Dynamics of Carbon Fixation and Sequestration in a Tropical Paddy Wetland, Kerala

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Under the Faculty of

Environmental Studies

By

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Certificate

This is to certify that the thesis entitled **"Dynamics of Carbon Fixation and Sequestration in a Tropical Paddy Wetland, Kerala"** is an authentic record of research work carried out by Mr. Akhilesh Vijay (Reg. No. 3906) under my scientific supervision and guidance in the in the Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfilment of the requirements for the Degree of Doctor of Philosophy under the faculty of Environmental Studies and that no part of this has been presented before for the award of any other degree, diploma or associateship in any university.

It is also certified that all the relevant corrections and modifications suggested by the audience during the pre-synopsis seminar and recommented by the doctoral committee has been incorporated in the thesis.

Kochi-16 **Dr. S. Bijoy Nandan**

January 2018 (Supervising Guide)

Declaration

I hereby declare that the thesis entitled **"Dynamics of Carbon Fixation and Sequestration in a Tropical Paddy Wetland, Kerala"** submitted by me is an authentic record of research work carried out by me under the supervision and guidance of Prof. (Dr.) S. Bijoy Nandan, Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology, in partial fulfilment of the requirement for the Degree of Doctor of Philosophy under the faculty of Environmental Studies and that no part thereof has been presented for the award of any other degree in any University.

Kochi-16 **Akhilesh Vijay**

January 2018

This thesis is a devotion to the almighty,

a tribute to my guide and dedication to my family

and friends…

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Akhilesh Vijay

CONTENTS

Chapter 1

GENERAL INTRODUCTION

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1.1 INTRODUCTION

Evidence from ancient civilization reveals that the earliest human civilization flourished along the banks of major rivers (Pohl, 1996), which supported nearly 70% of their population (Keddy and Fraser 2000). For ages, these watery lands have been coined to represent all the water-related land-use or land cover features, including lakes, ponds, reservoirs, estuaries, canals, and rivers. With the advent of modern civilization and detrimental human activities had made it a mear waterlogged lands, harbouring disease, hazardous and are also the source of immense human suffering (Dugan, 1993; Keddy P and Fraser 2000) which paved the way to its gradual disappearance. However, since the early 1980s, another term related to water bodies gained popularity, known as "wetland."(Anderson 2012). On recognizing the ecological functions wetland performs has resulted in redesigning some of the wetland as "Wetlands of International Importance" based on the international treaty for wetland conservation adopted during 1971 in Ramsar, Iran.

The Ramsar Convention (1971), defined wetlands in Article 1 as, "Areas of marsh, fen, and peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salty, including areas of marine water, the depth of which at low tide does not exceed six meters". Moreover, the Article 2 broadened the area of coverage of wetlands by incorporating "riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands" (Ramsar convention Secretariat 2013).

1.2 DISTRIBUTION OF WETLANDS

The anthropogenic unsustainable developmental activities had led to declining in wetland area and diversity. Therefore, it is essential to understand the historical and current abundance, distribution and diversity of wetlands existing on our planet. Wetlands exist in all the continents of the world except in Antarctica. In the early 1980s, Maltby and Turner (1983) estimated that 8.6 million km^2 (more than 6.4% of the land surface of the world) were a wetland. Later, Finlayson and Davidson (1999) included nearshore marine areas as one of the categories of wetlands as per the Ramsar Convention definition and estimated that the global extent of wetlands is 12.8 million km^2. However, based on several other previous studies, Mitsch and Gosselink (2007) estimated the extent of the world's wetlands as 7–10 million km^2. Global distributions of major wetland areas are shown in Fig. 1.1. According to Ramsar Convention's "Classification System for Wetland Types" have three main categories of wetlands, viz. "marine/coastal wetlands," "inland wetlands" and "human-made wetlands." Under these categories, a total of 42 wetland types were identified.

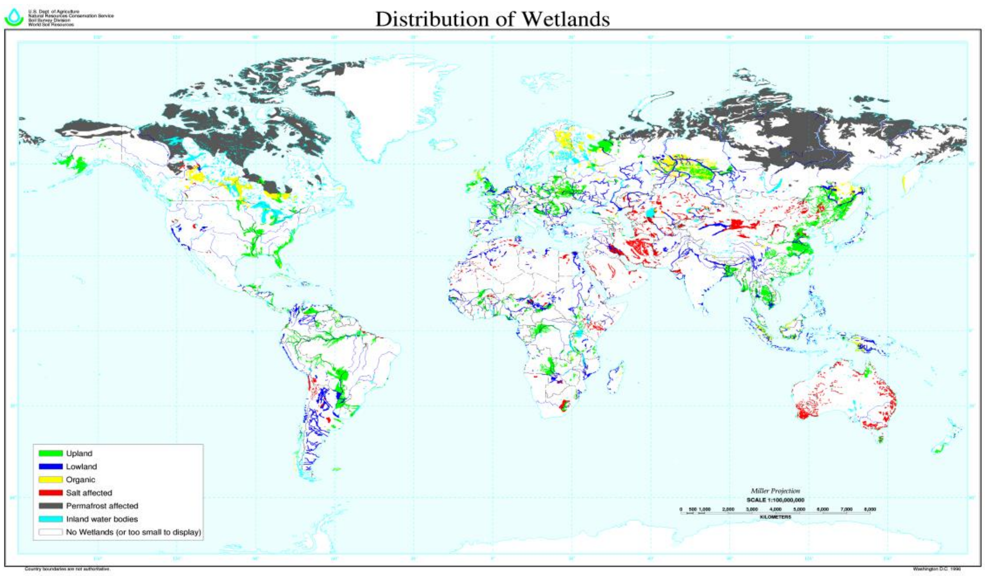

Figure 1.1 Distribution of major wetland area in the world (adapted from US Dept. of Agriculture 1999)

1.3 WETLANDS IN INDIA

Space Applications Centre (2011) has estimated total wetland area of India as 152,606 km^2, which accounts for 4.64% of the country's geographical area. The classification of Indian wetland by (MoEF 2007) is given in table 1.1

Table 1.1 Classification of wetland types of India according to MOEF (2009)

Wetland Classes	Wetland types
Inland Wetland	Freshwater lakes
	Freshwater Swamps
	Reservoirs
	Large Ponds
Coastal Wetlands	Estuaries / Backwaters
	Mangrove Forests
	Paddy wetland systems
	Coastal Swamps
	Mudflat
	Aquaculture pond
	Islets

1.4 WETLANDS IN KERALA

Wetlands in Kerala are distributed all along the coast and in the islands, and the total wetland area estimated is about 1,60,599 ha. The major wetland types are river/ stream (65,162 ha), lagoons (38,442 ha) reservoirs (26,167 ha) and waterlogged areas (20,305 ha) (SAC 2011). Geomorphologically the wetlands in Kerala could be classified into five major systems viz marine, estuarine, riverine, lacustrine and palustrine. The international convention of wetlands designated three wetland ecosystems in Kerala as Ramsar site on 19th August 2002, for the conservation of biological diversity and for sustaining human life through the ecological and hydrological functions they perform. They are the Vembanad- Kole, Asthamudi, and Sasthamkota wetlands.

