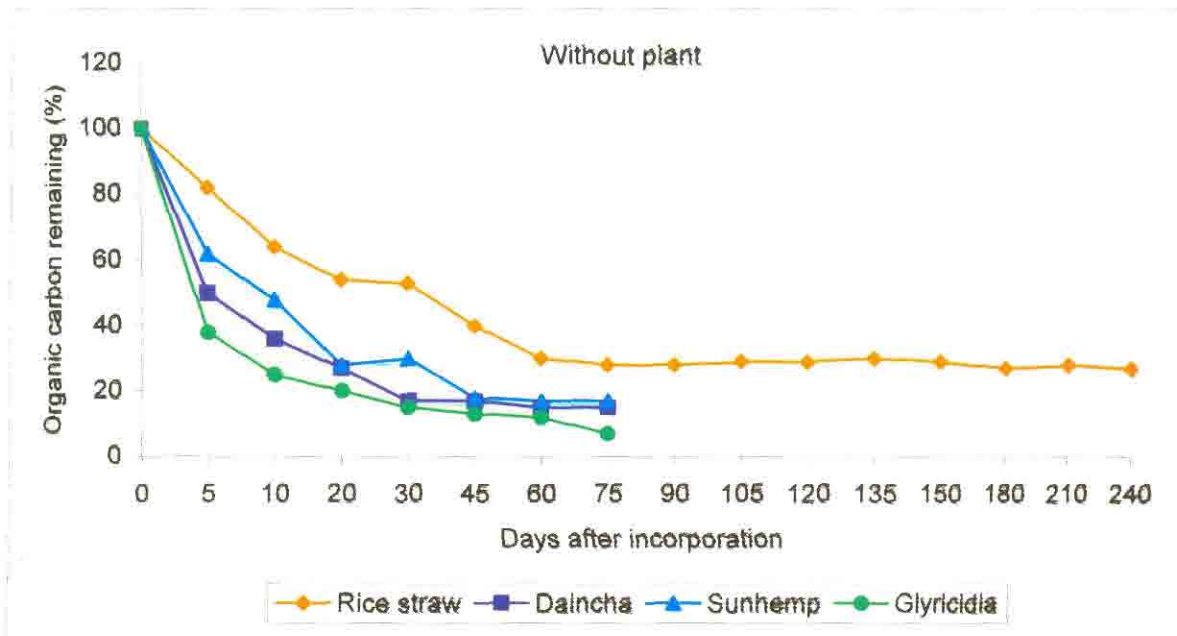
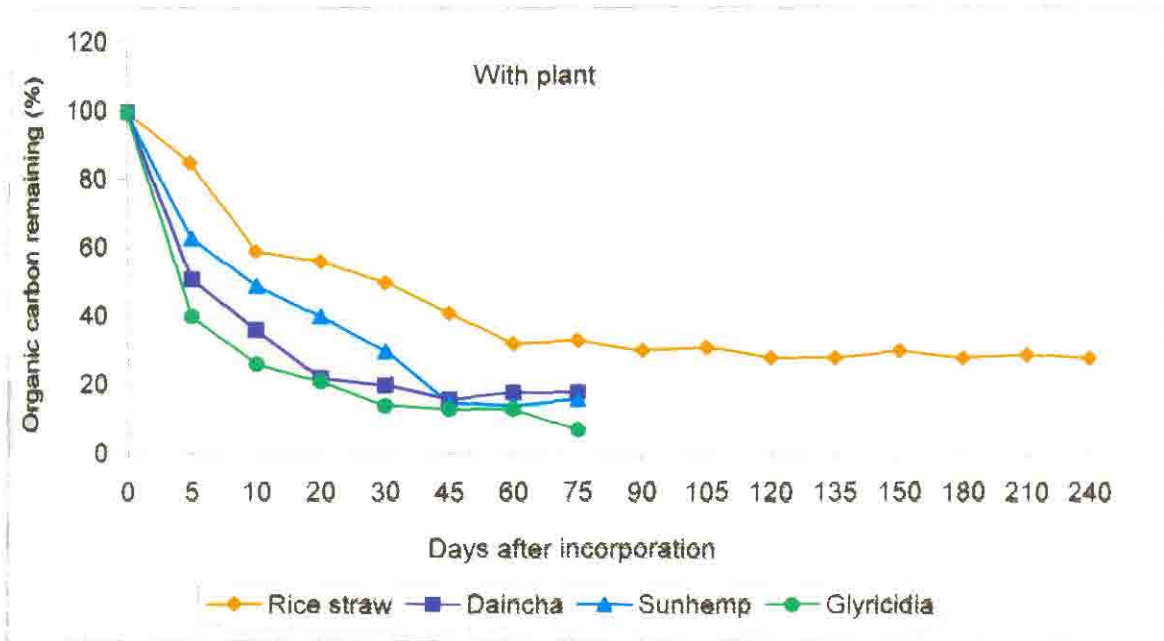


Fig. 9. Organic carbon remaining in soil as percentage of the added C at different intervals after incorporation in the presence and absence of rice



in the carbon content estimated at 75 days after incorporation. As in the case of the other manures, the presence or absence of the crop was not found to influence the decomposition pattern of glyricidia in soil (Fig. 8 and 9).

4.3.2 Effect of different sources of organic material on the pH regulation of the soil

The pH of the soil was measured at periodic intervals after the incorporation of organic materials and submergence (Table 27). The initial pH of the soil was 4.50 at a soil : water ratio of 1 : 2.5. The pattern of variation in pH during the course of the experiment was similar in the control as well as the organic material added pots. Significant difference in pH among the treatments was observed only at certain periods. The pH attained near neutral values 10 days after incorporation of organic manures. The control pot recorded significantly lower value than all the other treatments which were on par. The pH increased slightly at 20 days, and then decreased at 30 days. Rice seedlings were planted on the 30th day after incorporation. Significant variation in pH among the treatments was again manifested at 15 DAP and 60 DAP during the first crop season. No significant difference was observed between the treatments at 30, 45, 75 and 90 DAP, though straw added pots showed higher values in all the stages. A decreasing trend was observed in all the treatments from 30 DAP up to 90 DAP after which the water was drained. The soil remained dry for 10 days before and after harvest. The soil was again saturated and puddled and pH was measured before planting. The drying and rewetting brought about a decrease in pH towards the initial value in all the treatments except straw. Straw added pots recorded a significantly higher pH before planting which was maintained at 30, 60 and 90 days after planting, though not significant at 60 and 90 DAP. The pH values increased from 30 to 90 days after planting.

4.3.3 Effect of crop on the pH of soil after submergence

The presence of rice crop was always found to lower the pH value of the submerged soil, though it was significant only at certain stages. Significant

Table 27. pH of the soil as influenced by the organic manures and presence of crop

Treatments	Days after incorporation																																																																																																																																																																																		
	First crop									Second crop																																																																																																																																																																									
	10	20	30	45	60	75	90	105	120	150	180	210	240	150	180	210	240																																																																																																																																																																		
Rice straw				15DAP*	30DAP	45DAP	60DAP	75DAP	90DAP										7.11	7.33	6.24	6.58	6.59	6.35	6.72	6.22	6.15	5.24	5.87	5.98	6.29	5.24	5.87	5.98	6.29	Daincha	7.33	7.67	6.32	6.56	6.57	6.32	6.65	6.15	6.11	4.60	5.04	5.40	5.68	4.60	5.04	5.40	5.68	Sunhemp	7.14	7.60	5.93	6.48	6.52	6.31	6.56	6.17	6.04	4.46	4.83	5.53	5.85	4.46	4.83	5.53	5.85	Glyricidia	7.15	7.46	6.21	6.66	6.41	6.35	6.54	6.24	6.13	4.59	5.07	5.68	5.81	4.59	5.07	5.68	5.81	Control	6.75	7.30	6.29	6.54	6.49	6.34	6.68	6.18	6.13	4.48	4.80	5.54	5.92	4.48	4.80	5.54	5.92	CD (0.05)	0.31	NS	NS	0.1	NS	NS	0.09	NS	NS	0.27	0.29	NS	NS	0.27	0.29	NS	NS	With crop				6.54	6.46	6.31	6.61	6.15	6.07	4.66	4.75	5.51	5.94	4.66	4.75	5.51	5.94	Without crop				6.59	6.57	6.36	6.65	6.24	6.15	4.69	5.50	5.75	5.88	4.69	5.50	5.75	5.88	CD (0.05)				NS	NS	NS	NS	0.076	0.076	NS	0.18	NS	NS	NS	0.18	NS	NS
	7.11	7.33	6.24	6.58	6.59	6.35	6.72	6.22	6.15	5.24	5.87	5.98	6.29	5.24	5.87	5.98	6.29	Daincha	7.33	7.67	6.32	6.56	6.57	6.32	6.65	6.15	6.11	4.60	5.04	5.40	5.68	4.60	5.04	5.40	5.68	Sunhemp	7.14	7.60	5.93	6.48	6.52	6.31	6.56	6.17	6.04	4.46	4.83	5.53	5.85	4.46	4.83	5.53	5.85	Glyricidia	7.15	7.46	6.21	6.66	6.41	6.35	6.54	6.24	6.13	4.59	5.07	5.68	5.81	4.59	5.07	5.68	5.81	Control	6.75	7.30	6.29	6.54	6.49	6.34	6.68	6.18	6.13	4.48	4.80	5.54	5.92	4.48	4.80	5.54	5.92	CD (0.05)	0.31	NS	NS	0.1	NS	NS	0.09	NS	NS	0.27	0.29	NS	NS	0.27	0.29	NS	NS	With crop				6.54	6.46	6.31	6.61	6.15	6.07	4.66	4.75	5.51	5.94	4.66	4.75	5.51	5.94	Without crop				6.59	6.57	6.36	6.65	6.24	6.15	4.69	5.50	5.75	5.88	4.69	5.50	5.75	5.88	CD (0.05)				NS	NS	NS	NS	0.076	0.076	NS	0.18	NS	NS	NS	0.18	NS	NS																		
Daincha	7.33	7.67	6.32	6.56	6.57	6.32	6.65	6.15	6.11	4.60	5.04	5.40	5.68	4.60	5.04	5.40	5.68	Sunhemp	7.14	7.60	5.93	6.48	6.52	6.31	6.56	6.17	6.04	4.46	4.83	5.53	5.85	4.46	4.83	5.53	5.85	Glyricidia	7.15	7.46	6.21	6.66	6.41	6.35	6.54	6.24	6.13	4.59	5.07	5.68	5.81	4.59	5.07	5.68	5.81	Control	6.75	7.30	6.29	6.54	6.49	6.34	6.68	6.18	6.13	4.48	4.80	5.54	5.92	4.48	4.80	5.54	5.92	CD (0.05)	0.31	NS	NS	0.1	NS	NS	0.09	NS	NS	0.27	0.29	NS	NS	0.27	0.29	NS	NS	With crop				6.54	6.46	6.31	6.61	6.15	6.07	4.66	4.75	5.51	5.94	4.66	4.75	5.51	5.94	Without crop				6.59	6.57	6.36	6.65	6.24	6.15	4.69	5.50	5.75	5.88	4.69	5.50	5.75	5.88	CD (0.05)				NS	NS	NS	NS	0.076	0.076	NS	0.18	NS	NS	NS	0.18	NS	NS																																				
Sunhemp	7.14	7.60	5.93	6.48	6.52	6.31	6.56	6.17	6.04	4.46	4.83	5.53	5.85	4.46	4.83	5.53	5.85	Glyricidia	7.15	7.46	6.21	6.66	6.41	6.35	6.54	6.24	6.13	4.59	5.07	5.68	5.81	4.59	5.07	5.68	5.81	Control	6.75	7.30	6.29	6.54	6.49	6.34	6.68	6.18	6.13	4.48	4.80	5.54	5.92	4.48	4.80	5.54	5.92	CD (0.05)	0.31	NS	NS	0.1	NS	NS	0.09	NS	NS	0.27	0.29	NS	NS	0.27	0.29	NS	NS	With crop				6.54	6.46	6.31	6.61	6.15	6.07	4.66	4.75	5.51	5.94	4.66	4.75	5.51	5.94	Without crop				6.59	6.57	6.36	6.65	6.24	6.15	4.69	5.50	5.75	5.88	4.69	5.50	5.75	5.88	CD (0.05)				NS	NS	NS	NS	0.076	0.076	NS	0.18	NS	NS	NS	0.18	NS	NS																																																						
Glyricidia	7.15	7.46	6.21	6.66	6.41	6.35	6.54	6.24	6.13	4.59	5.07	5.68	5.81	4.59	5.07	5.68	5.81	Control	6.75	7.30	6.29	6.54	6.49	6.34	6.68	6.18	6.13	4.48	4.80	5.54	5.92	4.48	4.80	5.54	5.92	CD (0.05)	0.31	NS	NS	0.1	NS	NS	0.09	NS	NS	0.27	0.29	NS	NS	0.27	0.29	NS	NS	With crop				6.54	6.46	6.31	6.61	6.15	6.07	4.66	4.75	5.51	5.94	4.66	4.75	5.51	5.94	Without crop				6.59	6.57	6.36	6.65	6.24	6.15	4.69	5.50	5.75	5.88	4.69	5.50	5.75	5.88	CD (0.05)				NS	NS	NS	NS	0.076	0.076	NS	0.18	NS	NS	NS	0.18	NS	NS																																																																								
Control	6.75	7.30	6.29	6.54	6.49	6.34	6.68	6.18	6.13	4.48	4.80	5.54	5.92	4.48	4.80	5.54	5.92	CD (0.05)	0.31	NS	NS	0.1	NS	NS	0.09	NS	NS	0.27	0.29	NS	NS	0.27	0.29	NS	NS	With crop				6.54	6.46	6.31	6.61	6.15	6.07	4.66	4.75	5.51	5.94	4.66	4.75	5.51	5.94	Without crop				6.59	6.57	6.36	6.65	6.24	6.15	4.69	5.50	5.75	5.88	4.69	5.50	5.75	5.88	CD (0.05)				NS	NS	NS	NS	0.076	0.076	NS	0.18	NS	NS	NS	0.18	NS	NS																																																																																										
CD (0.05)	0.31	NS	NS	0.1	NS	NS	0.09	NS	NS	0.27	0.29	NS	NS	0.27	0.29	NS	NS	With crop				6.54	6.46	6.31	6.61	6.15	6.07	4.66	4.75	5.51	5.94	4.66	4.75	5.51	5.94	Without crop				6.59	6.57	6.36	6.65	6.24	6.15	4.69	5.50	5.75	5.88	4.69	5.50	5.75	5.88	CD (0.05)				NS	NS	NS	NS	0.076	0.076	NS	0.18	NS	NS	NS	0.18	NS	NS																																																																																																												
With crop				6.54	6.46	6.31	6.61	6.15	6.07	4.66	4.75	5.51	5.94	4.66	4.75	5.51	5.94	Without crop				6.59	6.57	6.36	6.65	6.24	6.15	4.69	5.50	5.75	5.88	4.69	5.50	5.75	5.88	CD (0.05)				NS	NS	NS	NS	0.076	0.076	NS	0.18	NS	NS	NS	0.18	NS	NS																																																																																																																														
Without crop				6.59	6.57	6.36	6.65	6.24	6.15	4.69	5.50	5.75	5.88	4.69	5.50	5.75	5.88	CD (0.05)				NS	NS	NS	NS	0.076	0.076	NS	0.18	NS	NS	NS	0.18	NS	NS																																																																																																																																																
CD (0.05)				NS	NS	NS	NS	0.076	0.076	NS	0.18	NS	NS	NS	0.18	NS	NS																																																																																																																																																																		

*DAP – Days after planting

differences were observed at 75 and 90 days after planting during the first crop and 30 days after planting during the residual crop (Table 27).