Kole wetland is the part of Vembanad – Kole wetlands are the most extensive brackish humid and tropical wetland system in the southwestern coastal state of Kerala. Kole- paddy wetlands are tracts lying 0.5 to 1.5 meters below the mean sea level, spreading over Thrissur and Malappuram districts of Kerala. Kol wetlands are among the water-logged paddy cultivating area in Kerala such as Kuttanad (Alappuzha, Kottayam, and Pathanamthitta), pokkali (Alappuzha, Ernakulam, and Thrissur) and Kaipad (Kozhikode and Kannur) (Jayan and Sathyanathan 2010). Kole wetlands were under rice cultivation for the past 200 years. The cycling nutrient recharges of the wetland during the flooding season making the area one of the most fertile soils of Kerala.

1.5 SIGNIFICANCE AND FUNCTIONS OF WETLANDS

Wetlands are prominent ecosystems lying at the interphase between terrestrial and aquatic ecosystems. As the influence of water dominates wetland ecosystems; they possess characteristics of both terrestrial and aquatic ecosystems which are unique properties of their own. As wetlands are highly productive, they are ranked among the third most productive ecosystems in the world. Wetland also supports a wide array of flora and fauna and deliver many ecological, climatic and societal functions. Higher rates of primary production and lower decomposition provide large storage of carbon and any changes that could affect the storage by drying could result in the massive positive feedback of even more emission of carbon dioxide to the atmosphere (Keddy and Fraser 2000). They are valuable sources, sinks and transforms of a multitude of chemicals, biological and genetic materials and are considered the kidneys of the earth for cleaning function they perform through biogeochemical cycles. The principal functions which wetlands perform are water storage and groundwater recharge, flood control, shoreline stabilization, water quality control, moderating climate and community structure, biodiversity and wildlife support. Wetlands are immensely valuable in various aspects, viz. recreational and aesthetic value, supply and quality, biodiversity value.

1.6 PRODUCTIVITY OF WETLANDS

Wetlands are among the most productive types of ecosystems (Leith and Whittaker, 1975), and thus can serve as a significant C sink. Primary productivity is an indicator of the ability of a plant to convert inorganic C in the atmosphere (CO_2) into part of the plant structure through photosynthesis. Thus NPP can be used as a proxy for C storage. According to Leith and Whittaker (1975), swamps and wetlands are the second most productive type of ecosystem, with algal beds and reefs as the most productive type of ecosystem. High productivity means high C storage, adding to the importance of wetlands for ecological services, as well as ecosystems that maintain high biodiversity. Many natural and cultivated tropical wetlands have an NPP of more than 1000 g C m^{-2} y^{-1} which is higher than that of any other ecosystem type. Schlesinger (1991) reported a global mean NPP of 1,125 g C m^{-2} y^{-1} for swamps and marshes and 900 g C $m^{-2}y^{-1}$ for tropical rain forests. Aselmann and Crutzen (1990) reported a range of 1600-3220 for swamps, 1350 for rice, 1170-1990 for floodplains, 620-1400 for bogs, 430-970 for fens, 290-740 for marshes and 50-100 g C m^{-2} y^{-1} for lakes.

The balance between accumulation, mainly NPP but also allochthonous deposits, and redox and pH-controlled decomposition determines if a tropical wetland acts as a sink or source of carbon. The significant spatial and temporal variability of the controlling factors and the limited geographic information of these factors currently do not allow reliable estimates of the global carbon balance of tropical wetlands.

1.7 CARBON DYNAMICS IN WETLANDS

Wetlands are significant carbon sinks attributed to low decomposition rates in anaerobic soils. It stores approximately 25000 Pg of the earth's carbon pool (Lal 2008; Bridgham et al. 2006). It comprises of five main carbon reservoirs namely (a) plant biomass carbon, (b) particulate organic carbon (POC), (c) dissolved organic carbon (DOC), (d) microbial biomass carbon (MBC), and (e) gaseous ends products such as CO_2 and CH_4.

Active biomass comprises wetland vegetation, which transforms the inorganic carbon such as CO_2 to organic carbon through photosynthesis. Particulate organic carbon (POC) consists of decaying plant materials, microbial exudates, and particulate organic substances found on the soil surface. Dissolved organic carbon (DOC) comprises dissolved biochemical oxygen demand and other carbon components in the water phase. Microbial biomass carbon occurs in heterotrophic micro-floral catabolic activities, transforming organic carbon back to inorganic carbon, and mineralizing particulate organic carbon and dissolved organic carbon (D'Angelo and Reddy 1999; Picek et al. 2007).

Carbon storage in the wetland is the balance between carbon input (organic matter production) and release (decomposition, respiration, and methanogenesis.). The resulting storage of carbon depends on several factors such as land use change, soil conditions, topography, geological position, the hydrological regime, the type of plant present, the temperature, moisture, pH and the redox conditions of the soil (Chabbi et al. 2009). Organic matter is entering the submerged wetlands as plant remnants; wetland biomass typically contains 45% to 50% of carbon, which undergoes complex processes of aerobic and anaerobic decomposition. The fundamental processes undergoing during this processes are respiration in the aerobic zone, fermentation, methanogenesis, sulfate, iron, and nitrate reduction in the anaerobic zone. The combination of the elevated water table, high productivity and slower or incomplete decomposition of organic matter under anaerobic conditions in wetlands allows significant storage of carbon in the soil from the atmosphere acting as a sink of carbon.

Even though wetlands are globally a significant sink for carbon, releases of CO_2 may exceed photosynthesis in some circumstances making it into a source. Wetlands are identified as ecosystems significantly contributing to emissions of major greenhouse gases (GHGs)- carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Smith et al. 2007). GHG emissions from wetland soils are complex heterogeneous processes in which CO_2 is released from soil autotrophic and heterotrophic respiration (Janzen 2004). CH_4 by methanogenesis under flooded, anoxic, low redox conditions by obligate anaerobes (Singh et al. 2000) and N_2O driven by microbial transformation of nitrogen compounds through nitrification and denitrification process (Li et al. 2013).

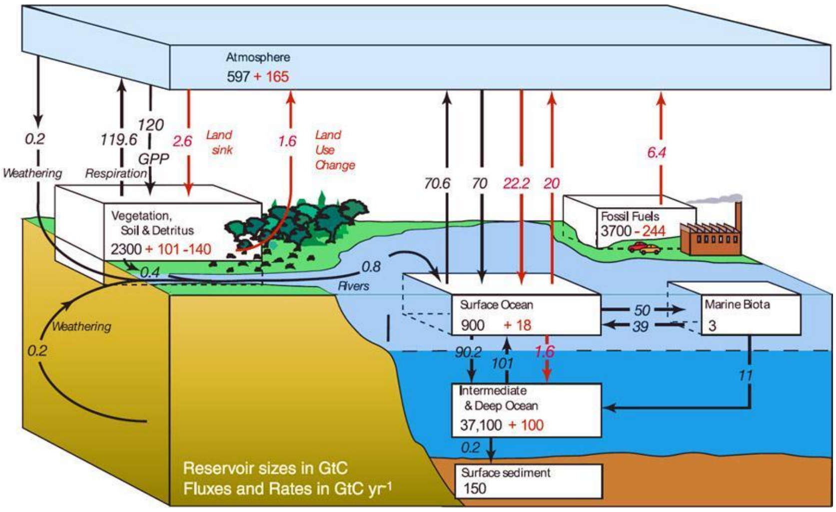

Figure 1.2 Cycling of carbon between earth systems
(adopted from IPCC AR4 WG1 1990)

Seasonal shift in soil aerobic and anaerobic pathways in line with changes in environmental and soil management factors determine the behavior of GHGs as a source or sink in the ecosystem (Janseens et al. 2003). Furthermore, production, emission and spatial-temporal distribution of CO_2, CH_4 and N_2O in tropical wetlands vary significantly with seasonal changes in micrometeorological conditions such as soil temperature, soil water content, alternate wetting, and drying. These factors affect the substrate precursors and microbial activity, mineralization of C and N, vegetation cover and soil management (García-Marco et al. 2014; Mitra et al. 1999). Globally wetlands emit 20–25 % of current global methane emissions, or about 115–227 Tg-CH_4 year^{-1} (Whalen 2005; Bergamaschi et al. 2007; Bloom et al. 2010) disturbing the radiative balance of the earth's atmosphere. In particular, the decomposition and turnover of soil organic matter (SOM) is recognized as an essential determinant of carbon-driven climate change as the regulatory effect of temperature on decomposition is crucial to the stability of organic matter stocks (Knorr et al. 2005; Fang et al., 2005).

1.8 CARBON SEQUESTRATION POTENTIAL OF WETLANDS

Globally wetlands stores nearly 44.6 Tg Cy^{-1} (Patil et al. 2012) with an average carbon sequestration rate of 20 to 30 g C $m^{-2}yr^{-1}$ (Roulet 1993) in which tropical, temperate and boreal wetlands sequester about 0.56 Pg Cyr^{-1}, 0.16 Pg Cyr^{-1}, and 0.11 Pg Cyr^{-1} respectively. On accounting the sequestration potential, it varies widely among wetlands and climatic regime as sequestration is a function of both biomass production and respiration. Coastal wetlands comprise more than 226,000 km^2 of mangroves, and salt marshes (Patra et al. 2013) that have a potential to sequester 4.77 g C $m^{-2}yr^{-1}$ (Chmura et al. 2003). Along with mangroves tidal wetlands of San Francisco Bay that sequester nearly 79 g C $m^{-2}yr^{-1}$ (Callaway et al. 2012). It has also been estimated that the northern and tropical peat based wetland systems constitute a carbon store of up to 510 Gt C which equates to approximately 30% of the total global organic soil carbon stock (Saunders et al. 2014). By carbon density carbon storage of temperate and tropical peatlands was estimated as 256 Gt C and 19.3 Gt C respectively whereas boreal and subarctic peatlands alone store nearly at 460 Gt C (Mitra et al. 2005). Globally SOC in most of the agricultural pools is below their ecological potential prone to soil erosion and other degrading processes. Wetland under cultivation has 0.2 to 7.6 g C $m^{-2}yr^{-1}$ under improved crop management and 8 to 10 g C $m^{-2}yr^{-1}$ through the restoration of wetlands (Lal 2008). Under the ongoing national wetland conservation action plan in China, the carbon sequestration potential of restored wetlands was 6.57 Gg C yr^{-1}. North American prairie pothole restored wetlands also has an annual sequestration rate of 27 g C m^{-2} yr^{-1}.

India accounts for nearly 757 wetlands contributing to nearly 4.7% of the total geographical area of the country. Of the total wetland area, coastal and inland wetlands constitute 27% and 69% respectively (SAC, 2011). The total extent of coastal ecosystems (including mangroves) in India is around 43,000 km^2 and can sequester about 1.5 Mt C ha^{-1} yr^{-1} (Kathiresan and Thakur, 2008). The total area under wetlands in Kerala is 1,279.3 km^2, of which 341.9 km^2 and 937.3 km^2 are constituted by inland and coastal wetlands, respectively. Studies on the sequestration of carbon from the wetlands of India are scanty and lesser studied. However, most of the studies deal with the emissions of GHG.

1.9 CLIMATE CHANGE ON WETLANDS

Globally wetlands are recognized as an essential component of the global carbon cycle invariably related to climatic factors both at global and regional scale. Prevailing unique biogeochemical processes facilitates wetlands as significant reservoirs of carbon (C) sequestering nearly 20-30% of the global carbon pool. As carbon stored in the wetland soils are highly sensitive to climate-driven environmental changes, including fluctuations in water inundation, temperature, the nutrient regime and microbial activity they also act as a significant source of carbon especially major greenhouse gases (GHG) CH_4, CO_2 and N_2O (Mitra et al., 2005). Since 1750 to 2011, atmospheric CO_2 had increased by 40% from 278 ppm to 390.5 ppm, CH_4 by 150% from 722 ppb to 1803 ppb and N_2O by 20% from 271 ppb to 324.2 ppb (IPCC 2013). This unprecedented rate of change in the atmospheric concentrations of radiatively and chemically important trace gases over the last century along with an increase in global temperature made it increasingly important to understand the climatic factors and processes regulating the sink and source of carbon and significant greenhouse gases emissions from wetlands to address the climate change issue.