4.3.4 Effect of sources of organic manure on the organic carbon content of the soil

The organic carbon content of the soil as influenced by the incorporation of different treatments at various intervals are given in Table 28.

Significant influence of organic materials added on the organic carbon content was evident from 10 days onwards. The addition of organic materials was found to lower the organic carbon content of the soil from the initial value of 0.46 per cent to 0.37 to 0.40 per cent but the content increased to 0.49 per cent in the pots without organic manure addition. At 25 days after incorporation it was observed that the content increased in straw added pots, decreased in the case of the other treatments but remained the same in control.

The organic carbon content of the different treatments at 15 days after planting varied not only among themselves but also with respect to the content before planting. The content in straw added pots and control pot decreased while that in sunhemp and glyricidia added pots increased and that in daincha remained the same. The organic carbon content reached a peak value at 60 DAP in all the treatments and was significantly higher for straw followed by control. The values then declined up to 90 DAP in control, straw and sunhemp. The content showed an increase in the pots having daincha and glyricidia from 75 DAP to 90 DAP. While straw and daincha showed a decreasing trend from 90 DAP also, sunhemp and control showed an increased at 105 DAP. The crop was harvested at 110 days after planting, that is, 140 days after incorporation of organic manures. The residual crop was planted 10 days after.

The organic carbon content in all the treatments was analysed before planting the residual crop. A decreasing trend was observed from the time of planting to 30 DAP in all the treatments. This was followed by an increase up to 90 DAP. The crop was harvested at 90 DAP, that is, 240 days after incorporation.

Table 28. Organic carbon content (%) of the soil as influenced by organic manures and presence of crop

Treatments	Days after incorporation																	
	First crop									Second crop								
	10	30	45	60	75	90	105	120	135	150	165	180	210	240				
Rice straw			15DAP*	30DAP	45DAP	60DAP	75DAP	90DAP	105DAP		15DAP	30DAP	60DAP	90DAP				
Daincha	0.37	0.44	0.40	0.40	0.46	0.72	0.53	0.52	0.49	0.47	0.41	0.36	0.43	0.43				
Sunhemp	0.38	0.34	0.34	0.35	0.35	0.46	0.42	0.44	0.38	0.37	0.32	0.28	0.31	0.35				
Glyricidia	0.40	0.38	0.39	0.36	0.38	0.48	0.42	0.37	0.43	0.39	0.36	0.30	0.33	0.36				
Control	0.37	0.32	0.35	0.32	0.31	0.48	0.35	0.37	0.37	0.36	0.31	0.28	0.32	0.32				
CD (0.05)	0.49	0.49	0.44	0.41	0.53	0.56	0.51	0.49	0.55	0.43	0.42	0.35	0.41	0.38				
With crop	0.04	0.05	0.05	0.05	0.03	0.07	0.04	0.04	0.07	0.05	0.04	0.04	0.05	0.05				
Without crop	0.41	0.39	0.38	0.36	0.39	0.56	0.43	0.45	0.46	0.42	0.35	0.31	0.35	0.37				
CD (0.05)	0.40	0.40	0.39	0.38	0.42	0.53	0.46	0.43	0.43	0.38	0.37	0.32	0.37	0.36				
CD (0.05)	NS	NS	NS	0.03	0.02	NS	0.02	NS	NS	0.03	NS	NS	NS	NS				

* DAP – Days after planting

It was observed that the final value in all the pots was lower than the initial value before the start of the experiment. However, a significantly higher organic carbon content was observed in the pots where straw was incorporated.

4.3.5 Effect of crop on the organic carbon content of the soil

Significant difference in the organic carbon content due to the presence or absence of rice was observed only at 30, 45 and 75 DAP during the first crop and before planting the residual crop. The organic carbon content was lower in the pots with rice during the early stages of growth. Higher values were observed in these pots at 60, 90 and 105 DAP, though not significant. Similarly, the organic carbon content was significantly higher in the pots with rice before planting the residual crop. No significant difference was noticed among the treatments throughout the period of residual crop (Table 28).

4.4 INCUBATION STUDY - DECOMPOSITION PATTERN OF RICE STRAW AND DAINCHA IN SELECTED RICE SOILS OF KERALA

4.4.1 Decomposition pattern in different soils

The decomposition pattern of straw and daincha in the different soils were studied using the ^{14}C tracer technique. Labelled plant materials were mixed with soil and incubated under anaerobic conditions. The decomposition pattern was studied based on ^{14}C remaining in the soil at periodic intervals.

4.4.1.1 *Straw*

The carbon remaining in soil at different intervals after incorporation are presented in Tables 29 and 30. The percentage of carbon remaining at different intervals are presented in Table 31. It was observed that the decomposition of straw started immediately after its incorporation into the soil. The percentage of organic carbon remaining in the soil averaged over the seven soils revealed that the decomposition of rice straw occurred in a steady manner. The rate of decay remained constant between different intervals. While 15 per cent was lost in the first two days, only 50 per cent was lost in 38 days. The percentage of decay was

Table 29. Organic carbon remaining in soils (^{14}C dpm g soil $^{-1}$) from the added rice straw

Soil	Days after incorporation												
	2	4	6	8	10	25	40	55	70	85	100	115	
Lateritic	2737	2486	2391	2172	2089	1941	1804	1593	1127	976	891	832	
Chittoor black	2331	2055	1969	1690	1634	1533	1425	1287	1198	1017	758	621	
Pokkali	2491	2242	2045	1726	1677	1461	1275	1123	1056	916	851	736	
Onattukara	2736	2428	2003	1662	1366	1240	1169	1188	986	960	904	810	
Karappadam	2445	1958	1569	1493	1383	1209	1229	1129	1085	978	888	844	
Kole	2566	2428	2254	2082	1741	1623	1463	1430	1214	1104	983	945	
Kari	2899	2598	2521	2318	2063	2067	1664	1598	1439	1281	1177	1029	

 ^{14}C dpm of added rice straw: 3000 g soil $^{-1}$

Table 30. Organic carbon remaining in soils (mg g soil^{-1}) from the added rice straw

Soil	Days after incorporation												
	2	4	6	8	10	25	40	55	70	85	100	115	
Lateritic	3.11	3.13	3.01	2.73	2.63	2.44	2.27	2.00	1.42	1.23	1.12	1.05	
Chittoor black	2.93	2.59	2.48	2.13	2.06	1.93	1.79	1.62	1.51	1.28	0.95	0.78	
Pokkali	3.13	2.82	2.57	2.17	2.11	1.84	1.84	1.41	1.33	1.15	1.07	0.93	
Onattukara	3.44	3.06	2.52	2.09	1.72	1.56	1.47	1.49	1.24	1.21	1.14	1.02	
Karappadam	3.08	2.46	1.97	1.88	1.74	1.52	1.55	1.42	1.36	1.13	1.12	0.53	
Kole	3.23	3.05	2.83	2.62	2.19	2.04	1.84	1.80	1.53	1.39	1.23	1.19	
Kari	3.64	3.27	3.17	2.92	2.59	2.60	2.09	2.01	1.81	1.61	1.48	1.29	
CD (0.05)	NS	0.36	0.35	0.43	0.44	0.48	0.46	0.35	0.26	0.27	0.32	0.28	

Organic carbon incorporated $3.77 \text{ mg g soil}^{-1}$

Table 31. Organic carbon remaining in soils as percentage of the added C from rice straw

Soil	Days after incorporation												
	2	4	6	8	10	25	40	55	70	85	100	115	
Lateritic	82.3	83.0	79.8	72.4	69.8	64.6	60.1	53.1	37.6	32.5	29.7	27.8	
Chittoor black	77.7	68.6	65.7	56.4	54.6	51.1	47.5	42.9	40.0	33.9	25.3	20.7	
Pokkali	83.0	74.7	68.2	57.6	55.9	48.8	48.8	37.5	35.2	30.5	28.4	24.6	
Onattukara	91.2	81.0	66.9	55.5	45.5	41.4	38.9	39.6	32.8	32.0	30.2	27.0	
Karappadam	81.7	65.3	52.3	49.8	46.1	40.3	41.0	37.6	36.1	30.0	30.0	14.1	
Kole	85.7	80.9	75.2	69.5	58.1	54.1	48.8	47.7	40.5	36.9	32.7	31.5	
Kari	96.5	86.7	84.1	77.4	68.8	69.0	55.5	53.2	47.9	42.6	39.2	34.3	
CD (0.05)	NS	9.7	9.2	11.4	11.6	12.9	12.1	9.3	6.9	7.2	8.5	7.4	

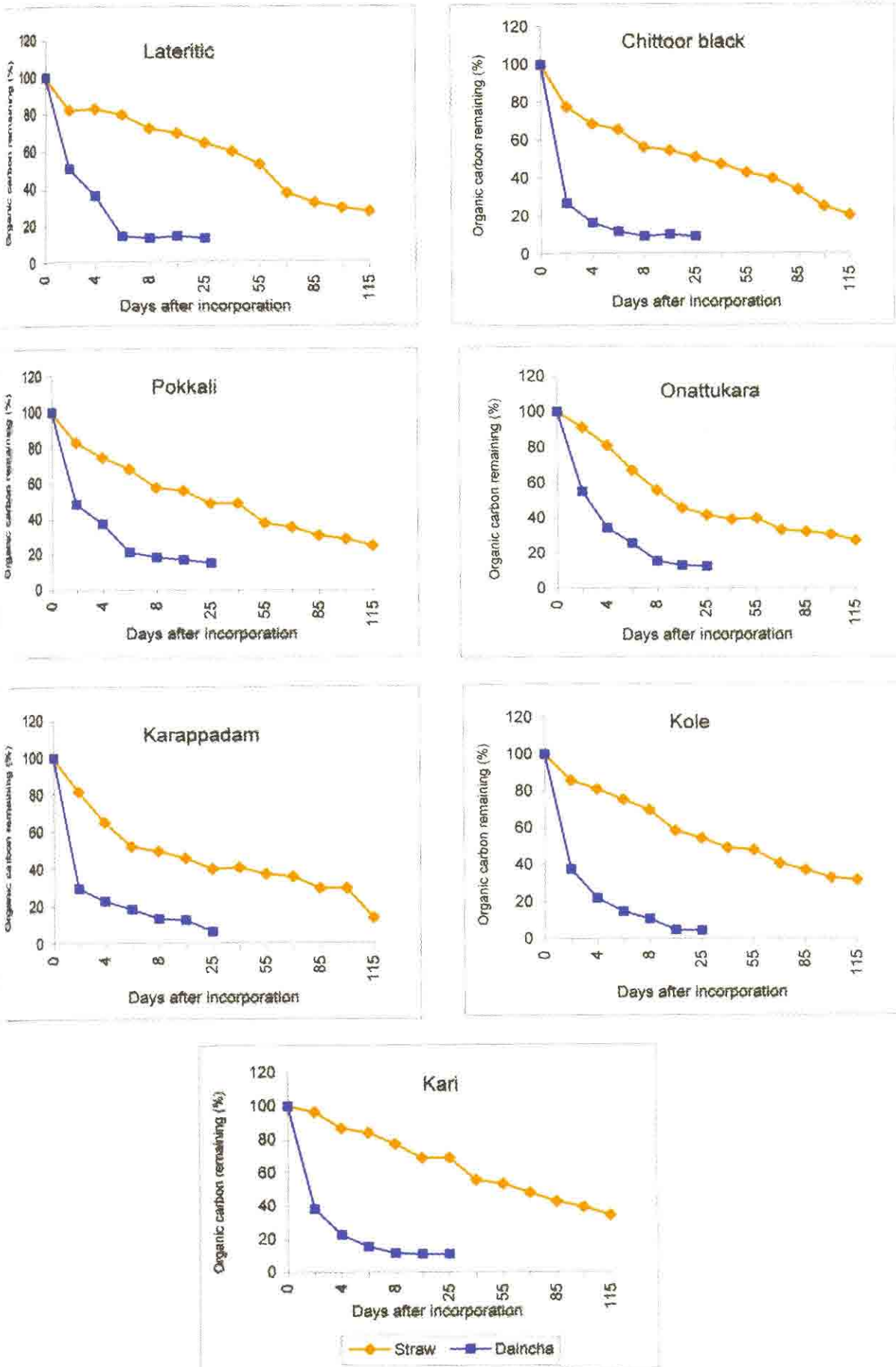
75 per cent in 115 days. Hence it could be assumed that the decay process occurs in two phases, a rapid declining process up to 38 days followed by a slow and steady process.

Though not significant, different soils showed variation in their ability to retain the added organic carbon at two days itself. The highest percentage of organic carbon (96.5) was retained in the Kari soil followed by the Lateritic and the Onattukara soils (91 per cent). The lowest amount of organic carbon (78 per cent) remained in the black soil. From four days onwards, the percentage of organic carbon remaining showed significant difference among the seven soils up to 115 days. They exhibited a gradual declining trend in the retained organic carbon except for a sudden decrease in the Lateritic soil from 55 to 70 days. At 10 days after incubation, both Lateritic and Kari soils retained similar amounts of the added organic carbon, that is, approximately 70 per cent which was significantly superior to all the soils. Lower values of organic carbon retention were indicated by the Chittoor black, Pokkali, Onattukara and Karappadam soils. This was maintained up to 55 days.

At 70 days there was a sudden decrease in the amount of organic carbon retained in the Lateritic soil from 53 per cent to 37 per cent, which rendered it comparable with the other soils except the Kari soil. The Kari soil retained the highest amount of organic carbon approximately amounting to 48 per cent, followed by the Kole soil. The lowest amount of 32 per cent was retained in the Onattukara soil. However, at 115 days after incorporation, it was observed that the Karappadam soil retained the lowest amount of added organic carbon (14 per cent). The highest amount of 34 per cent was retained in the Kari soil. All the other soils including the Lateritic and Chittoor black soils retained intermediate amounts of organic carbon ranging from 20 to 27 per cent. Out of the initial amount of 3.77 mg added per gram soil, 1.29 mg remained in the Kari soil, 1.19 in the Kole and 0.53 mg in the Karappadam soil (Fig. 10).

The decay pattern of rice straw in the different soils can be explained using the single exponential model $C = C_0 e^{-kt}$ where C_0 is the carbon content of the

Fig. 10. Organic carbon remaining as percentage of the added carbon at periodic intervals after incorporation of rice straw and daincha in soil



labelled material added to the soil, C is the carbon remaining in the soil at time 't', 'e' is the base of the natural logarithm, K is the decay rate constant and 't' is the time in days after incubation (Fig. 11). Half life of the labelled material was calculated using the relation $t_{1/2} = \frac{0.693}{K}$ and presented in Table 32.

Table 32. Half life of labelled rice straw in different soils

Soils	Decay rate constant (K)	t _{1/2} (days)
Lateritic	0.0108	64
Chittoor black	0.0105	66
Pokkali	0.0103	67
Onattukara	0.0095	73
Karappadam	0.0081	85
Kole	0.0089	78
Kari	0.0086	80

The decay rate constant indicated that the decomposition was a declining process. Half life of added carbon in straw was almost similar for the Lateritic, Chittoor and Pokkali soils while the Onattukara and Kole recorded similar half lives. The half life for straw decomposition was highest in the Kari and Karappadam soils.

Correlation coefficients were worked out between the decay rate constants for the different soils and soil properties like pH, percentage of sand, clay, silt and organic carbon per cent. Though not significant, negative correlations were obtained between the decay rate constant and the soil properties (Table 33).