1.10 SIGNIFICANCE OF RICE PADDY WETLANDS

Since the evolution of the earth, wetlands have played and continued to play a significant role in supporting a large population of people especially in Asia and humid areas of the world via rice production in lowlands. Evidence of rice cultivation dates back to the earliest age of humans, long before the era of historical records. It was the staple food and the first cultivated crop in Asia. Rice culture probably began within a broad belt that extends from the Ganges plains below the eastern foothills of the Himalayas through upper Burma, northern Thailand, Laos, and Vietnam, to southwestern and southern China. Archaeological digs in 1973 and 1974 near Homutu village in Yuyao county of Chekiang province, China, uncovered "rice" dated more than 6,960 years old. Findings throughout the lowlands of the south and Southeast Asia and the southern tier of China substantiate that a significant portion of the population was dependent on rice between the fourth and fifth millennia B.C. Because wetlands are dynamic systems, they are susceptible to climatic changes. Thus, if the predicted global warming trend materializes shortly, wetlands are apt to increase or decrease in various regions of the world as the precipitation to evapotranspiration ratio increases or decreases, respectively.

1.11 ROLE OF RICE PADDY IN C STORAGE AND CYCLING

Globally rice paddies share a significant portion of the wetlands and have a high carbon sequestration capacity, holding up nearly 466 to 2011 Gt C in soils and plant biomass. The primary source for carbon storage in paddy wetlands is directly through crop residue and indirectly by fertilizer inputs, vulnerable to decomposition and lost back to the atmosphere as both carbon dioxide and methane. As paddy wetlands are dynamic systems with flooding and drying events, carbon storage has many implications, functioning both as a significant sink as well as a source of carbon micromanaging the emissions of major greenhouse gases (GHG). The evolution of primary greenhouse gases CO_2, CH_4 and N_2O emissions from paddy soils are as a result of mineralization of SOC through complex heterogeneous processes of respiration, methanogenesis, and denitrification influenced by soil management activities and environmental parameters. Thus carbon storage in paddy fields is the balance between ongoing accumulation and decomposition process, influenced by several environmental and micro-meteorological factors such as temperature, moisture, pH, redox conditions, topography, geological position, the hydrological regime and type of vegetation (Akhilesh Vijay and Bijoy Nandan, 2017).

Globally, occupying about 5.8% of the total agricultural area, rice paddies contribute nearly 12,000 MT of CO_2-equivalents per year in which Indian agriculture has an emission potential of 94,012.79 Gg, accounting nearly 13.5% of the global anthropogenic GHG emissions. Through the increase in organic matter, paddy soils may sequester atmospheric CO_2 emitted by anthropogenic sources thereby mitigating climate change. As land use and soil management practices significantly influence the SOC dynamics and C flux from paddy soils. The emerging shifts in soil management by organic manures and various inorganic fertilizers is, expected to influence on GHG emissions and retention of SOC from paddy ecosystems, therefore, demands research attention.

At present, the uncertainty in understanding the role of paddy soils in the global carbon cycle due to the poor understanding of the spatial distribution and dynamics of soil organic carbon. The literature reviewed in Indian context revealed limited availability regarding the C storage and its stock changes with related parameters concerning paddy wetlands. In this regard, this work would be an early attempt in Kerala- India aiming to give preliminary insights into C dynamics from rice paddy wetlands. Thus the spatially distributed estimates of SOC pools and flux are essential for better understanding the significance of soils in the global C cycle and for assessing the potential of biospheric responses.

Significance and scope of the Study

Wetlands are prominent ecosystems lying at the interphase between terrestrial and aquatic ecosystems. Owing to its unique biogeochemical features they are capable of storing nearly 20–30% of earth's SOC with an average carbon sequestration rate of 20 –30 g C m^{-2} yr^{-1}. Globally rice paddies share a significant portion of the wetlands and have a high carbon sequestration capacity, holding up nearly 466 to 2011 Gt C in soils and plant biomass. The primary source for carbon storage in paddy wetlands is directly through crop residue and indirectly by fertilizer inputs, vulnerable to decomposition and lost back to the atmosphere as both carbon dioxide and methane. As paddy wetlands are dynamic systems with flooding and drying events, carbon storage has many implications, functioning both as a major sink as well as a source of carbon micromanaging the emissions of major GHG. The evolution of major greenhouse gases CO_2, CH_4 and N_2O emissions from paddy soils are as a result of mineralization of SOC through complex heterogeneous processes of respiration, methanogenesis, and denitrification influenced by soil management activities and environmental parameters. Thus carbon storage in paddy fields is the balance between ongoing accumulation and decomposition process, influenced by several environmental and micro meteorological factors such as temperature, moisture, pH, redox conditions, topography, geological position, the hydrological regime and type of vegetation.

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Objectives of the Study

1. Analyse the soil carbon sequestration potential and its dynamics.
2. Assess the emission potential and fluxes of GHG- methane, carbon dioxide and nitrous oxide in the paddy wetland.
3. Assess the effect of different soil management practices on GHG emissions.
4. Suggest measures adaptive for the adaptive management of paddy lands vis-a-vis global climate variability.

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Chapter - 2

STUDY AREA SAMPLING DESIGN AND ANALYSIS

Kerala lies within East Longitudes 74° 52' and 77° 22' and North Latitudes 8° 18' and 12° 48' and constitutes approximately 1.18 % area of India with a total geographical area of 38,863 km^2. Geologically, Pre-Cambrian and Pleistocene formations comprise the bulk of Kerala's terrain. Kerala has an undulating topography with open lands, valleys, and hills. The width of the State varies between 15 and 120 km, and coastal belt extends up to 580 km in length (SOE 2007).

Physiographically, Kerala State is divided into three natural zones: the lowland, the middle land, and the high land. These zones form parallel belts running across the length of the state while the width of the state varies from 15 to 120 Km. The lowland is characterized by numerous lagoons and backwaters, such as the Vembanad, Asthamudi, which receives drainage from the rivers. The backwaters are connected by a network of artificial canals which help in inland navigation for a length of about 558 Km. The lowland is often subjected to salinity intrusion. Rice and coconut are the principal crops grown in the lowland. Kol-lands of Trichur and *padasekharam* (Paddy fields) of Kuttanad are situated in the lowland. The highland is situated on the eastern boundary comprising of the high ranges of the Western Ghats; the lowland is a narrow strip along the coast, and the Midland lies between the highland and the lowland (SOE 2007).

The Western Ghats is situated in the highland, which form the eastern part of the state, rise from very low latitudes of a few hundred meters up to 2000m on an average. Most of the reverse forest of the state is in the highland region. The important peaks in the Western Ghats are the Anamudi, Mukurti, and Nilgiri. The Palghat Gap with a width of about 32 Km is the most significant gap in the Western Ghats (SOE 2007)

2.1 STUDY SITE: PADAYATTI AGRO WETLAND ECOSYSTEM-PALAKKAD

Palakkad is the largest district located centrally in Kerala and is often known as "the rice granary." The district lies between 10° 21' and 11° 14' N and 76° 02' and 76° 54' E covering an area of 4,475.8 sq. Km. Palakkad is the major paddy growing district of the state with its economy primarily dependent on agriculture. In the area, paddy is cultivated mainly in the mid-low plains where the red loamy soils with irrigation favor wet paddy cultivation. Of the total geographic area of Palakkad 45% is used for agricultural activities, in which 86 % of the net sown area is cultivated aided by irrigation. The rest of the areas are rainfed, where agricultural activities are solely depended on southwest and northeast monsoon.