Fig. 11. Exponential model of decay pattern of rice straw in different soils

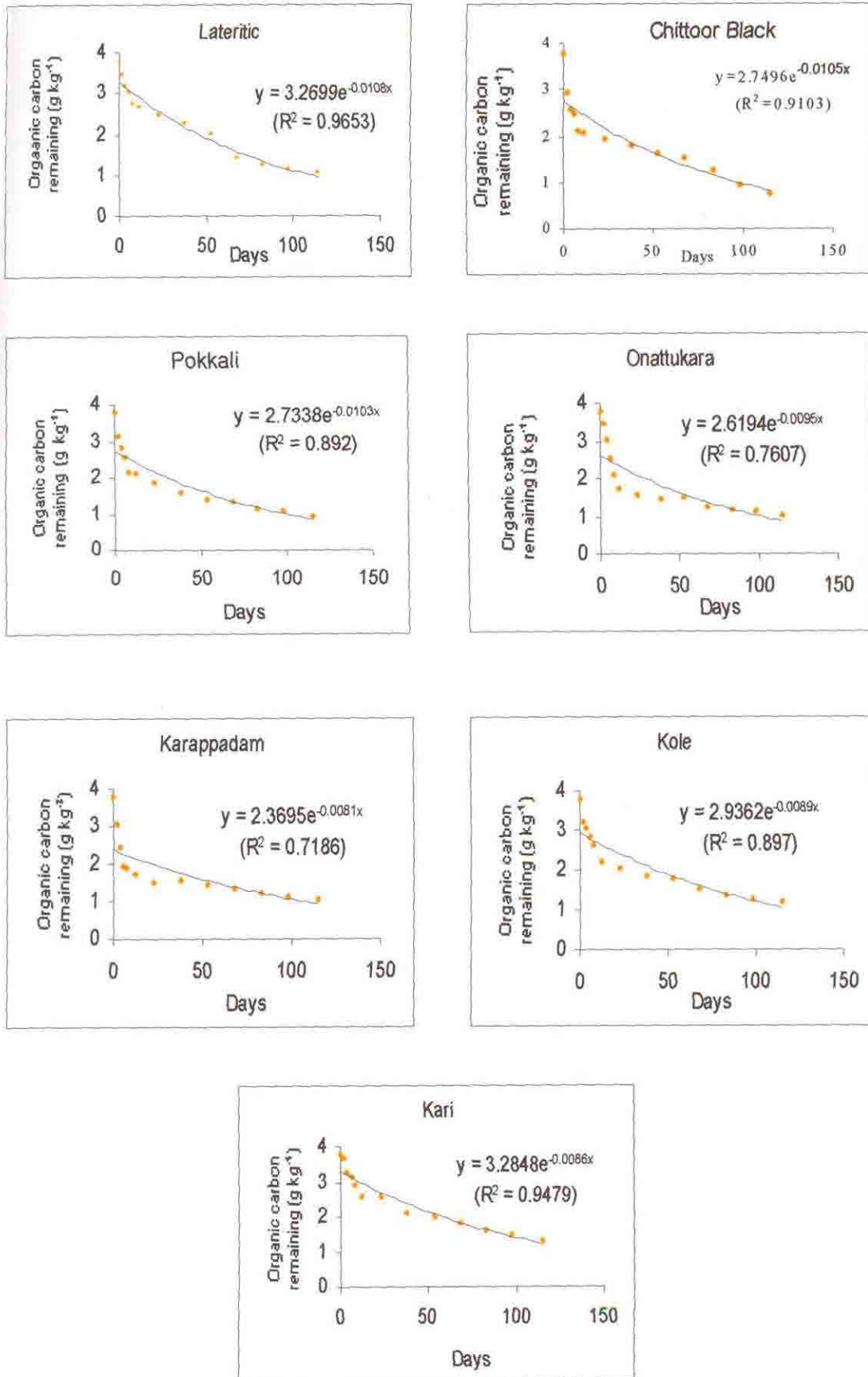


Table 33. Correlation coefficient of the percentage of the organic carbon remaining in soil from added rice straw at different intervals and decay rate constant with soil properties

Soil properties	Organic carbon remaining (%)			Decay rate constant
	2 days	25 days	115 days	
Sand (%)	0.48	0.28	0.38	0.20
Silt (%)	-0.36	-0.38	-0.50	-0.41
Clay (%)	-0.41	-0.25	-0.27	-0.18
Organic carbon	0.09	-0.09	0.06	-0.74
pH	-0.62	-0.30	-0.47	0.50

The correlation of decay rate constant with initial pH was found to be positive, though not significant. The initial rate of decomposition was faster in the neutral to alkaline Chittoor black soil and lowest in the highly acidic Kari soil. The negative correlation coefficients obtained between the percentage of organic carbon remaining at 2, 25 and 115 days after incorporation and soil properties were also not significant. Similarly, the percentage of organic carbon remaining at 115 days after incubation was lower in the soils that exhibited a pH range of 5 to 7.5. The highest percentage of organic carbon was retained in the Kole and Kari soils which maintained an acidic range at 115 days after incubation.

4.4.1.2 *Daincha*

The decomposition pattern of daincha in different soils expressed as organic carbon remaining at different intervals are given in Tables 34 and 35. The percentage of the added organic carbon remaining are presented in Table 36.

It was observed that daincha decomposed faster than straw in all the soils at different intervals. The percentage of carbon lost cumulatively at different intervals was higher in daincha (Fig. 10). Averaged over the seven soils 60 per cent of the carbon in the added material was lost within the first two days while it was only 15 per cent in straw.

Table 34. Organic carbon remaining in soils (^{14}C dpm g soil $^{-1}$) from the added daincha

Soil	Days after incorporation							
	2	4	6	8	10	25		
Lateritic	329	236	94	88	96	88		
Chittoor black	174	107	78	62	68	62		
Pokkali	313	241	137	118	109	96		
Onattukara	357	223	165	100	83	80		
Karappadam	150	122	89	84	46	38		
Kole	243	143	96	70	30	28		
Kari	248	147	100	75	72	71		

 ^{14}C dpm of added daincha: 650 g soil $^{-1}$

Table 35. Organic carbon remaining in soils (mg g soil⁻¹) from the added daincha

Soil	Days after incorporation						
	2	4	6	8	10	25	
Lateritic	1.82	1.31	0.53	0.49	0.53	0.49	
Chittoor black	0.97	0.60	0.43	0.35	0.38	0.34	
Pokkali	1.74	1.34	0.76	0.65	0.61	0.54	
Onattukara	1.98	1.24	0.92	0.55	0.46	0.44	
Karappadam	1.07	0.83	0.68	0.49	0.47	0.25	
Kole	1.35	0.79	0.53	0.39	0.17	0.15	
Kari	1.38	0.82	0.56	0.41	0.40	0.39	
CD (0.05)	0.40	0.19	0.17	0.12	0.10	0.10	

Organic carbon added: 3.60 mg g soil⁻¹

Table 36. Organic carbon remaining in soil as percentage of the added C from daincha

Soil	Days after incorporation						
	2	4	6	8	10	25	
Lateritic	50.7	36.4	14.6	13.6	14.7	13.5	
Chittoor black	26.9	16.6	12.1	9.6	10.5	9.5	
Pokkali	48.3	37.2	21.1	18.2	16.8	14.9	
Onattukara	55.1	34.3	25.5	15.4	12.9	12.3	
Karappadam	29.8	23.1	18.8	13.7	13.1	6.8	
Kole	37.5	22.0	14.7	10.7	4.6	4.3	
Kari	38.2	22.7	15.5	11.5	11.1	10.9	
CD (0.05)	11.2	5.4	4.6	3.6	2.6	2.8	

As in the case of straw the carbon remaining at a particular interval varied in daincha also depending on the type of the soil. At two days, only 55 per cent of the added organic carbon remained in the Onattukara soil while only 38 per cent remained in the Kari soil. The lowest retention of 27 per cent was observed for the Black soil. The Lateritic soil followed a similar trend of that of the Onattukara soil.

The declining trend in the retention of carbon reached almost a stable value after 25 days. Hence the data are presented only up to 25 days. The stable value was attained at six days in the Lateritic soil, eight days in the Kari, Black and Pokkali soils and 10 days in the Onattukara and Kole soils. In the Karappadam soil, though a levelling was observed at eight and ten days, a steep decline was observed at 25 days. The highest amount of organic carbon was retained by the Pokkali soil which was statistically on par with the Lateritic and Onattukara soils (15, 13 and 12 per cent, respectively). The lowest amount of organic carbon was retained by the Kole soil at 25 days which was about four per cent of the organic carbon in the original material.

The experimental model of decay was attempted but the r^2 values were not significant.

The carbon remaining in the soil at different intervals expressed as percentage of the added organic carbon was correlated with different soil characters like organic C, pH of the soil before incubation and sand, silt and clay per cent (Table 37). Significant negative correlations were obtained between the percentage of carbon remaining at two days and clay and silt percentage at 5% level of significance. At 25 days, the percentage of organic carbon remaining from the added carbon in daincha was significantly and negatively correlated with organic carbon and silt percentage of the soil. The carbon remaining from daincha at two days was positively and significantly correlated with the percentage of sand.

Table 37. Correlation coefficient between organic carbon remaining from the added daincha and soil properties

Days after incorporation	Sand (%)	Silt (%)	Clay (%)	Organic carbon (%)	pH
2	0.87*	-0.87*	-0.81*	-0.51	-0.30
25	0.74	-0.79*	-0.72	-0.92**	-0.02

* Significant at 5% level

** Significant at 1% level

4.4.2 Variation in pH due to the incorporation of rice straw and daincha in different soils

The data on the variation in pH due to incorporation of rice straw and daincha in different soils are presented in Table 38 and Fig. 12.

4.4.2.1 *Lateritic soil*

Submergence brought about a decrease in pH in the treatment without any organic manure addition. The pH increased to the original value after 90 days. In the rice straw incorporated treatment, the pH increased on submergence and was maintained up to 15 days. But in the case of treatment where daincha was incorporated, after a slight increase at 15 days, the pH decreased and remained as such up to 105 days.

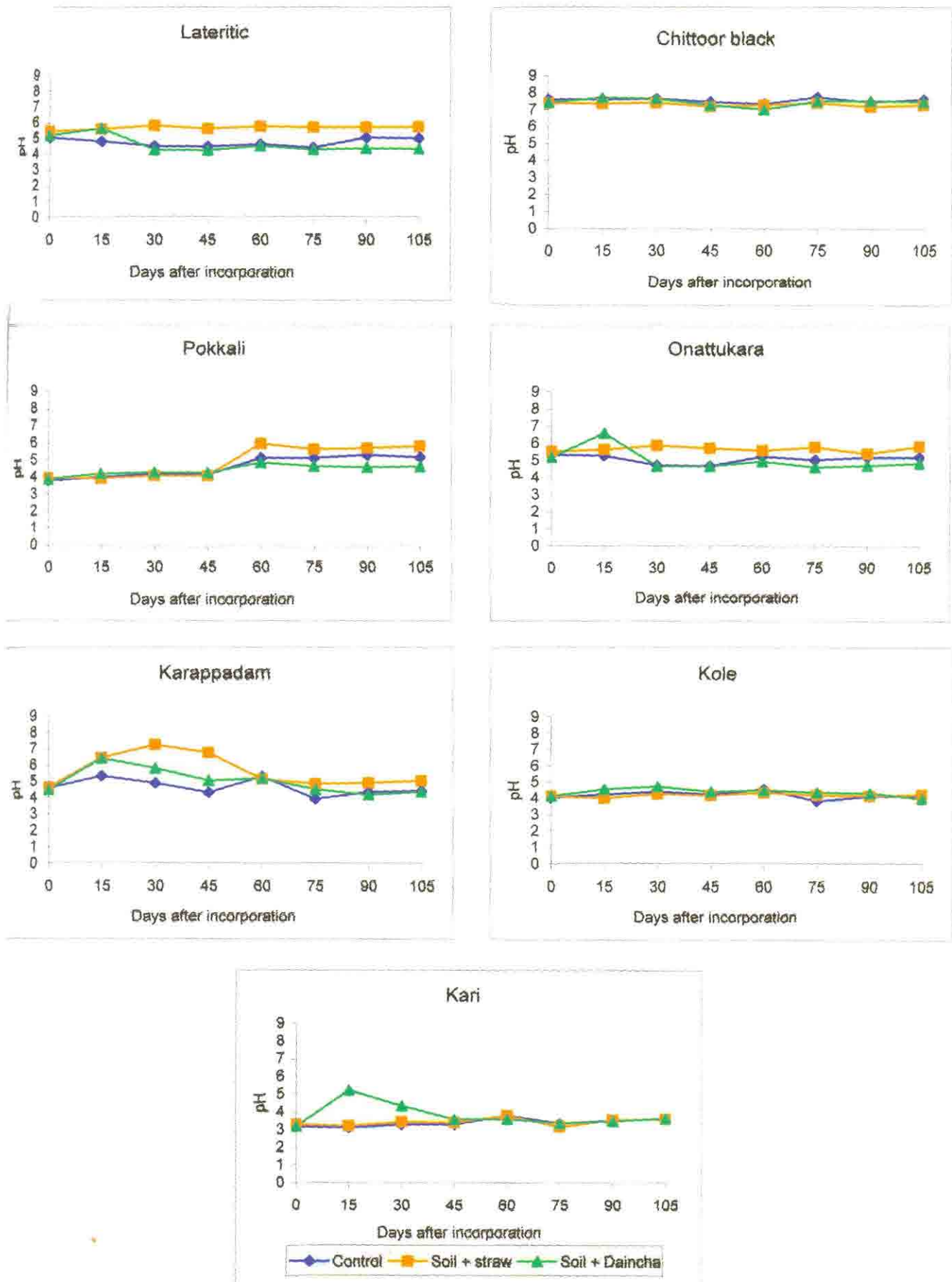
4.4.2.2 *Chittoor black*

The pH of the soil immediately after submergence was maintained in the control plots up to the end of the incubation period. Incorporation of daincha or rice straw was not found to influence the pH and followed a trend similar to that of control.

Table 38. Variation in pH over time (days) due to the incorporation of organic manures in different soils

Days after incubation	Lateritic			Chittoor black		
	Control	Soil + rice straw	Soil + daincha	Control	Soil + rice straw	Soil + daincha
0	5.05	5.45	5.19	7.62	7.39	7.42
15	4.81	5.60	5.64	7.62	7.35	7.72
30	4.53	5.83	4.29	7.66	7.41	7.66
45	4.51	5.63	4.26	7.47	7.18	7.26
60	4.65	5.78	4.54	7.34	7.28	7.01
75	4.43	5.73	4.31	7.75	7.39	7.50
90	5.08	5.73	4.38	7.46	7.18	7.54
105	5.03	5.75	4.36	7.62	7.28	7.47
Mean	4.76	5.68	4.62	7.57	7.31	7.45
	Pokkali			Onattukkara		
0	3.80	3.94	3.88	5.34	5.53	5.20
15	3.98	3.92	4.20	5.29	5.64	6.61
30	4.20	4.09	4.28	4.74	5.89	4.69
45	4.15	4.09	4.26	4.69	5.74	4.68
60	5.13	5.98	4.86	5.25	5.60	4.96
75	5.15	5.65	4.65	5.05	5.80	4.62
90	5.32	5.72	4.59	5.22	5.42	4.71
105	5.18	5.83	4.64	5.21	5.85	4.85
Mean	4.62	4.90	4.42	5.10	5.68	4.99
	Karappadam			Kole		
0	4.60	4.64	4.50	4.05	4.14	4.14
15	5.35	6.49	6.45	4.25	4.02	4.58
30	4.92	7.29	5.84	4.43	4.29	4.76
45	4.35	6.80	5.08	4.27	4.21	4.44
60	5.34	5.18	5.23	4.60	4.38	4.54
75	3.96	4.90	4.56	3.87	4.23	4.41
90	4.39	4.96	4.22	4.16	4.19	4.36
105	4.47	5.08	4.41	4.21	4.27	4.02
Mean	4.67	5.67	5.04	4.23	4.22	4.41
	Kari					
0	3.19	3.31	3.20			
15	3.15	3.24	5.25			
30	3.32	3.45	4.37			
45	3.33	3.42	3.61			
60	3.83	3.82	3.63			
75	3.39	3.19	3.40			
90	3.56	3.58	3.52			
105	3.65	3.63	3.68			
Mean	3.43	3.46	3.83			

Fig. 12. Variation in pH over time (days) due to the incorporation of organic manures in different soils



4.4.2.3 *Pokkali*

Incorporation of rice straw did not bring about a change in the pattern of pH variation in the Pokkali soils after submergence. The pH values showed an increasing trend up to 105 days. But in the treatment with incorporation of daincha, a lower pH was recorded from 60 days after incubation.