The area selected for the study was a tropical paddy wetland located in Padayatti village, Palakkad Dist, Kerala, India (Fig. 2.1). The study area extends between 10° 41'10.63 and 10°41'67and 76° 32´ 47.47 E, and 76° 33'16.70 E. Padayatti is an interior agricultural village located in Eriymayur panchayat, Alathur block Palakkad, is a unique in many aspects. It is a micro-watershed situated at an altitude of approximately 86 m above the mean sea level spreading over an area of 161.6 ha in the mid low land plain areas of the district. The floodplains of Padayatti were drained mainly by the rivers Bharathapuzha and its tributaries, which is divided into 50 watersheds and 290 micro-watersheds.

According to Thornthwaite's climatic classifications, Padayatti agro wetlands experience tropical arid and humid climate (Raj & Azeez, 2010). The temperatures in the area remain moderate throughout the year, except in the summer seasons (March and April) being the hottest months. At Palakkad, the maximum temperature ranges from 28.1 to 37.4 °C whereas the minimum temperature was in the ranges from 22.2 to 25.3 °C.

All the agricultural operations in Padayatti agro wetland systems are depended on Southwest and northeast monsoon which is the only source of irrigation in the area. The paddy fields of the area are flooded from June to January. The agro wetland system of Pdayatti has two crop seasons namely "Virippu" (autumn crop) and Mundakan (winter crop) depending on the southwest monsoon and northeast monsoon. During the summer months, the field is kept fallow. Agriculture season in Padayatti agro wetland ecosystem starts with the onset of southwest monsoon. Farmers prepare their lands by plowing, fertilizing, smoothing, and strengthening of the earthen bunds which demarcate each plot with multifunctional soil preparation machines before the onset of monsoon. During the south-west monsoon, the inflow of rainwater into the floodplain submerges all the paddy area. During heavy rains, the water drains out through the canals which are meant for irrigation. In areas where paddy is entirely grown as rain-fed crop, no systems of canals were there for drainage. The water simply overflows the fields and reaches the lowest fields from where it runs to the bottom of the valley where there will be natural water flow outlet. The first crop is "Virippu" (autumn crop) raised during June to October. It is normally a broadcast crop as it is sown expecting the rain. The second crop season starts immediately after the first is "Mundakan" (winter crop) raised during October to January. The second crop "Mundakan" is mainly dependent on the northeast monsoon. Weeds were removed from the field manually and were done twice in a season. During harvesting, the whole plant is cut leaving 5 to 8 cm at the base.

2.2 STUDY STATIONS

A total of nine stations were selected for the study based on the agricultural practices in the area in which seven stations were selected from the conventional field, and two were from the organic field (Fig. 2.1). Field samples were collected from these nine stations for 33 months from July 2011 to March 2014. Whereas weekly samples were taken during October 2014 to January 2014 exclusively for the study of gaseous emissions. All study stations were typical paddy wetland ecosystems, and details on the latitude and longitude of the stations are given in Table 2.1.

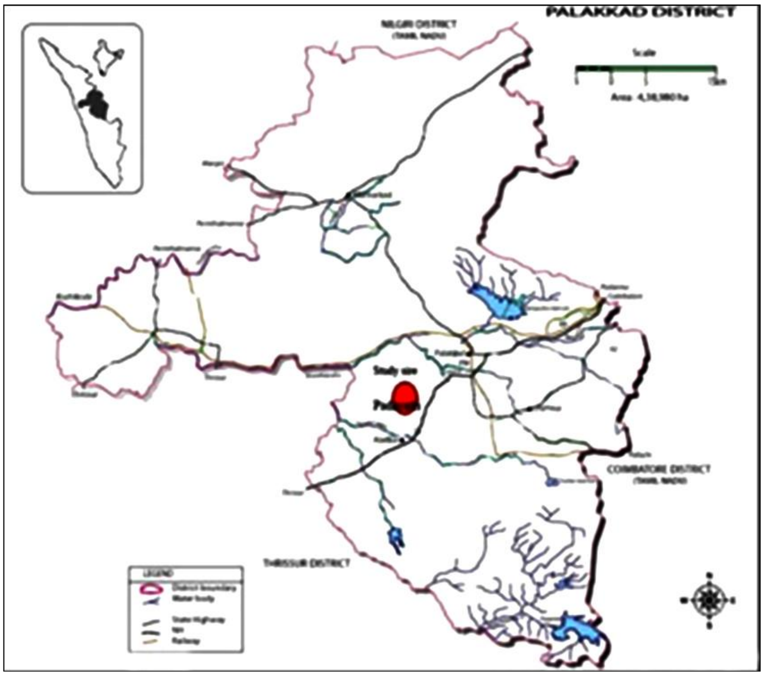

Figure 2.1 (a) Location map showing Padayatti agro wetland ecosystem in Palakkad, Kerala India

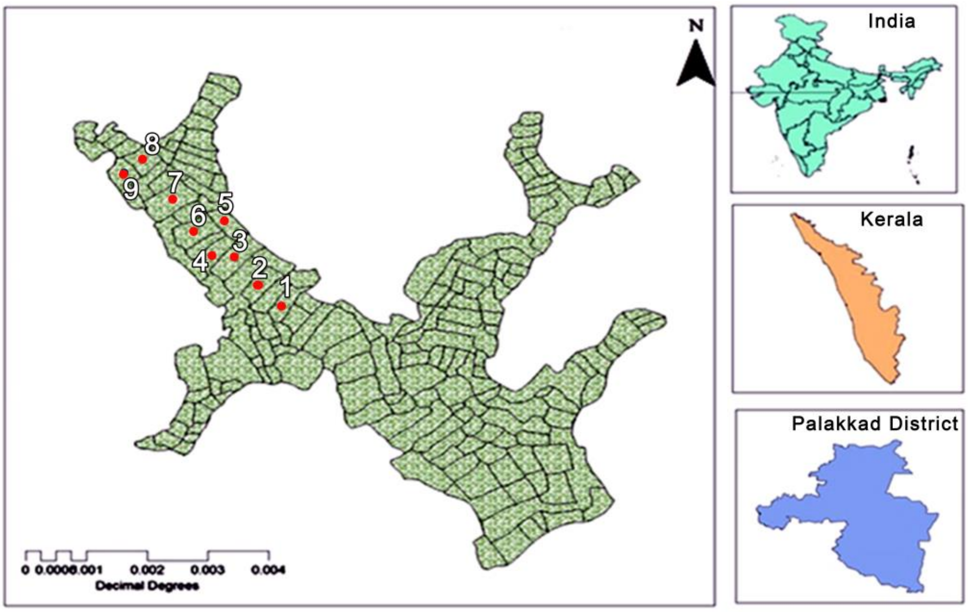

Fig 2.1 (b) Location map showing study stations in Padayatti agro wetland ecosystem

Figure 2.1(c) Google earth imagery showing of study area in Padayatti, agroecosystem Palakkad

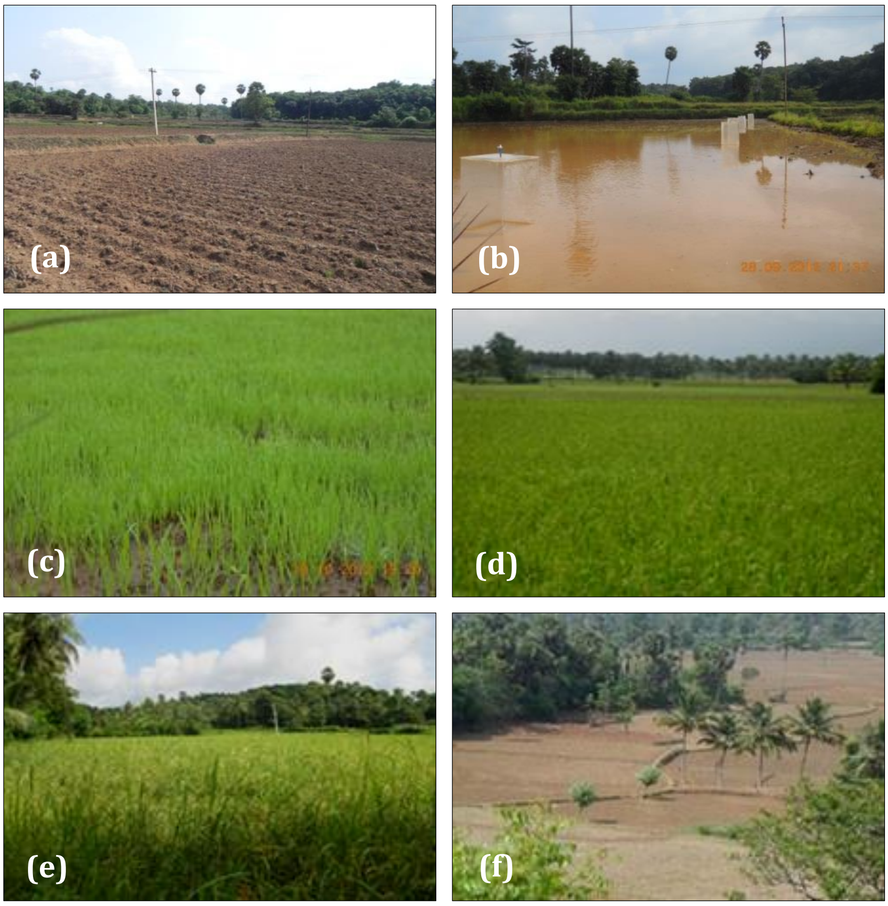

Figure 2.1 Study stations of Padayatti wetland, Palakkad during different staged of rice paddy cultivation (a) field preparation, (b) water submerged condition before sowing, (c) Rice paddy plant transplanted stage (d) and (e) Rice paddy growth period and (f) summer fallow period

Table 2.1 The latitude and longitude of study stations of Padayatti, agroecosystem Palakkad

Station	Latitude	Longitude	Fertilizers
1	10° 41'.127' N	76° 32'. 846 E	Conventional
2	10° 41.' 117' N	76° 32'. 860 E	„
3	10° 41'. 046' N	76° 32'. 926 E	„
4	10° 41.' 078' N	76° 32'. 934 E	„
5	10° 40'. 098' N	76° 32'. 934 E	„
6	10° 40'. 907' N	76° 32'. 954 E	„
7	10° 40.' 913' N	76° 32'. 961 E	„
8	10° 41'.101' N	76°.32'. 834 E	Organic
9	10° 41'.097' N	76° 32'.826 E	„

2.3 Crop Seasons in Padayatti, Palakkad

In Padayatti, Palakkad, the rice variety *Orizya sative L* (*Jyothy) (PTB 39*) was cultivated following a double cropping pattern. Agricultural practices were based on three seasons depending on the south-west and northeast monsoon. The first agricultural crop season (CS-I) begins with the onset of southwest monsoon in June and ends in September (monsoon season). Whereas the second Crop season (CS-II) starts from October to February and is associated with the northeast monsoon (post-monsoon season) which ceases by December. The remaining months from March to May are dry non-growing Fallow summer season (FS) known as pre-monsoon season.

2.3.1 Conventional mineral fertilizers (CMF)

Rice paddy cultivation practices followed by farmers in agroecosystems of Padayatti dates back to 100's of years. During the years the soil management practices followed were organic. Materials of organic origins especially cow dung, composts, plant residues, and plant remains were used for farmland management along with a native variety of seeds. Indicting that organic farming practice is native to ancient agriculture. With the increasing demand for food necessitated the introduction of modern agriculture as part of the green revolution in 1966, unaware of its darker side. Modern agricultural practices use high yielding varieties of seeds, mineral fertilizers and pesticides and alternative land management activities. In this study, we term this practice of agriculture as conventional agriculture practices as it is being continued for the last 50 years.

We define Non-organic (Conventional) farming system, which relies on synthetic mineral fertilizers along with farmyard manures as it was locally practiced by the farmers for long. Synthetic fertilization practices make use of the mineral fertilizers-FACTAMFOS (AMMONIUM PHOSPHATE SULPHATE), chemical pesticides, and locally available farmyard manures. FACTAMFOS 20:20:0:13 is a chemical blend of 40 parts of ammonium phosphate and 60 parts of ammonium sulfate. It contains 20% N and 20% P_2O5 (FACT 2016).Fertilizers were applied three times in a crop season. Initially during the paddy bed formation, and during the first and second top dressing.

2.3.2 Organic Farming (ORG)

Organic fertilization practices were introduced in the Padayatti agroecosystem are as a part of a pilot project "Agro-Biodiversity Enhancement Programme" by the state government of Kerala –India, to promote organic farming to enhance the biodiversity of the area. For this,100 acres of land from a total of 161 ha micro watershed from Padayatti agroecosystem was demarcated for the organic cultivation and maintained in the same state from July 2011 onwards till the completion of the study in March 2014. Organic (ORG) fertilization practices include organic manure (Biogrow, http://www.tstanes.com/products-bio-gro.html), cow dung, farmyard manures, leaf decoctions and Panchagavaya (Kumar et al., 2011). The organic manures applied was at a rate of one tonne/ acre (100 kg Ha^{-1}) during 0, 30, 40 and 50th days after field preparation. Table1 shows the composition of organic manure applied, in the farming site.