4.4.2.4 *Onattukara*

As in the case of Lateritic soil, the pH values decreased after submergence in the control plots and then increased. But in the rice straw added treatments there was no decrease in pH in the initial days. The pH of the soil increased after incorporation of daincha and then decreased to a value lower than that of control and rice straw incorporation.

4.4.2.5 *Karappadam*

The pH of the soil increased at 15 days after incubation. The magnitude of increase was higher for the treatments amended with organic manures. A decrease in pH was observed at 30 days and was maintained up to 105 days in the control plots. The decrease in pH observed in the treatments with organic manures was more gradual. The rice straw incorporated treatment recorded a slightly higher pH than treatment with daincha and control at the end of the incubation period.

4.4.2.6 *Kole*

The incorporation of organic manures had no significant effect on the pH of the soil. More or less similar values were maintained by the treatments throughout the period of incubation.

4.4.2.7 *Kari*

No substantial change in pH was observed due to rice straw incorporation in Kari soil. The increase in pH observed at 15 days due to the application of daincha was levelled off after 45 days after incubation. The three treatments recorded similar values at the end of the experiment.

DISCUSSION

DISCUSSION

5.1 FIELD EXPERIMENT I - DIURNAL AND SEASONAL VARIATIONS IN METHANE EMISSION FROM RICE FIELDS

The experiment to study the diurnal and seasonal variations in methane emission during the first and second crop seasons revealed that the methane emission was in general higher during the evening. Studies on the diurnal variations in methane flux in Japan (Yagi and Minami, 1990) and Italy (Sass *et al.*, 1991) showed similar trends in methane emission and the fluxes were minimum in the morning and maximum in the afternoon. In the Philippines, methane emission generally increased rapidly after sunrise, peaked early in the afternoon and declined rapidly to a plateau during night (Neue *et al.*, 1994b).

The diel pattern of methane emission had been positively correlated to the diel variations in soil temperature at 5 cm depth. (Parashar *et al.*, 1991), soil solution temperature (Satpathy *et al.*, 1997), maximum air temperature and solar radiation. In the present study, it was observed that though the temperature of the standing water in the field and that of the soil at 5 cm depth did not vary between noon (12 to 2 pm) and evening (4 to 6 pm) (Table 6), differences could be observed in the methane emission rate between noon and evening. The soil and water temperatures in the morning were always lower than the values at noon and evening. Despite this, a higher methane flux was noticed occasionally in the morning. Even though no location wise difference was observed in the temperature, methane emission rate varied with the sampling site. Methane emission at a particular site is the balance between methane production and oxidation which are controlled by a large number of abiotic and edaphic factors and their interaction. This might have resulted in masking the individual influence of any one of the factors involved, particularly when the emission per se was low.

Seasonal variations in methane efflux had been reported from paddy fields in different agro climatic situations. The emissions were generally low in the early growth period, increased gradually with two or three peaks in the vegetative and

reproductive phases and then decreased during the maturity period. (Yagi and Minami, 1990, Wang *et al.*, 1994). Even though no such peaks were observed in this experiment, the methane emission rate was found to increase steadily from tillering to booting stage (Fig. 6).

Several workers have reported that the methane emission rate increased from tillering to reproductive stage (Seiler *et al.*, 1984, Kludze *et al.*, 1993). Since ninety per cent of the methane emission from a paddy field is by transport through rice plants, the increase in the plant biomass and the concomitant development of the aerenchyma lead to a progressive increase in methane emission. The increased release of root exudates and decaying plant and root parts could also contribute to higher methane production and emission during the reproductive phase. The results of the present study, where a higher methane emission was observed during the booting and flowering stages, are in conformity with the above findings.

The rate of methane emission estimated during the first and second crop seasons showed wide variation. While the mean values for the tillering stage of the first crop season was $0.65 \text{ mg m}^{-2}\text{hr}^{-1}$, the corresponding value for the second crop season was $3.57 \text{ mg m}^{-2} \text{ hr}^{-1}$ (Table 5). Similarly, the values showed an increasing trend from the tillering to booting stage during the first crop season, but the methane flux remained almost stable during the three growth stages during the second crop season. The higher methane emission rate during the second crop season could be explained on the basis of the higher methane production in the soil. The left over stubbles remaining in the field from the preceding first crop might have served as suitable substrates for the microorganisms responsible for methanogenesis. It is to be noted that the second crop was planted two weeks after the harvest of the first crop.

The total rainfall received during the second crop season was 595 mm compared to the higher rainfall of 2567 mm during the first crop season. The crop was given intermittent irrigation during the second crop season towards the fag end of the crop growing period. Such a situation might have led to increased soil

aeration and higher redox potential which finally resulted in lack of methane flux during the flowering and maturity stages.

As methane production and emission is a continuous process, continuous monitoring of all the concerned regulatory factors is necessary from a number of locations in a single field itself to understand the exact pattern of methane emission.

5.2 FIELD EXPERIMENT II - EFFECT OF DIFFERENT ORGANIC MANURES AND INORGANIC FERTILISERS ON METHANE FLUX FROM RICE FIELDS

5.2.1 Effect of different sources of organic manure on methane emission

The methane production in a wetland rice soil is the result of anaerobic decomposition of organic matter. Hence the quantum of emission depends largely on the substrate availability. Application of organic manures such as crop residues, green manure and compost in the soil provides additional source of readily mineralisable carbon depending on the C : N ratio of the material added. The positive influence of organic manures on methane emission observed in the present study could be explained on the basis of the added carbon source. Increase in methane emission due to incorporation of rice straw, green manures and compost has also been reported by several workers (Wang *et al.*, 1992, Bronson *et al.*, 1997, Denier van der Gon and Neuf, 1995). While rice straw and green manure resulted in several fold increase in emission rate, the effect of farm yard manure or compost was only marginal (Yagi and Minami, 1990). A higher influence of rice straw and glyricidia on methane emission compared to farm yard manure was observed in the present study also.

The soil and plant characters studied were not significantly influenced by the different sources of organic manure (Table 8). Hence the favourable effect of organic manure in increasing methane flux could not be substantiated based on these characters.

5.2.2 Effect of different sources of nitrogen on methane emission

The application of nitrogen significantly influenced methane flux during the tillering stage of the first crop season and booting stage of the second crop season (Table 7). This can be ascribed to the enhanced plant growth as evidenced by the significant increase in plant height due to application of nitrogen. An increased plant height resulted in an increased area for the transport of methane from the soil to the atmosphere.

The enhanced effect of urea over factomphos in producing a higher methane emission during the second crop season could be attributed to several factors. The pH of the soil was higher during the second crop season compared to the first crop season (Table 8). This might have resulted in an enhanced hydrolysis of urea thereby increasing the concentration of ammonium ions in the soil. Ammonium ions could inhibit methane oxidization (Conrad and Ruthfuss, 1991). At the same time, the presence of sulphate in factomphos, which is a combination of ammonium phosphate and ammonium sulphate might have contributed to the inhibition of methanogenesis in the plots where factomphos was applied.

The possible role of sulphate in inhibiting methanogenesis and thereby reducing methane emission have been well documented. Under field conditions, the use of sulphate containing fertilisers such as ammonium sulphate and calcium sulphate were found to reduce methane emission (Denier van der Gon and Neue, 1994, Lindau, 1994). Similarly, the supply of phosphorus and potassium through sulphate containing fertilisers reduced methane emission at 30 days in both P-deficient and P – normal Indian soils (Adhya *et al.*, 1997). In the thermodynamical sequence of soil reduction, sulphate reduction occurs before methane formation (Patrick and Reddy, 1978). It is observed that sulphate reducers could out compete methanogens for substrates such as acetate or hydrogen, resulting in an inhibition of methane formation (Achnich *et al.*, 1995). But the reduction in the methane flux expected from the treatments where factomphos was applied, was manifested only during the second crop season. However, this decrease in the plots where factomphos was applied could not be solely and conclusively related to the effect

of sulphate since single super phosphate was applied as the source of P in all the other treatments. Single super phosphate also contains more or less comparable amounts of sulphate.

5.2.3 Seasonal variation in methane emission

The methane emission values obtained in the experiment ranged from 1.22 to 8.76 mg m⁻² hr⁻¹ during the tillering stage of the first crop season and from 0.32 to 2.17 mg m⁻² hr⁻¹ for the tillering stage of the second crop season and 0.17 to 6.99 mg m⁻² hr⁻¹ during the booting stage (Table 7). These values compare with those reported for paddy fields of Delhi (0.39 to 2.90 mg m⁻² hr⁻¹), Dehradun (0.07 to 0.13 mg m⁻² hr⁻¹), Faizabad (0.1 to 3.5 mg m⁻² hr⁻¹), Allahabad (0.4 mg m⁻² hr⁻¹) and Varanasi (0.11 to 11.93 mg m⁻² hr⁻¹).

The emission rates in all the treatments were higher during the first crop season. The methane emission in a paddy field is the emerging balance between methane formation, oxidation and transport through rice plants. This in turn is regulated by the interaction of various chemical, physical and biological factors operating under anaerobic conditions.

The factors that led to the higher methane emission during the tillering stage of the first crop season as compared to the tillering stage of the second crop season could be related to the lower Eh values and the higher biomass of plants, compared to the second crop season. Soil Eh ranging from about -100 mV to -200 mV has been reported to be necessary for the initiation of methane production in soil (Lindau *et al.*, 1991, Wang *et al.*, 1993). However methane emissions have been reported at higher Eh values in field studies (Denier van der Gon, 1996) where methane emission occurred at an Eh of 60 ± 40 mV. The average Eh values in the present experiment during the tillering stage of first crop was -118.6 mV while the average value of second crop tillering stage was 5.4 mV.

Another factor which might have contributed to the high methane emission rate at tillering stage during the first crop season is the higher biomass production

of the plants during this season. The average biomass per hill was 4.85 g as against 3.55 g per hill during the tillering stage of the second crop. The mean plant height was 46.8 cm during the tillering stage of the first crop season and 28.9 cm during the second crop season. However, no significant correlation was obtained between methane efflux at these two stages and growth indices such as plant height, number of tillers per hill and dry weight per hill.

The plausible reason for the higher methane emission rate observed during the booting stage of the second crop season compared to the tillering stage have already been discussed (p.99). The plant height at this particular stage was positively and significantly correlated with methane efflux. The higher emission could also be the result of a higher methane production in the soil contributed by root exudates and decaying plant tissues. In the present experiment, it was observed that the tiller number declined from panicle initiation stage to flowering stage. Such a phenomenon was earlier reported by Mustafa (1995) as a means of survival by escape from the inhibiting influences.

Though sampling for estimating methane emission was done at the flowering and the maturity stages, the concentration of samples were more or less equal to that of ambient air. Nouchi *et al.* (1994) suggested that the decline of methane efflux at ripening and maturity stages was due to the decline in conductance and transport capacity of rice plant resulting from root ageing and degradation. The balance between root exudation, root porosity and root oxidation power controlled the methane emission rate during this phase (Neue, 1997). It is to be noted that the flowering and maturity stages of the second crop season coincided with the beginning of the summer season and irrigations were given only intermittently. This resulted in occasional draining of standing water keeping the field at saturation point, which in turn might have led to aeration and methane oxidation. The lowering of methane emission during the flowering and maturity stages could be attributed to this particular field situation. It could also be explained on the basis of the findings reported by Nouchi *et al.* (1994) and the statements of Neue (1997). However, Neue *et al.* (1994b), Chidthaisong and Watanabe (1997) and Singh *et al.* (1998) reported peak methane emission during

the ripening phase. The inherent variations in soil and climatic conditions as well as the varietal differences could be the reasons for the contrasting results of the present study.

5.2.4 Effect of different sources of organic manure and nitrogen fertilisers on plant growth characters, yield contributing characters and grain yield and straw yield

As management of crop nutrition in respect of organics and nitrogen for maintaining crop productivity without enhancing methane emission is desirable, the various growth and yield parameters of rice have been recorded as ancillary data (section 4.2.6 to 4.2.8).

The biometric characters except height of plants and yield contributing characters were not significantly influenced by the treatments during the first crop season. During the second crop season, the height of plants at the different stages of growth, number of tillers per hill at panicle initiation, flowering and maturity stages and the number of panicles per m² were significantly and positively influenced by the application of nitrogen.

The influence of organic manures and nitrogen on the grain yield was observed only during the second crop season. The increase in yield over control due to the application of organic manures is brought about by an increase in the number of spikelets per panicle which alone was found to be positively and significantly influenced by the application of organic manure, among the yield contributing characters.

Similarly, the positive influence of the application of nitrogen on grain yield was manifested through the increased number of panicles per m². The two sources of nitrogen fertiliser, namely, urea and factomphos, recorded grain yields statistically on par.

The straw yield was influenced neither by the incorporation of organic residues nor by the application of nitrogen during both seasons.

Substantial variation was observed in all the treatments the two crop growing seasons with respect to the grain yield and straw yield. Higher grain yield and straw yield were obtained during the first crop season. The yield contributing characters, such as number of spikelets per panicle and 1000 grain weight were higher during the first crop season. The height of plants and total biomass of plants at different stages were also higher during this season.

The high harvest index obtained in the present experiment could be explained partly on the basis of the plant character of variety Kanchana. The variety is of medium stature with moderate tillering habit. The grain is long and bold having higher 1000 grain weight. Further more, it is indicated that the high content of iron in the Lateritic soils of Kerala leading to high accumulation of iron in the plant results in tiller decline during the later stages. This phenomenon was reported by many workers as a means of survival from inhibiting influences.

5.3 POT CULTURE EXPERIMENT - DECOMPOSITION PATTERN OF DIFFERENT ORGANIC MANURES IN THE PRESENCE AND ABSENCE OF RICE IN LATERITIC SOIL

5.3.1 Decomposition pattern of different organic manures

This pot culture study was conducted using the Lateritic soils since 60 per cent of the wetland rice fields of Kerala come under this soil type. The objective was to generate data on the availability of carbon substrates on incorporation of organic residues in soil as methanogenesis and methane emission from wetland rice fields are regulated by the anaerobic carbon mineralisation (Segers and Kengen, 1998).

A study of the decomposition pattern of the different ^{14}C labelled organic residues in soil revealed that there was an initial rapid declining process irrespective of the nature of the crop residue (Fig. 7 and 8). But the quantity of organic carbon mineralized at periodic intervals revealed variations among the different crop residues. The high rates of decomposition in the early stages following incorporation could be attributed to the decay of readily decomposable

fractions of plant organic carbon (Knapp *et al.*, 1983, Reinertsen *et al.*, 1984). With passage of time, the residual carbon would become resistant to further transformations.

The rate of decomposition was observed to be faster in the green manures than in rice straw. The chemical composition of the manure plays an important role in the turn over and fate of organic residues in soil. The C : N ratio, nitrogen content, cellulose, hemicellulose and lignin content have been reported to influence the decomposition rate. The nitrogen content in glyricidia was the highest among the four organic manures and it was the lowest in rice straw. Glyricidia exhibited the fastest rate of decomposition (Table 27 and 28). Similarly the C : N ratio was also narrower for glyricidia. Even though the carbon contents of the added materials were comparable, the relative proportions of the forms of organic carbon present in the material were quite different. In general rice straw contains a higher proportion of lignin than green manures, 13.3 per cent as against 1.7 per cent (Nandi *et al.*, 2000).