Table 2.2 Composition of organic manure used for the study during 2013-2014 period

Parameters	Concentration
TC	36.14 6 $mg^{-1}Kg$
TOC	18.6 $mg^{-1}Kg$
TN	1.25%
P_2O5	0.58%
k_2O	0.81%
Ca	1.75%
Mg	0.27%
Mn	175ppm
Zn	15ppm
Fe	100ppm
Cu	12ppm

Panchagavya is an essential traditional formulation used by the organic farmers of Padayatti, Palakkad, which is effective as an antimicrobial and antifungal agent, which is sprayed over plants during cultivation. Farmers of Padayetti locally prepared the “Panchagavya” with the technical support of the State Agriculture Department. The constituents of the Panchagavya assortment were milk (2 liters), curd (2 liters), groundnut cake (1 kg), tender coconut water (3 liters), banana (12 nos.), toddy (2 liters), cow dung (7 kg), and urine (5 liters). The constituents were mixed, and 1 liter of it was diluted to 10 liters and applied in the organic farming areas. The period of application of Panchagavya was for 25 days, 45 days, and 60 days, the interval from the date of sowing paddy and its further growth.

2.4 EXPERIMENTAL DESIGN: ORGANIC (ORG) AND CONVENTIONAL MINERAL FERTILIZERS (CMF)

The dynamics of organic and conventional mineral fertilizers on soil were monitored in the rice paddy ecosystem (*Orizya sativa*). Two neighboring rectangular plots (one acre in dimension) permanently separated by earthen bund pathway (1 m width) were chosen for the study. The plot is demarcated as

ORG where the only organic way of agricultural practice was followed. Whereas the second plot is demarcated as CMF where conventional mineral fertilizer aided treatments were carried out. In addition to organic and conventional plots, a control plot was also maintained devoid of fertilizer and pesticide treatments.

Measures were taken to prevent intercalation of water and materials between the plots throughout the experimental period. Both plots were prepared by ploughing, fertilizing and smoothing with a multifunctional soil preparation machines. The seedlings are prepared in seedling beds in the respective plots and transplanted after 30-50 days to fields, which have been flooded by irrigation or by rain. Normally, three to five seedlings compose a group that is transplanted in a hill by hand. During the growth period, depth of paddy water (DPW) was maintained by seasonal rainfall assisted by irrigation. Field irrigation was initiated few weeks before transplanting and maintained for 30-40 days until mid-season drainage, which lasted for one week. After that paddy were intermittently flooded until final drainage before rice harvesting. The fields were allowed to drain completely before harvesting.

2.5 SAMPLING AND ANALYTICAL METHODS

Monthly field sampling for the collection and analysis of gaseous measurements of CO_2, CH_4 and N_2O and soil physicochemical parameters from the selected stations were undertaken from July 2011 to March 2014 in Padayatti paddy wetlands of Palakkad.

2.5.1 Ambient temperature and rainfall

Data such as daily temperature, rainfall, and humidity were obtained from the weather station at Integrated Rural Technology Centre (IRTC)-Palakkad (http://www.irtc.org.in/). Where temperature was expressed in °C and rainfall in mm.

2.5.2 Diurnal Temperature, Humidity, and Solar radiation

The In-situ measurement of temperature was carried out using an automatic humidity and temperature recorder RHT Temp 101, (MadgeTechUSA, 0.1 K resolution). The recorder was placed inside a Stevenson's Screen mounted in a pole in the center of the field. Solar radiation was measured using a pyranometers LPPYRA05, Licore USA. The measurements were recorded for 24 hrs.

2.5.3 Depth of Paddy Water (DPW)

The depth of paddy water (DPW) in the paddy fields was also recorded using a permanently installed metric scale during the sampling period and expressed in cm.

2.5.4 Soil sampling and analytical methods

Soil core samples (15cm) were collected using standard soil corer and were air dried. Less than 2 mm size fraction of soil samples were used for chemical analysis.Soil surface temperature (0 to 5cm) was measured during the sampling period with a portable digital thermometer with an accuracy of 0.01and was expressed in ^{0}C (Metravi DTM-902). Soil pH was determined using Systronics pH meter No.371 with an accuracy of ±0.01 (APHA 2005).Sediment oxidation-reduction potential Eh (accuracy ±0.05) was determined in the field using digital Eh meter (Systronics no. 318). Eh is measured with an electrode pair consisting of an inert electrode and reference electrode. Eh of soil is expressed in mV.Soil moisture content (SMC) was determined by gravimetric analysis after drying at a maximum temperature of 105 °C. The temperature was maintained for five hours to eliminate free form of water and no organic matter and unstable salts that lost by volatilization (Pansu and Gautheyrou, 2006). Moisture content is expressed in percentage.

Soil Particle size was analyzed using automated particle analyser sympatrec T 100 laser diffraction granulometer. The aggression of particles resulting from cementing action was eliminated by dissolution of the soil into elementary particles by adding the dispersing agent, sodium hexametaphosphate. Measurements were linked to the size of the particle to physical characteristics of the suspension of the soil after dispersion. A dispersing liquid containing suspended particles circulates in a measuring cell intersected by monochromatic laser beam collimated by a condenser on a window of analysis of a defined surface. The light of the laser was diffracted on the outside of the particle, and the analysis of the diffraction is inversely proportional to the size of the particles. An optical system collects the signal engraved with pre-determined angles. The signal was treated to extract the distribution of the particle. The output was in the form of curves; averaging diameter (particle size distribution) expressed as a volume (Carter 1993). The result is expressed in percentage of sand silt and clay.

Available forms of potassium (K), Sodium (Na) and available calcium (Ca) from soil was analysed using a flame photometer (Systronics no. 128 make). A known volume of samples was mixed with 1N ammonium acetate and shaken for 5 minutes in a reciprocating shaker. The filtrate was extracted through Whatman No.42 filter paper, and 5ml of the filtrate was made up to 50ml with NH_4OAc and readings were taken with the respective filter in a pre-calibrated flame photometer. The NH_4 ion provides a sharp, rapid separation of elements from exchange complex. The extract is atomized in the flame where the atoms of the element are excited, emitting radiations of characteristics wavelength. The radiation emitted by the K, Na and Ca atoms is passed through the filter which falls on photocell emitting electronsie, the electric current which is measured on digital galvanometer of the flame photometer. The electric current generated is proportional to the concentration of elements in the extract.