5.3.2 Effect of presence of crop on decomposition pattern

The results of the experiment further revealed that the presence of plants had no significant influence on the decomposition pattern of different organic manures. There are many conflicting reports on the stimulatory and retarding effect of living roots on the decomposition of organic residues. The explanations suggested for the stimulatory effect of plants include the breakdown of soil aggregates and the stimulation of rhizosphere microflora (Helal and Sauerbeck, 1984). The negative effect was assumed to be due to the use of labile compounds released from roots by the microflora in preference to plant material, inhibition of microbial activity by compounds originating in the roots and rhizosphere and due to the uptake of organic carbon compounds by the plant to a limited extent (Reid and Goss, 1982). In the present experiment, only negligible amount of ^{14}C was detected in the plant in different stages. This is fully in consonance with the results of Sallih and Bottner (1988) and Cogle *et al.* (1989). The rice seedlings

were planted 30 days after the incorporation of organic residues by which time a major portion of the added carbon had mineralised.

5.3.3 Effect of organic manures on the pH of the soil at different intervals

Application of organic residues into the soil was found to increase the soil pH during the initial days. Submergence itself brought about an increase in pH in all the treatments. At ten days after incorporation, the increase in pH in the organic manure incorporated pots were significantly higher than that in the pots without organic manure. Green manures brought about a higher increase in pH than rice straw. This difference was not prominent among the treatments from 30 days onwards.

The initial increase in pH due to the addition of green manures were reported by Singh *et al.* (1992). Lal *et al.* (2000) observed an increased in soil pH following the application of organic manures up to 60 days after incubation beyond which it decreased significantly. This may be due to the release of basic cations from the residues. Increase in soil pH may also result through the mineralisation of organic anions to CO₂ and H₂O thereby removing H⁺. The average ash alkalinity of legume crop (110 C mol kg⁻¹) is greater the forage crop (69 C mol kg⁻¹) (Pierre and Banwart, 1973). The decrease in pH after 20 days can be attributed to the release of organic acids and CO₂ during the decomposition process.

5.3.4 Effect of organic manures on the organic carbon content of soil at different intervals after incorporation

The organic manures were found to lower the organic carbon content of the soil during the initial periods after incorporation. However, the organic carbon content increased or remained more or less similar to the initial value in the control plots. The rapid multiplication of microorganisms following the incorporation of organic residues subsequently leading to 'priming effect' (Datta and Goswami, 1962) could be the reason for this particular phenomenon. It is to be recalled that the soil samples were sieved to remove the undecomposed plant

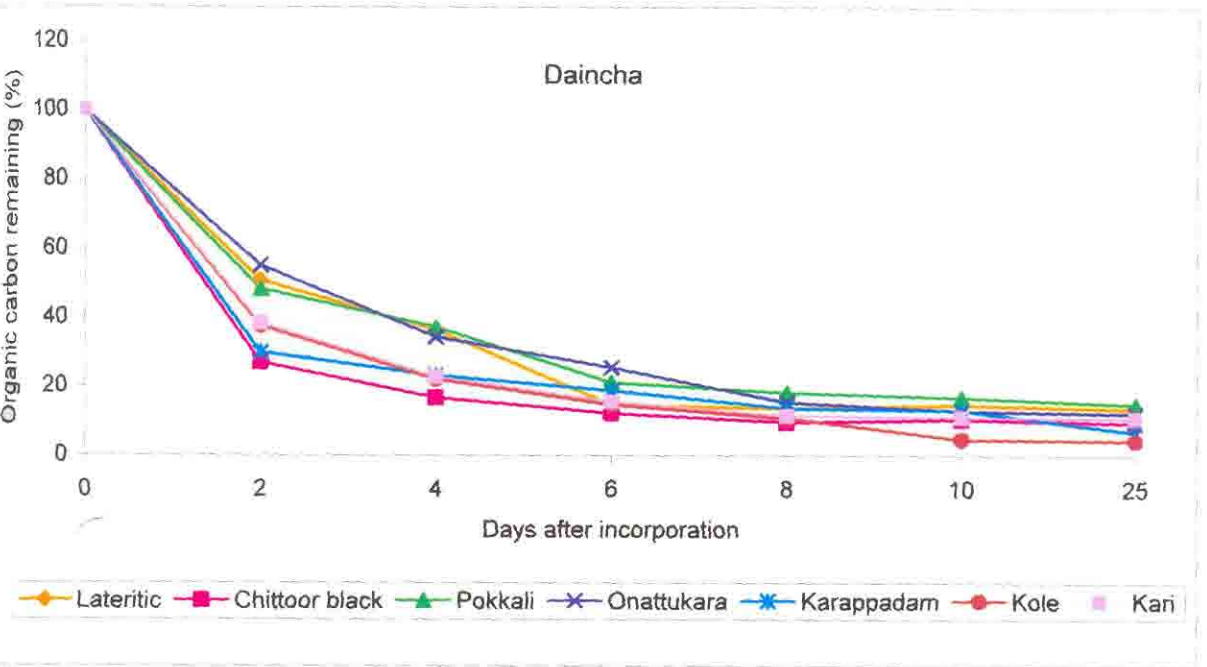
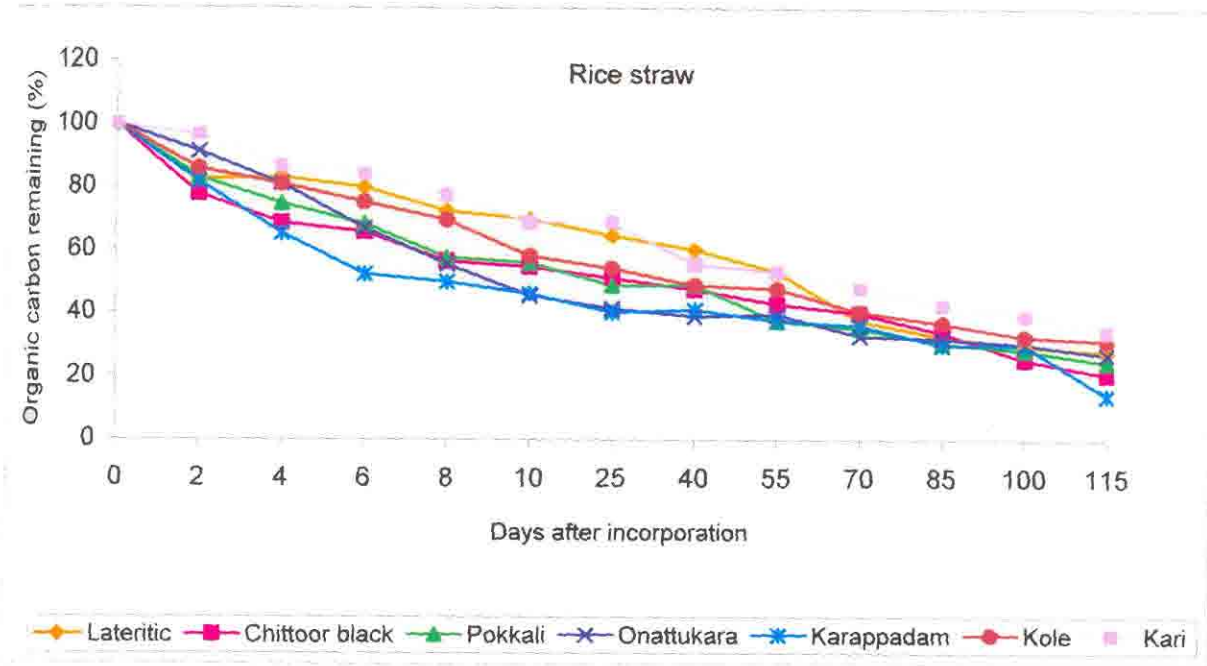
material before analysis. The increase in organic carbon content observed in all the treatments from 60 DAP to 90 DAP could be attributed to the release of root exudates by the rice crop.

5.4 INCUBATION STUDY - DECOMPOSITION PATTERN OF RICE STRAW AND DAINCHA IN SELECTED RICE SOILS OF KERALA

The decomposition rates in different rice soils were compared based on the ^{14}C labelled organic carbon remaining in the soil at selected intervals after incubation (Fig. 13). The soils differed in their ability to retain organic carbon from the added rice straw and daincha. The initial rate of decomposition was faster in the Chittoor black soil than the other soils. It can be observed that pH of this soil was near neutral while all the other soils showed acidic reactions. Several workers (Cerri and Jenkinson, 1981; Diane *et al.*, 1983) have reported that the rate of decomposition was rapid in near neutral to alkaline soils than acidic soils. Significant correlations were not obtained between decay rate constant and soil pH in the present experiment. According to Jenkinson (1977), the significant effect of low pH in decreasing the decomposition rate was observed only in extreme acid conditions. Though the initial soils reaction of the Pokkali, Kari and Kole soil was in the highly acidic range, submergence as well as incorporation of organic residues were found to enhance the soil reaction subsequently (Fig. 12). This could be the reason for the lack of significant correlation.

The organic carbon content of the soil showed negative correlation with decay rate constant, though not significant. The organic carbon content of the Karappadam, Kole and Kari soils were higher than the other soils. These soils also showed a higher retention of organic carbon, especially at the initial stages. As an exception, the Lateritic and Onattukara soils with lower organic carbon contents showed higher retention at 115 days after incubation. The retention in the Karappadam soil was the lowest at 115 days irrespective of the high organic carbon content.

Fig. 13. Organic carbon remaining in soils at different intervals after incorporation of rice straw and daincha



The organic carbon remaining in the soils from the added rice straw and daincha at different intervals after incorporation showed a nonsignificant and negative correlation with clay content of the soils. The value was significant in the case of daincha in the initial stages. This is at variance with the observations of Amato *et al.* (1987), Amato and Ladd (1992) where soils with higher clay content were found to retain more organic carbon from the added material. This may be due to the anoxic environment in which the decomposition occurred in the present study compared to the moist conditions from where the reported results emerged. The overriding effect of other modified soil factors such as soil reaction also might have resulted in this contradictory observation.

The magnitude of organic carbon mineralized from the added substrate was very much higher for daincha in all the soils. This can be attributed to the difference in the chemical composition of straw and daincha. The lower C : N ratio and low lignin content in daincha enabled a more rapid decomposition, and thereby attaining a stable value within 20 days (Fig. 11).

The decomposition pattern of different organic residues was studied to find out the extent of organic carbon that could be retained by the different types of soil. This can serve as a basis for further studies on the substrate availability for methanogenesis in the changing scenario of organic farming.

SUMMARY

SUMMARY

The research project entitled 'Methane emission from wetland rice fields of Kerala' included two field experiments, a pot culture experiment and an incubation study. The salient features of the results are summarised below:

- ♦ The methane efflux from the Lateritic rice soils was found to be low, to the tune of $2.4 \text{ mg m}^{-2} \text{ hr}^{-1}$.
- ♦ Diurnal and seasonal variations were exhibited in the pattern of methane emission. The emission was generally higher in the evening, although variations were observed, with different growth stages of the crop. A higher methane flux was noticed during the second crop season.
- ♦ In general, the methane flux increased progressively from tillering stage to booting stage, levelled off at flowering and declined thereafter.
- ♦ Incorporation of organic manures significantly increased the methane emission from rice fields. The effect of rice straw and glyricidia were higher than that of farm yard manure. The significant effect of rice straw was more pronounced during the second crop season.
- ♦ Application of nitrogenous fertilisers significantly enhanced the methane efflux from rice fields. The relatively higher methane emission indicated for urea, compared to factomphos, was dependant on crop growth stages and season.
- ♦ The plant growth characters studied were not significantly influenced by the application of organic manures in both seasons. Application of nitrogen fertilisers significantly improved the plant growth characters over control.
- ♦ The grain yield during the second crop season was significantly increased by the application of organic manures and nitrogen fertilisers.
- ♦ The mineralisation of organic carbon added through organic residues started immediately after their incorporation under anaerobic conditions. The

decomposition was characterised by an initial rapid declining phase followed by a slower and steady phase.

- ♦ Green manures exhibited a faster decomposition rate than rice straw and in the order glyricidia > daincha > sunhemp in the Lateritic soil.
- ♦ The decomposition pattern of the added organic manures was not significantly influenced by the presence of rice crop.
- ♦ Incorporation of organic manures brought about an increase in soil pH during the initial periods of submergence which decreased subsequently.
- ♦ When applied in equal quantities, rice straw was found to be more effective than green manures in maintaining the soil organic carbon levels.
- ♦ Soils coming under the major rice growing areas of Kerala exhibited similar pattern of decomposition of the added organic manures under anaerobic situations. However, significant variations were observed in their ability to retain organic carbon from the added residues at different intervals after incorporation.
- ♦ The decomposition of daincha was faster than rice straw in all the soil types and attained a steady phase much earlier.
- ♦ In general, the Kari soil retained the highest amount of organic carbon from added rice straw followed by the Lateritic and Kole soils. The lowest quantity was retained by the Karappadam soil.
- ♦ The highest retention of organic carbon from daincha was observed in the Pokkali soil followed by the Lateritic and Onattukara soil. The lowest retention was observed in the Kole and Karappadam soils.
- ♦ The basic soil properties such as textural composition, pH and organic carbon were not found to individually and significantly influence the organic carbon remaining from rice straw and daincha in different soils.

The single exponential model developed to explain the decay pattern of added rice straw in different soils could reliably predict the organic carbon remaining from the added organic carbon at different intervals.

The application of farm yard manure and factomphos are suggested as suitable mitigation options for reducing methane emission from the Lateritic rice soils of Kerala, without affecting the realisable grain yield. However, based on the methane efflux values obtained for the different treatments, it could be assumed that the contribution of these rice fields to increase in concentration of methane in the atmosphere was meagre. Therefore the use of rice straw and glyricidia as organic manures could be continued under situations of limited availability of farm yard manure.

REFERENCES

REFERENCES

- Achtnich, C., Bak, F. and Conrad, R. 1995. Competition for electron donors among nitrate reducers, ferric iron reducers, sulphate producers and methanogens in anoxic paddy soil. *Biol. Fertil. Soils* 19: 65-72
- Adhya, T.K., Patnaik, P., Satpathy, S.N., Kumaraswamy, S. and Sethunathan, N. 1997. Influence of phosphorus application on methane emission and production in flooded paddy soils. *Soil Biol. Biochem.* 30: 177-181
- Adhya, T.K., Rath, A.K., Gupta, P.K., Rao, V.R., Das, S.N., Parida, K.M., Parashar, D.C. and Sethunathan, N. 1994. Methane emission from flooded rice fields under irrigated conditions. *Biol. Fertil. Soils* 18: 245-248
- *Agnihotri, S., Kulshreshtha, K. and Singh, S.N. 1999. Mitigation strategy to contain methane emission from rice fields. *Environ. Monitor. and Assess.* 58: 95-104
- Ajwa, H.A. and Tatabai, M.A. 1994. Decomposition of different organic materials in soils. *Biol. Fertil. Soils* 18: 175-182
- *Alvarez, R., Santanatoglia, B.J. and Brazzda, G.M. 1991. Biological activity and decomposition of wheat straw in soil with different amounts of added material and different bulk density. *Revista-de-la-Facultad-de-Agronomia-Universidad – de Buenos – Acies* 252-299
- Amato, M and Ladd, J.N. 1980. Studies of nitrogen immobilization and mineralisation in calcareous soils V. Formation and distribution of isotope labelled biomass during decomposition of ^{14}C and ^{15}N labelled plant material. *Soil Biol. Biochem.* 12: 405-411
- Amato, M. and Ladd, J.N. 1992. Decomposition of ^{14}C labelled glucose and legume material in soil. Properties influencing the accumulation of organic residue C and microbial biomass. *Soil Biol. Biochem.* 24: 455-464

- Amato, M., Ladd, J.N., Ellington, A., Ford, G., Mahoney, J.E., Taylor, A.C. and Walscott, D. 1987. Decomposition of plant materials in Australian soils: IV. Decomposition in situ of ^{14}C and ^{15}N labelled legume and wheat materials in a range of Southern Australian Soils. *Aust. J. Soil. Res.* **25**: 95-103
- Anon, 1992. *Greenhouse Gas Emissions in India*. Scientific Report No. 2. CSIR and Ministry of Environment and Forests (ed. Mitra, A.P.), Council of Scientific and Industrial Research, New Delhi, 91 p.
- Aulakh, M.S., Wassmann, R. and Rennenberg, H. 2001. Methane emissions from rice fields – quantification, mechanism, role of management and mitigation options. *Adv. Agron. Vol. 74* (ed. Sparks, D.L.). Academic Press, London, pp. 193-260
- *Aulakh, M.S., Wassmann, R., Rennenberg, H. and Fink, S. 2000. Pattern and amount of aerenchyma relates to variable methane transport capacity of different rice cultivars. *Pl. Soil* **222**: 182-184
- Azam, F., Haider, K. and Malik, K.A. 1985. Transformation of ^{14}C labelled plant components in soil in relation to immobilization and mineralisation of ^{15}N fertiliser. *Pl. Soil* **86**: 15 – 25
- Bachelet, D. and Neue, H.U. 1993. Methane emissions from wetland rice areas of Asia. *Chemosphere* **26**: 219-237
- Bek, 1994. Mineralisation of ^{14}C labelled unripe straw in soil with and without rape (*Brassica napus*). *Biol. Fertil. Soils* **17**: 21-26
- Bhat, A.K. and Beri, V. 1996. Methane emission in irrigated rice soils of Punjab. *Curr. Sci.* **70**: 154-155
- Bhat, A.K. and Beri, V. 2002. Methanogenesis in rice soils: effect of temperature, pH, fertiliser and organics. *J. Indian Soc. Soil Sci.* **50**: 306-308

- Bronson, K.F. and Mosier, A.R. 1991. Effect of encapsulated calcium carbide on dinitrogen, nitrous oxide, methane and carbon dioxide emission from flooded rice. *Biol. Fertil. Soils* 11: 116-120
- Bronson, K.F., Neue, H.U., Singh, U. and Abao, E.B. Jr. 1997. Automated chamber measurements of methane and nitrous oxide flux in a flooded rice soil: I. Residue, nitrogen and water management. *Soil Sci. Soc. Am. J.* 61: 981-987
- *Buendia, L.V., Neue, H.U., Wassmann, R., Lantin, R.S., Javellana, A.M., Araha, J., Wang, Z., Wanfang, L., Makarim, A.K., Corton, T.M. and Charoensilp, N. 1998. An efficient sampling strategy for estimating methane emission from rice field. *Chemosphere* 36: 395-407
- *Butterbach – Bahl, K., Papen, H. and Rennenberg, H. 1997. Impact of gas transport through rice cultivars on methane emission from rice paddy fields. *Pl. Cell Environ.* 20: 1175-1183
- *Byrd, G.T., Fisher, F.M. and Sass, R.L. 2000. Relationships between methane production and emission to lacunal methane concentrations in rice. *Global Biogeochem. Cycles* 14: 73-83
- Byrnes, B.H., Austin, E.R., and Tays, B.K. 1995. Methane emission from flooded rice soils and plants under controlled condition. *Soil Biol. Biochem.* 27: 331-339
- Cai, Z.C., Xing, H., Yan, X., Xu, H., Tsurata, H., Yagi, K. and Minami, K. 1997. Methane and nitrous oxide emissions from rice paddy soils as affected by nitrogen fertilisers and water management. *Pl. Soil* 196: 7-14
- Cerri, C.C. and Jenkinson, D.S. 1981. Formation of microbial biomass during decomposition of ¹⁴C labelled rye grass in soil. *J. Soil Sci.* 32: 619-626
- *Chanton, J.P., Whiting, G.J., Blair, N.E., Lindau, C.W. and Bollisch, P.K. 1997. Methane emission from rice : stable isotopes, diurnal variations and CO₂ exchange. *Global Biogeochem. Cycles* 11: 15 – 27

- Cheng, W. and Coleman, D.C. 1990. Effect of living roots on soil organic matter decomposition. *Soil Biol. Biochem.* **22**: 781-787
- Chidthaisong, A. and Watanabe, I. 1997. Changes in concentration and ¹³C values of soil entrapped CH₄ and CO₂ in flooded rice soil. *Biol. Fertil. Soils* **24**: 70 – 75
- *Cicerone, R.J. and Shetter, J.D. 1981. Sources of atmospheric methane : measurements in rice paddies and a discussion. *J. Geophys. Res.* **86**: 7203 – 7209
- *Cicerone, R.J., Shetter, J.D. and Delwiche, C.C. 1983. Seasonal variation of methane flux from a Californian rice paddy. *J. Geophys. Res.* **88**: 11022-11024
- Cogle, A.L., Saffigna, P.G. and Strong, W.M. 1989. Carbon transformations during wheat straw decomposition. *Soil Biol. Biochem.* **21**: 367-372
- Conrad, R. and Rothfuss, F. 1991. Methane oxidation in the soil surface layer of a flooded rice field and the effect of ammonium. *Biol. Fertil. Soils* **12**: 28-32
- *Corton, T.M., Bajita, J.B., Grospe, F.S., Pamplona, R.R., Asis, C.A.Jr., Wassman, R., Lantin, R.S. and Buendia, L.V. 2000. Methane emission from irrigated and intensively managed rice fields in central Luzon. *Nutr. Cycling Agroecosys.* **58**: 37-53.
- Datta, N.P. and Goswami, N.N. 1962. Transformation of organic matter in soil in relation to the availability of nutrients to plants. *Proceedings of the Symposium on the Use of Radioisotopes in Soil – Plant Nutrition Studies*. International Atomic Energy Agency, Vienna, pp.223-237
- *Denier van der Gon, H.A.C. 1996. Methane emission from wetland rice fields. PhD thesis, Agricultural University, Wageningen, Netherlands
- Denier van der Gon, H.A.C. and Neue, H.U. 1994. Impact of gypsum application on methane emission from a wetland rice field. *IRRN.* **19** (3): 41-42

- Denier van der Gon, H.A.C. and Neue, H.U. 1995. Methane emission from a wetland rice field as affected by salinity. *Pl. Soil* 170: 307-313
- *Denier van der Gon, H.A.C. and Van Breemen, N. 1993. Diffusion – controlled transport of methane from soil to atmosphere as mediated by rice plants. *Biogeochemistry* 21: 117 – 190
- *Denier van der Gon, H.A.C., Neue, H.U., Lantin, R.S., Wassman, R., Alberto, M.C.R. Aduna, J.B. and Tan, M.J.P. 1992. Controlling factors of methane emission from rice fields. *Wise Report 2*, International Soil Reference and Information Centre, Netherlands, pp. 81-92
- *Denier van der Gon, H.A.C., Van Breemen, N., Neue, H.U., Lantin, R.S., Wassmann, R., Aduna, J.B. and Alberto, M.R.C. 1996. Release of entrapped methane from wetland rice fields upon drying. *Global Biogeochem. Cycles* 10: 1–9
- *Devevre, O.C. and Horwath, W.R. 2000. Decomposition of rice straw and microbial carbon use efficiency under different soil temperatures and moistures. *Soil Biol. Biochem.* 32: 1773-1785
- Diane, E.S., Kassim, G., Jarrel, W.M., Martin, J.P. and Haider, K. 1983. Stabilisation and incorporation into biomass of specific plant carbons during biodegradation in soil. *Pl. Soil* 70: 15-16
- Dickinson, R.E. and Cicerone, R.J. 1986. Future global warming from atmospheric trace gases. *Nature* 319: 109-114
- *Ding, A., Willis, C.R., Sass, R.L. and Fisher, F.M. 1999. Methane emissions from rice fields: effect of plant height among several rice cultivars. *Global Biogeochem. Cycles* 13: 1045-1052
- *Dunfield, P.F., Topp, E., Archambault, C. and Knowles, R. 1995. Effect of N fertilisers and moisture content on methane and nitrous oxide fluxes in a humisol measurement in the field and intact soil cores. *Biogeochemistry* 29: 192-222

- El-Shakweer, M.H.A., Gomah, A.M., Barakat, M.A. and Abdel – Ghaffar, A.S. 1977. Effects of salts on decomposition of plant residues. *Proceedings of the Symposium on Soil Organic Matter Studies Vol. I*, International Atomic Energy Agency, Vienna, pp. 205 – 213
- *Fließbach, A., Mader, P. and Niggli, U. 2000. Mineralisation and microbial assimilation of ^{14}C labelled straw in soils of organic and conventional agricultural systems. *Soil Biol. Biochem.* **32**: 1131 – 1139
- Fuhr, F. and Sauerbeck, D.R. 1968. Decomposition of wheat straw in the field as influenced by cropping and rotation. *Proceedings of Symposium on Use of Isotopes and Radiation in Soil Organic Matter Studies*, International Atomic Energy Agency, Vienna, pp.241-250
- *Ghidey, F., Gregory, J.M., McCarty, T.R. and Alberts, E.E. 1985. Residue decay evaluation and prediction. *Transactions of the ASAE* **28** (1): 102–105
- *Glissmann, K., and Conrad, R. 2000. Fermentation pattern of methanogenic degradation of rice straw in anoxic paddy soil. *FEMS Microbiol. Ecol.* **31**: 117-126
- *Harper, S.H.T. and Lynch, J.M. 1981. The chemical components and decomposition of wheat straw leaves, internodes and nodes. *J. Fd. Agric.* **32**: 1057-1062
- *Harrison, W.H. and Aiyer, P.A.S. 1913. The gases of swamp rice soil. I: Their composition and relationship to the crop. *Mem. Dep. of Agric. India Chemistry Series* **5** (3): 65-104
- Helal, H.M. and Sauerbeck, D.R. 1984. Influence of plant roots on C and P metabolism in soil. *Pl. Soil* **76**: 175-182
- Herman, W.A., McGrill, W.B. and Dormaar, J.F. 1977. Effects of initial chemical composition on decomposition of roots of three grass species. *Can. J. Soil Sci.* **60**: 97-106

- Holzapel – Pschorn, A., Conrad, R. and Seiler, W. 1986. Effects of vegetation on the emission of methane from submerged paddy soil. *Pl. Soil* **92**: 223 – 291
- Holzapel-Pschorn, A and Seiler, W. 1986. Methane emission during a cultivation period from an Italian rice paddy. *J. Geophys. Res.* **91**:11803-11814
- Hosono, T. and Nouchi, I. 1997. Effect of gas pressure in the root and stem base zone on methane transport through rice bodies. *Pl. Soil* **195**: 65-73
- *Husin, Y.A., Murdiyarso, D., Khalil, M.A.K., Rasmussen, R.A., Shearer, M.J., Sabiham, S., Sunar, A. and Adjuwana, H. 1995. Methane flux from Indonesian wetland rice : the effects of water management and rice variety. *Chemosphere* **31**: 3153-3180
- *IPCC – Intergovernmental Panel on Climate Change. 1992. Climate change – the supplementary report to the IPCC scientific assessment (eds. Houghton, J.T., Callander, B.A. and Varney, S.K.). Cambridge University Press, UK, 200 p.
- *IPCC. 1994. Climate change – Radioactive forcing of climate change and an evaluation of the IPCC 1992 emission scenarios (eds. Houghton, J.T., Meira F.L.G., Bruce, J., Lee, H., Callander, B.A., Haites, E., Hareis, N. and Maskell, K.). Cambridge University Press, UK, 230 p.
- *IRRI – International Rice Research Institute. 1995. *IRRI Rice Almanac, 1993 – 1995*. International Rice Research Institute, Lon Banos, Philippines
- *IRRI, 1999. *Sustaining Food Security Beyond the Year 2000. A Global Partnership for Rice Research : Medium – term plan 2000-2002*. International Rice Research Institute, Los Banos, Philippines, 130 p.
- Jackson, M.L. 1958. *Soil Chemical Analysis*. Indian Reprint 1967. Prentice Hall of India Private Ltd., New Delhi, 498 p.

- *Jain, M.C., Kumar, S., Wassman, R., Mitra, S., Singh, S.D., Singh, J.P., Singh, R., Yadav, A.K. and Gupta, S. 2000. Methane emissions from irrigated rice fields in Northern India (New Delhi). *Nutr. Cycling Agroecosys.* **58**: 75-83
- Janzen, H.H. and Kucey, R.M.N. 1988. C, N and S mineralisation of crop residues as influenced by crop species and nutrient regime. *Pl. Soil* **106**: 35-41
- Jenkinson, D.S. 1977. Studies on decomposition of plant material in soil: V. The effect of plant cover and soil type on the loss of carbon from ¹⁴C labelled rye grass decomposing under field conditions. *J. Soil Sci.* **28**: 424-434
- *Jia Z.J., Cai, Z.C., Xu, H. and Li X.P., 2001. Effect of rice plants on methane, production, transport, oxidation and emission in rice paddy soil. *Pl. Soil* **230**: 211-221
- Justine, S.H.F.W. and Armstrong, W. 1987. The anatomical characteristics of roots and plant response to soil flooding. *New Phytol.* **106**: 465 – 495
- *Kaku, N., Ueki, A., Fujii, H. and Ueki, K. 2000. Methanogenic activities on rice roots and plant residue and their contributions to methanogenesis in wetland rice field soil. *Soil Biol. Biochem.* **32**: 2001-2010
- *Kato, K., Chairaj, P., Yagi, K., Tsuruta, H., Minami, K. and Cholitkul, W. 1999. Diel and seasonal variations of methane flux from Bang Khen paddy field in Thailand. *JIRCAS J.* **7**: 69-75
- KAU, 1996. *Package of Practices Recommendations "Crops 96"*. Kerala Agricultural University, Vellanikkara, Kerala, 267 p.
- Keerthisinghe, D.G., Freney, J.R. and Mosier, A.R. 1993. Effect of wax coated calcium carbide and nitrapyrin on nitrogen loss and methane emission from dry seeded flooded rice. *Biol. Fertil. Soils* **16**: 71 – 75
- *Khalil, M.A.K. and Rasmussen, R.A. 1987. Atmospheric methane: Trends over the last 10,000 years. *Atmos. Environ.* **21**: 2445-2452

- *Khalil, M.A.K. and Rasmussen, R.A. 1990. Constraints on the global sources of methane and an analysis of recent budgets. *Tellus* 428: 229-236
- Kludze, H.K. and De Laune, R.D. 1995. Straw application effects on methane and oxygen exchange and growth in rice. *Soil Sci. Soc. Am. J.* 59: 824-830
- Kludze, H.K., De Laune, R.D. and Patrick, W. H. Jr. 1993. Aerenchyma formation and methane and oxygen exchange in rice. *Soil Sci. Soc. Am. J.* 57: 386-391
- Knapp, E.P., Elliot, L.F. and Campbell, G.S. 1983. Microbial respiration and growth during the decomposition of wheat straw. *Soil Biol. Biochem.* 15: 319 – 323
- *Koyama, T. 1964. Biogeochemical studies on lake sediments and paddy soils and the production of hydrogen and methane. *Recent Research in the Field of Hydrosphere, Atmosphere and Geochemistry* (eds. Miyaki, T. and Koyama, T.). Maruzen, Tokyo, pp. 143-177
- Kumaraswamy, S., Rath, A.K., Satpathy, S.N., Ramakrishnan, B., Adhya, T.K. and Sethunathan, N. 1998. Influence of the insecticide carbofuran on the production and oxidation of methane in a flooded rice soil. *Biol. Fertil. Soils* 26: 362- 366
- Ladd, J.N., Amato, M., Grace, P.R. and van Veen, J.A. 1995. Simulation of ^{14}C turnover through the microbial biomass in soils incubated with ^{14}C labelled plant residues. *Soil Biol. Biochem.* 27: 777-783
- Lal, J.K., Mishra, B. and Sarkar, A.K. 2000. Effect of plant residue incorporation on specific microbial groups and availability of some plant nutrient in soil. *J. Indian Soc. Soil Sci.* 48: 67-71
- Lee, J., Park, M., Yun, S. and Lee, B. 1994. Effects of heat balance in methane emission in rice plant canopy. *IRRN* 19 (3): 40-41
- Liang, S. and Yang, G. 1994. Possibilities for reducing methane emission from rice fields of China. *IRRN* 19 (3): 39

- Lindau, C.W. 1994. Methane emissions from Louisiana rice fields amended with N fertilisers. *Soil Biol. Biochem.* **26**: 353-359
- Lindau, C.W., Bollich, P.K., De Laune, R.D., Patrick, W.H. Jr. and Law, V.J. 1991. Effect of urea fertilisers and environmental factors on methane emission from a Louisiana USA rice field. *Pl. Soil* **136**: 195 – 203
- Lindau, C.W., De Laune, R.D., Patrick, W.H., Jr. and Bollisch, P.K. 1990. Fertiliser effects on Dinitrogen, nitrous oxide and methane emission from lowland rice. *Soil Sci. Soc. Am. J.* **54**: 1789-1794
- *Liou, R.M., Lin, C.W. and Huang, S.N. 1999. Effect of organic fertiliser on methane emission of paddy soils in Taiwan. *Chinese J. Agrometeorology* **6**:139-148
- *Lu, W.F., Chen, W., Duan, B.W., Guo, W.M. Lu, Y., Lantin, R.S., Wassman, R. and Neue, H.U. 2000a. Methane emissions and mitigation options in irrigated rice fields in South East China. *Nutr. Cycling Agroecosys.* **58**: 65-73
- Lu, Y.H., Wassmann, R., Neue, H.U. and Huang, C.Y. 2000b. Dynamics of dissolved organic carbon and methane emissions in a flooded rice soil. *Soil Sci. Soc. Am. J.* **64**: 2011-2017
- Malik, K.A. and Haider, K. 1977. Decomposition of ¹⁴C labelled plant material in saline sodic soils. *Proceedings of Symposium on Soil Organic Matter Studies Vol. I.* International Atomic Energy Agency, Vienna, pp. 215 – 225
- Mandal, A.K. and Sen Gupta, M.B. 1981. Transformation of ¹⁴C labelled wheat and berseem plant material in different Indian soils under green house conditions. *J. Nuclear agric. Biol.* **10**: 84-88
- Mariko, S., Harazono, Y., Owa, N. and Nouchi, I. 1991. Methane in flooded soil water and the emission through rice plants to the atmosphere. *Environ. exp. Bot.* **31**: 343-350

- Martens, D.A. 2000. Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. *Soil Biol. Biochem.* **32**: 361 – 369
- Masscheleyn, P.H., DeLaune, R.D. and Patrick, Jr. W.H. 1993. Methane and nitrous oxide emissions from a flooded rice soil : effect of soil oxidation reduction status. *Chemosphere* **26** : 189-200
- Mishra, S., Rath, A.K., Adhya, T.K., Rao, V.R. and Sethunathan, N. 1997. Effect of continuous and alternate water regimes on methane efflux from rice under green house conditions. *Biol. Fertil. Soils* **24**: 399-405
- Mosier, A.R. 1998. Soil processes and global warming. *Biol. Fertil. Soils* **27**: 221-229
- Mustafa, K. 1995. Productivity of semi-dry rice under simultaneous insitu green manuring. MSc (Ag.) thesis submitted to Kerala Agricultural University, Thrissur, Kerala, 147 p.
- Nandi, N., Rahman, F.H., Sinha, N.B. and Hajra, J.N. 2000. Compatibility of lignin – degrading and cellulose – decomposing fungi during decomposition of rice straw. *J. Indian Soc. Soil Sci.* **48**: 387-389
- Neue, H.U. 1997. Fluxes of methane from rice fields and potential for mitigation. *Soil use Mgmt.* **13**: 258-267
- Neue, H.U. and Scharpenseel, H.W. 1984. Gaseous products in the decomposition of organic matter in submerged soils. *Organic matter and rice*. International Rice Research Institute, Los Banos, Philippines, pp. 311 – 328
- Neue, H.U., Becker-Heidmann, P. and Sharpenseel, H.W. 1990. Organic matter dynamics, soil properties and cultural practices in rice lands and their relationship to methane production. *Soils and the Greenhouse Effect* (ed. A.F. Bouwman) John Wiley and Sons, NewYork, pp. 457-466
- Neue, H.U., Wassmann, R., Lantin, R.S., Alberto, M.C. and Aduna, J.B. 1994d. Effect of rice cultivars on methane emission. *IRRN* **19** (3): 32

- Neue, H.U., Wassmann, R., Lantin, R.S., Alberto, M.C. and Aduna, J.B. 1994b.
Diel and seasonal patterns of methane fluxes in rice fields. *IRRN* 19 (3): 33
- Neue, H.U., Wassmann, R., Lantin, R.S., Alberto, M.C. and Aduna, J.B. 1994c.
Effect of fertilisation on methane emission. *IRRN* 19 (3): 33-34
- Neue, H.U., Wassmann, R., Lantin, R.S., Alberto, M.C. and Aduna, J.B. 1994a.
Ebullition of methane. *IRRN* 19 (3): 36
- Neue, H.U., Wassmann, R., Lantin, R.S., Alberto, M.C. and Aduna, J.B. 1994e.
Methane production potential of soils. *IRRN* 19 (3): 37
- Nouchi, I., Hosono, T., Aoki, K. and Minami, K. 1994. Seasonal variation in methane flux from rice paddies associated with methane concentration in soil water, rice biomass and temperature, and its modeling. *Pl. Soil* 161: 195 – 208
- Nouchi, I., Mariko, S. and Aoki, K. 1990. Mechanism of methane transport from the rhizosphere to the atmosphere through rice plants. *Pl. Physiol.* 94: 59 – 66
- Nugroho, S.G., Lumbanraja, J., Suprpto, H., Sunyoto, Ardjasa, W.S., Haraguchi, H. and Kimura, M. 1994. Methane emission from an Indonesian paddy field subjected to several fertiliser treatments. *Soil Sci. Pl. Nutr.* 40: 275-281
- Nugroho, S.G., Lumbanraja, J., Suprpto, H., Sunyoto, Ardjasa, W.S., Haraguchi, H. and Kimura, M. 1996. Three-year measurement of methane emission from an Indonesian paddy field. *Pl. Soil* 181: 287-293
- Panse, V.G. and Sukhatme, P.V. 1978. *Statistical Methods for Agricultural Workers*. Third Edition ICAR, New Delhi, 381 p.

Parashar, D.C., Mitra, A.P., Gupta, P.K., Rai, J., Sharma, R.C., Singh, N., Kaul, S., Lal, G., Chaudhary, A., Ray, H.S., Das, S.N., Parida, K.M., Rao, S.B., Kanungo, S.P., Ramasami, T., Nair, B.U., Swamy, M., Singh, G., Gupta, S.K., Singh, A.R., Saikia, B.K., Barua, A.K.S., Pathak, M.G., Iyer, C.S.P., Gopalakrishnan, M., Sane, P.V., Singh, S.N., Banerjee, R., Sethunathan, N., Adhya, T.K., Rao, V.R., Palit, P., Saha, A.K., Pukait, N.N., Chaturvedi, G.S., Sen, S.P., Sen, M., Sarkar, B., Banik, A., Subbaraya, B.H., Lal, S., Venkataramani, S. and Sinha, S.K. 1994. Methane budget from paddy fields in India. *Curr. Sci.* 66: 938-940

*Parashar, D.C., Rai, J., Gupta, P.K. and Singh, N. 1991. Parameters affecting methane emission from paddy fields. *Indian J. Radio Space Physics.* 20: 12-17

Patel, G.G. and Roth, I.A. 1979. Effect of sodium chloride in growth and methane production of methanogens. *Can. J. Microbiol.* 6: 893

Patrick, W.H. Jr. and Reddy, C.N. 1978. Chemical changes in rice soils. *Soils and Rice*. International Rice Research Institute, Los Banos, Philippines, pp. 361-376

Pierre, W.M. and Banwart, W.L. 1973. Excess base and excess base/nitrogen ratios of various crop species and plant parts. *Agron. J.* 65: 91-96

Piper, C.S. 1942. *Soil and Plant Analysis*. Asian Reprint 1966. Hans Publishers, Bombay, 368 p.

Prasad, B. and Sinha, S.K. 1996. Kinetics of carbon mineralisation in calcareous soil amended with crop residues and organic manures. *J. Indian Soc. Soil Sci.* 44: 772-774

Raina, J.N. and Goswami, K.P. 1988. Effect of added ^{14}C labelled organic material on the decomposition of soil organic matter. *J. Indian Soc. Soil Sci.* 36: 646-651

- Reid, J.B., Goss, M.J. 1982. Suppression of decomposition of ^{14}C labelled plant roots in the presence of living roots of maize and perennial rye grass. *J. Soil Sci.* 33: 387-395
- Reinertsen, S.A., Elliot, L.F., Cochran, V.L. and Campbell, G.S. 1984. Role of available carbon and nitrogen in determining the rate of straw decomposition. *Soil Biol. Biochem.* 16: 459-464
- Roy, S.N. and Prasad, K. 1991. Climate change and global scientific response. *Vayu Mandal* 69-82
- *Saini, R.C., Gupta, S.R. and Rajvanshi, R. 1984. Chemical composition and decomposition of crop residues in soil. *Pedo biologia* 27 (5): 323-329
- Sallih, Z. and Bottner, 1988. Effect of wheat (*Triticum aestivum*) roots on mineralisation rates of soil organic matter. *Biol. Fertil. Soils* 7: 67-70
- Sarmah, A.C. and Bordoloi, P.K. 1994. Decomposition of organic matter in soils in relation to mineralisation of carbon and nutrient availability. *J. Indian Soc. Soil Sci.* 42: 199 – 203
- *Sass, R.L. 1994. Short summary chapter for methane. *CH₄ and N₂O : Global emissions and controls from Rice Fields and other Agricultural and Industrial Sources* (eds. Minami, K., Mosier, A and Sass, R.L.). NIAES series 2, Yokendo Publishers, Japan, pp. 1-7
- *Sass, R.L., Fisher, F.M., Harcombe, P.A. and Turner, F.T. 1990. Methane production and emission in a texas rice field. *Global Biogeochem. Cycles* 4: 47-68
- *Sass, R.L., Fisher, F.M., Harcombe, P.A. and Turner, F.T. 1991. Methane emission from rice fields as influenced by solar radiation, temperature and straw incorporation. *Global Biogeochem. Cycles* 5: 335 – 350
- Satpathy, N., Mishra, S., Adhya, T.K., Ramakrishnan, B., Rao, V.R. and Sethunathan, N. 1998. Cultivar variation in methane efflux from tropical rice. *Pl. Soil* 202: 223-229

- Satpathy, S.N., Rath, A.K., Ramakrishnan, B., Rao, V.R., Adhya, T.K. and Sethunathan, N. 1997. Diurnal variation in methane efflux at different growth stages of tropical rice. *Pl. Soil* **195**: 267-271
- Sauerbeck, D. 1968. Comparison of plant material and animal manure in relation to their decomposition in soil. *Proceedings of Symposium on the Use of Isotopes and Radiation in Soil Organic Matter Studies*, International Atomic Energy Agency, Vienna, pp. 219 – 225
- Sauerbeck, D.R. and Gonzales, M.A. 1977. Field decomposition of ^{14}C labelled plant residues in various soils of the Federal Republic of Germany and Costa Rica. *Proceedings of the Symposium on Soil Organic Matter Studies Vol. 1*. International Atomic Energy Agency, Vienna, pp. 159-170
- Segers, R. and Kengen, S.W.M. 1998. Methane production as a function of anaerobic carbon mineralisation, a process model. *Soil Biol. Biochem.* **30**: 1107-1117
- *Seiler, W., Holzapfel – Pschorn, A., Conrad, R. and Scharffe, D. 1984. Methane emission from rice paddies. *J. Atmos. Chem.* **1**: 241–268
- Senapati, H.K. and Behera, B. 2000. Effect of moisture on evolution of carbon dioxide and microbial activity in soil amended with organic substrates. *J. Indian Soc. Soil Sci.* **48**:384-386
- Shields, J.A. and Paul, E.A. 1973. Decomposition of ^{14}C labelled plant material under field conditions. *Can. J. Soil Sci.* **53**: 297-306
- *Shin, Y.K. and Yun, S.H. 2000. Varietal difference in methane emission from Korean rice cultivars. *Nutr. Cycling Agroecosys.* **58**: 315-319
- *Shutz, H., Holzapfel-Pschorn, A., Conrad, R., Rennenberg, H. and Seiler, W. 1989. A three year continuous record on the influence of day time season and fertiliser treatment on methane emission from an Italian rice paddy field. *J. Geophys. Res.* **94**: 16405-16416

- *Sims, J.T. and Johnson, G.V. 1991. Micronutrient soil tests. *Micronutrient in Agriculture*. Second Edition. (ed. Mortvedt, J.J., Cox, F.R., Shuman, L.M. and Welch, R.M). Soil Science Society of America, Madison, USA, pp. 427-472
- Singh, J.S., Singh, S., Raghubanshi, A.S., Singh, S. and Kashyap, A.K. 1996. Methane flux from rice/wheat agroecosystem as affected by crop phenology, fertilization and water level. *Pl. Soil* 183: 323-327
- Singh, P. 1991. What drives Global climate and Ecosystem-An overview. *Impact of Global Climatic Changes on Photosynthesis and Plant Productivity*. (eds. Abrol, Y.P., Wattal, P.N., Gnanam, A., Govindjee, Ort, D.R. and Teramura, A.H.). Proceedings of the Indo-US workshop New Delhi, India. Oxford and IBH Publishing Co. Private Ltd., New Delhi, pp. 699-703
- Singh, S., Kashyap, A.K. and Singh, J.S. 1998. Methane flux in relation to growth and phenology of a high yielding rice variety as affected by fertilisation. *Pl. Soil* 201: 157-164
- Singh, S., Kumar, S. and Jain, M.C. 1997. Methane emission from two Indian soils planted with different rice cultivars. *Biol. Fertil. Soils* 25: 285-289
- Singh, Y., Singh, B. and Khind, C.S. 1992. Nutrient transformations in soils amended with green manures. *Adv. Soil Sci. Vol. 20* (ed. Steward, D.A.). Springer – Verlag, New York, pp. 237-309
- Sinha, M.K., Sinha, D.P. and Sinha, H. 1977. Organic matter transformations in soils: V. Kinetics of carbon and nitrogen mineralisation in soils amended with different organic materials. *Pl. Soil* 46: 579-590
- Sinha, S.K. 1995. Global methane emission from rice paddies - excellent methodology but poor extrapolation. *Curr. Sci.* 68: 643-646

- Sorensen, L.H. 1975. The influence of clay on the rate of decay of amino acid metabolites synthesized in soils during decomposition of cellulose. *Soil Biol. Biochem.* 7: 171 – 177
- Sparling, G.S., Chechire, M. and Mundie, C.M. 1982. Effect of barley plants on the decomposition of ^{14}C labelled soil organic matter. *J. Soil Sci.* 33: 89-100
- *Tragore, I., Shen, D.S., Min, H., Chen, M.C. and Feng, X.S. 1999. Effect of different fertilisers on methane emission from a paddy field of Zhejiang, China. *J. Environ. Sci.* 11: 457-461
- Trolldenier, G. 1995. Methanogenesis during rice growth as related to the water regime between crop season. *Biol. Fertil. Soils* 19: 84-86
- van Veen, J.A., Ladd, J.N. and Amato, M. 1985. Turnover of carbon and nitrogen through the microbial biomass in a sandy loam and a clayey soil incubated with ^{14}C (u) glucose and ^{15}N $(\text{NH}_4)_2 \text{SO}_4$ under different moisture regimes. *Soil Biol Biochem.* 17: 747-756
- Vanlauwe, B., Nwoke, O.C., Sanginga, N. and Merckx, R. 1996. Impact of residue quality on the C and N mineralisation of leaf and root residues of three agroforestry species. *Pl. Soil* 183: 221-231
- Wang, B., Neue, H.U. and Samonte, H.P. 1997. Role of rice in mediating methane emission. *Pl. Soil* 189: 107 – 115
- *Wang, M.X., Dai, A., Shangguan, X., Ren, L., Shen, R., Schutz, H., Seiler, W., Rasmussen, R.A. and Khalil, M.A.K. 1994. Sources of methane in China. *CH₄ and N₂O : Global Emissions and Controls from Rice Fields and other Agricultural and Industrial Sources* (eds. Minami, K., Mosier, A. and Sass, R.L.). NIAES series 2, Yokendo Publishers, Japan, pp. 9-26
- Wang, Z.P., De Laune, R.D., Masscheleyn, P.H. and Patrick, Jr., W.H. 1993. Soil redox and pH effects on methane production in a flooded rice soil. *Soil Sci. Soc. Am. J.* 57: 382-385

- Wang, Z.P., Lindau, C.W., Delaune, R.D. and Patrick Jr. W.H. 1992. Methane production from anaerobic soil amended with rice straw and nitrogen fertilisers. *Fertil. Res.* **33**: 115-121
- Wassman, R., Neue, H., Bueno, C., Lantin, R.S., Alberto, M.C.R. Buendia, L.V., Bronson, K., Papen, H. and Rennenberg, H. 1998. Methane production capacities of different rice soils derived from inherent exogenous substrates. *Pl. Soil* **203**: 227-237
- *Wassmann, R., Neue, H.U., Alberts, M.C.R., Lantin, R.S., Bueno, C., Llenaresas, D., Arah, J.R.M., Papen, H., Seiler, W. and Rennenberg, H. 1996. Fluxes and pools of methane in wetland rice soils with varying organic inputs. *Environ. Monitor. Assess.* **42**: 163 – 173
- Watanabe, A., Katoh, K. and Kimura, M. 1994. Effect of rice straw application on CH₄ emission from paddy fields. *Soil Sci. Pl. Nutr.* **40** (3):497-504
- Watanabe, F.S. and Olsen, S.R. 1965. Test on ascorbic acid method for determining phosphorus in water and sodium bicarbonate extracts from soil. *Proc. Soil Sci. Soc. Am.* **29**: 677-678
- *Xu, H., Cai, Z.C., Li, X.P. and Tsuruta, H. 2000. Effect of antecedent soil water regime and rice straw application time on methane emission from rice cultivation. *Aust. J. Soil Res.* **38**: 1-12
- Yadav, K., Jha, K.K., Prasad, C.R. and Sinha, M.K. 1989. Kinetics of carbon mineralisation from poultry manure and sewage sludge in two soils at field capacity and submergence moisture. *J. Indian Soc. Soil Sci.* **37**: 240-243
- Yagi, K. and Minami, K. 1990. Effect of organic matter application on methane emission from some Japanese paddy fields. *Soil Sci. Pl. Nutr.* **36** (4): 599-610

- *Yang, S. and Chang, H. 1999. Diurnal variation of methane emission from paddy fields at different growth stages of rice cultivation in Taiwan. *Agric. Ecosys. Environ.* 76: 75-84
- *Yao, H., Yagi, K. and Nouchi, I. 2000. Importance of physical plant properties on methane transport through several rice cultivars. *Pl. Soil* 222: 83-93

* Originals not seen

172024

APPENDICES

Appendix – 1
Abstract of weather parameters during 1998 – 1999 (June to February)

Std. week	Period	Max. temp.	Min. temp.	Humidity		Wind speed (km hr ⁻¹)	Sunshine (hr day ⁻¹)	Total RF (mm)	Total Evaporation (mm)
				1	2				
23	4/6 – 10/6	32.0	23.9	92	71	3.1	6.4	65.7	26.4
24	11/6 - 17/6	30.0	23.1	94	81	2.0	2.2	118.0	21.8
25	18/6 – 24/6	29.0	22.4	96	79	2.5	3.0	257.3	15.9
26	25/6 – 1/7	27.8	23.2	95	89	3.4	0.3	368.7	14.5
27	2/7 – 8/7	29.0	23.3	96	81	2.6	2.5	250.6	16.7
28	9/7 – 15/7	29.2	24.0	95	81	2.2	2.4	140.1	18.2
29	16/7 – 22/7	29.2	23.7	96	77	2.4	4.9	166.2	20.2
30	23/7 – 29/7	29.2	23.4	96	84	2.8	3.0	151.6	17.0
31	30/7 – 5/8	30.3	24.4	97	76	3.1	4.6	80.0	22.6
32	6/8 – 12/8	29.2	23.8	95	80	2.5	2.1	80.9	19.6
33	13/8 – 19/8	30.5	24.5	94	73	2.2	4.6	12.7	21.4
34	20/8 – 26/8	28.5	23.5	95	84	2.9	2.5	274.7	14.9
35	27/8 – 2/9	30.2	23.6	94	72	2.4	5.4	129.9	23.8
36	3/9 – 9/9	30.7	23.7	96	82	1.8	3.8	184.4	18.9
37	19/9 – 16/9	28.4	22.9	95	80	2.2	3.2	169.4	20.1
38	17/9 – 23/9	30.2	23.3	95	72	2.2	6.8	29.9	23.5
39	24/9 – 30/9	28.6	23.1	95	77	1.6	2.4	63.0	16.5
40	1/10 – 7/10	29.3	23.1	93	79	1.5	3.8	51.8	19.6
41	8/10 – 14/10	27.8	23.0	95	91	2.7	1.5	319.4	13.1
42	15/10 – 21/10	29.8	22.6	94	73	1.8	4.8	70.2	21.7
43	22/10 – 28/10	31.1	22.5	92	66	2.0	8.2	10.8	24.3
44	20/10 – 4/11	31.1	23.2	94	68	1.6	5.5	6.9	19.5
45	5/11 – 11/11	30.8	23.6	93	70	1.8	4.1	86.0	18.1
46	12/11 – 18/11	31.9	22.8	94	63	1.9	8.9	16.9	24.5
47	19/11 – 25/11	31.7	22.8	93	58	1.3	9.0	-	22.1
48	26/11 – 2/12	32.2	23.0	88	58	1.7	7.9	4.8	23.3
49	3/12 – 9/12	31.3	23.8	78	60	6.0	6.1	1.4	31.6
50	10/12 – 16/12	29.7	23.4	82	71	7.1	3.3	27.0	20.0
51	17/12 – 23/12	31.4	22.4	79	57	4.3	8.6	-	29.3
52	24/12 – 31/12	31.1	22.0	76	40	6.7	8.2	-	40.8
1	1/1 – 7/1	31.9	21.8	75	45	7.4	9.4	-	39.5
2	8/1 – 14/1	32.5	21.9	79	43	5.1	9.5	-	34.8
3	15/1 – 21/1	32.2	22.8	70	40	9.8	10.0	-	48.2
4	22/1 – 28/1	32.5	19.5	74	32	5.5	7.9	-	41.2
5	29/1 – 4/2	33.9	22.1	83	39	3.6	10.1	-	31.5
6	5/2 – 11/2	34.0	23.4	80	44	4.3	9.2	-	35.8
7	12/2 – 18/2	34.7	23.2	79	39	5.3	10.0	-	43.9
8	19/2 – 25/2	34.2	24.5	70	33	7.9	6.9	-	53.0
9	26/2 – 4/3	36.4	22.2	74	33	5.0	10.4	-	53.4

Appendix – II
Abstract of weather parameters during 1999 – 2000 (June to February)

Std. week	Period	Max. temp.	Min. temp.	Humidity		Wind speed (km hr ⁻¹)	Sunshine (hr day ⁻¹)	Total RF (mm)	Total Evaporation (mm)
				1	2				
23	4/6 – 10/6	29.1	22.8	94	81	3.0	4.8	135.4	22.7
24	11/6 – 17/6	28.4	22.7	95	81	2.6	1.8	170.9	17.3
25	18/6 – 24/6	29.6	23.2	95	76	2.8	5.1	114.8	20.6
26	25/6 – 1/7	30.9	23.0	92	67	2.1	8.9	21.6	26.4
27	2/7 – 8/7	29.6	23.1	95	80	2.5	3.7	114.7	20.5
28	9/7 – 15/7	29.0	22.9	96	76	2.6	3.1	124.6	18.0
29	16/7 – 22/7	26.9	22.8	97	92	2.3	0.5	326.5	12.6
30	23/7 – 29/7	27.7	22.7	95	83	2.4	1.1	182.8	13.0
31	30/7 – 5/8	28.7	23.3	95	84	2.5	2.7	194.1	17.1
32	6/8 – 12/8	29.5	23.7	95	74	2.8	5.2	121.5	20.8
33	13/8 – 19/8	30.6	24.1	93	69	2.4	7.5	8.9	24.7
34	20/8 – 26/8	30.0	23.6	93	69	2.3	6.9	3.2	25.1
35	27/8 – 2/9	30.0	23.6	93	71	2.1	5.3	7.1	20.0
36	3/9 – 9/9	30.0	23.2	93	67	1.9	4.9	18.3	18.7
37	19/9 – 16/9	31.0	23.0	92	65	2.2	8.1	10.1	27.6
38	17/9 – 23/9	32.6	23.4	90	56	2.3	8.5	-	31.0
39	24/9 – 30/9	32.9	23.8	90	60	2.1	6.4	-	28.2
40	1/10 – 7/10	30.5	23.1	93	71	1.4	4.8	80.5	19.7
41	8/10 – 14/10	31.5	23.6	95	75	1.9	6.8	185.7	23.6
42	15/10 – 21/10	29.5	23.3	95	80	1.9	2.9	161.6	16.6
43	22/10 – 28/10	31.3	23.5	93	74	1.4	5.5	38.8	19.4
44	20/10 – 4/11	29.6	22.7	96	73	1.4	6.2	41.9	20.0
45	5/11 – 11/11	31.4	22.1	87	62	1.4	7.8	2.8	22.3
46	12/11 – 18/11	31.9	22.1	74	46	3.3	10.1	-	26.5
47	19/11 – 25/11	31.1	23.5	79	62	5.4	6.3	4.0	29.2
48	26/11 – 2/12	31.9	23.7	76	55	6.8	8.7	-	36.2
49	3/12 – 9/12	31.8	21.6	79	49	4.7	9.4	-	34.4
50	10/12 – 16/12	31.8	22.6	72	47	7.8	8.7	-	44.9
51	17/12 – 23/12	31.4	22.6	72	47	7.8	8.7	-	44.9
52	24/12 – 31/12	31.4	23.4	68	43	8.8	8.8	-	56.3
1	1/1 – 7/1	32.2	23.8	71	45	8.5	9.6	-	48.5
2	8/1 – 14/1	31.9	24.3	73	50.7	8.7	7.6	-	45.2
3	15/1 – 21/1	33.5	22.4	78	37	5.1	9.5	-	43.6
4	22/1 – 28/1	33.8	22.1	82	39	5.3	9.9	-	41.5
5	29/1 – 4/2	33.7	19.9	74	41	7.3	10.1	-	49.7
6	5/2 – 11/2	33.2	22.2	92	57	2.9	7.2	-	31.8
7	12/2 – 18/2	34.2	23.0	80	44	4.1	9.3	-	42.0
8	19/2 – 25/2	33.2	22.6	90	59	2.5	8.7	-	33.0
9	26/2 – 4/3	33.9	23.8	81	47	4.5	8.0	4.6	44.1

ABSTRACT

The studies on 'Methane emission from wetland rice fields of Kerala' revealed that the methane efflux from the Lateritic soils of Kerala was generally low, to the tune of $1.64 \text{ mg m}^{-2} \text{ hr}^{-1}$ during the first crop season (June to September) and $3.5 \text{ mg m}^{-2} \text{ hr}^{-1}$ during the second crop season (October to January). Temporal including diurnal and seasonal as well as spatial variations were detected in methane emission from the rice fields. The methane emission during the second crop season was relatively higher and the emission pattern revealed evening peaks. The methane efflux showed progressive increase from the tillering stage to the booting stage in both crop seasons. The factors such as soil temperature, water temperature, redox potential and solar radiation did not show any individual influence on the methane emission.

The application of organic manures such as rice straw, glyricidia and farm yard manure @ 5 t ha^{-1} produced significant and positive influence on methane emission probably due to the enhanced availability of carbon substrate for methane production. In this respect, rice straw and glyricidia showed a better influence compared to farm yard manure.

The positive influence of nitrogen has been detected in the present study, with the two sources of nitrogen fertiliser, namely, urea and factomphos, showing variations in their influence on methane efflux. Application of urea contributed to a significantly higher methane emission than factomphos during the second crop season.

Incorporation of organic manures and application of nitrogen positively and significantly influenced the grain yield and straw yield of rice during the second crop season. A higher grain yield was observed during the first crop season compared to second crop season. The ancillary data on biometric and yield contributing characters also indicated variable influence of the sources of organic manure and nitrogen fertilisers during the two crop seasons.

In a pot culture experiment in Lateritic soil using ^{14}C labelled rice straw, daincha, sunhemp and glyricidia, it was observed that the decomposition of added

residues started immediately after their incorporation. The process of decomposition consisted of an initial rapid declining phase followed by a slow and steady phase. The presence of rice crop was not found to influence the pattern of decomposition.

The green manures exhibited a higher decomposition rate than rice straw due to their low C : N ratio and low lignin content. The highest rate of decay among the green manures was exhibited by glyricidia, followed by daincha and sunhemp. While 60 per cent of the added organic carbon from sunhemp was retained in the soil in the first five days after incorporation, 50 per cent was retained from daincha and only 40 per cent was retained from glyricidia. In the mean while, about 85 per cent of the added organic carbon from rice straw was retained in the soil in the first five days.

The incubation study on the decomposition pattern of rice straw and daincha in different rice soils of Kerala employing radio tracer technique revealed that the decomposition rate of daincha was faster than rice straw in all the soil types. Averaged over the seven soils, 60 per cent of the added organic carbon was lost from daincha within the first two days, while it was only 15 per cent in the case of rice straw.

In general the Kari soil retained the highest amount of organic carbon (34 per cent) added through rice straw followed by the Kole soil (31 per cent) and the lowest amount was retained by the Karappadam soil (14 per cent). The other soils namely Lateritic, Onattukara, Pokkali and Chittoor black exhibited intermediate retention of organic carbon ranging from 20 to 28 per cent. The half life of labelled rice straw estimated for different soils ranged from 64 days to 80 days.

The highest amount of the added organic carbon from daincha was retained in the Pokkali soil (15 per cent) followed by the Lateritic soil (14 per cent), the Onattukkara soil (12 per cent) and the Kari soil (11 per cent). The lowest amount was retained in the Kole soil (4 per cent) while the Karappadam and Chittoor black soil retained 9 per cent and 7 per cent respectively.