Total nitrogen (TN) of soils was analysed by automated Kjeldhal distillation method (KelplusDISTYL EM). The samples to be analysed were digested at 400°C before distillation. Digestion is carried out with Con. H_2SO_4 in the presence of $CuSO_4$ as a catalyst and K_2SO_4 which raise the digestion temperature. During digestion, H_2SO_4 is reduced to SO_2 which in turn reduces N to NH_3 and this ammonia forming ammonium sulphate to combine with excess H_2SO_4. Digest is made alkaline and ammonia liberated is distilled off into the boric acid solution. The quantity of ammonia liberated is determined by titration against standard acid (Jackson 1973, Carter 1993). The result was expressed in percentage of Total Nitrogen gKg^{-1}. Available nitrogen (aV) of soils was analysed by alkaline permanganate method (KelplusDISTYL EM). The amount of nitrogen released as ammonia by alkaline permanganate solution was estimated by distillation and distillate was collected in boric acid mixed indicator solution. The ammonia liberated was determined by titration against standard sulfuric acid (Jackson 1973, Carter 1993). The result is expressed in percentage of available nitrogen.

Available phosphorus was determined by Olsen's method (Olsen et al. 1954). Available phosphorus was extracted with sodium bicarbonate at pH of 8.5 for 30 minutes. Interference from organic matter dissolved in the solution has frequently been eliminated by sorbing other organic matter on to activated charcoal added to the extract. The phosphomolybdate complex was measured at a wavelength of 712 nm in a Systronics UV-VIS 117spectropotometer (Carter 1993). Available phosphorus is expressed in mg kg^{-1}.

Total carbon (TC) and soil organic carbon (SOC) concentrations were determined on dried samples by thermal combustion using a TOC – analyzer, (Analytik Jena multi N/C 2100s) using the direct method. The soil samples are treated with non-oxidizing acid (10% HCl) to remove the Soil Inorganic Carbon content. Afterwards, the same sample is combusted at a temperature above 900°C in the oxygen flow to gain the SOC content. TC, SIC, and SOC were expressed in g kg^{-1}.

2.5.5 Estimation of Soil Bulk Density

Bulk density (g/cm^3) = Dry soil weight (g) / Soil volume (cm^3)

Bulk density is usually expressed in megagrams per cubic meter (Mg/m^3) (Cresswell and Hamilton, 2002).

2.5.6 Estimation of Soil Carbon stock

Carbon stock is calculated for total carbon (TC), soil organic carbon (SOC) and soil inorganic carbon (SIC) by substituting corresponding TC, SOC and SIC values in the equation (Bhattacharyya et al., 2007a)

$$\textbf{Carbon Stock (Mg ha}^{-1}\textbf{) = C}_{con}\textbf{ (\%) x Bulk density (Mg m}^{-3}\textbf{) x depth (m) *100}$$

2.5.7 GHG flux measurements

2.5.7.1 Experimental Design

The greenhouse gas (GHG) fluxes in triplicates were measured from paddy fields of Padayatti from 2011-2014 (month or date) for CH_4 and 2013 - 2014 (month or date) for CO_2 and N_2O. Weekly samples were also collected for gaseous flux measurements of CO_2, CH_4, and N_2O from October 2013 to January 2014. Diurnal samples for gaseous analysis of CH_4, CO_2, and N_2O was carried out on 18th December 2013, where samples were collected at the one-hour interval during 04 am to 06 pm and from 06 pm to 04 am samples were collected at an interval of 02 hrs. Static chamber method and gas chromatography techniques were applied to determine the fluxes of CO_2, CH_4, and N_2O from the paddy fields (Chen et al., 2013). The static chamber of perspex in different dimensions (0.45 X 0.45 X 0.75 m^2 and 0.45 X 0.45 X 0.5 m^2) (Fig.2.2) with a square metal base was used for the study and height of the chamber varying with the growth of paddy plants. The metal frame was permanently inserted into the soil to a depth of 20 cm during the entire crop season. The chamber was mounted on the metal frames during the incubation period and immediately removed after the collection of the gas samples. The chamber was inverted after each experiment to remove the gas that accumulated during the incubation period. Gas sample collections regularly started at 8:00 am to 9:00 am local time. Soil heterotrophic respiration was also measured from respective stations devoid of plant and roots using an opaque chamber of an area of 0.131 m^2. The chambers were closed for 30 minutes, and 30 ml of gas samples were collected in a hypodermic plastic syringe with a lure lock. The concentrations of CO_2, CH_4, and N_2O in the gas samples were analysed using PerkinElmer Calrus 580 gas chromatograph. Gas samples were injected using a 1ml gas sampling valve. The isothermal separation was performed at 55°C in 30 m long 0.53 mm internal diameter split duel Elite-Plot Q column for simultaneous measurements using an ECD for N_2O analysis and a methanizer FID for the CH_4 and CO_2 analysis. The gas fluxes were calculated from changes in the initial rate of concentration within the chambers headspace. This was calculated from the initial slope of a non-linear regression of concentration against time (Bhattacharyya et al., 2013).

$$F = \rho \times (V/A) \times (\Delta C/\Delta t) \times [273/(273/T)] \quad (1)$$

Where F is the CO_2, CH_4, or N_2O flux, ρ is the respective gas density, V is the volume of the chamber area, $\Delta C/\Delta t$ is the rate of gas accumulation in the chamber and T is the absolute temperature. Negative flux values indicate gas uptake from the atmosphere, and positive flux values indicate gas emissions to the atmosphere.

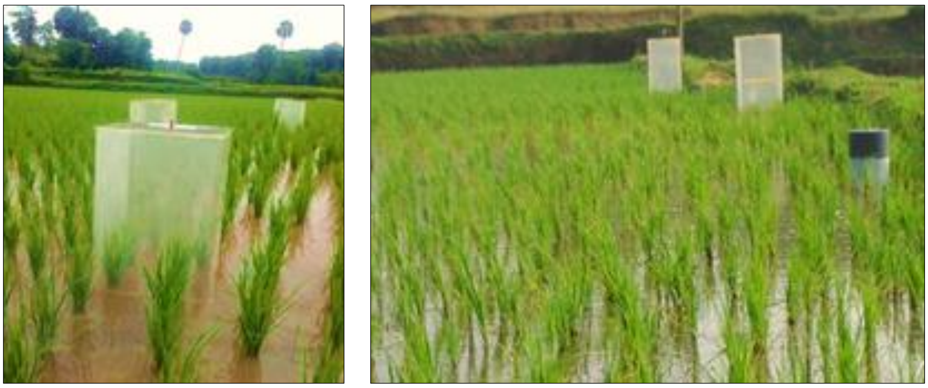

Figure 2.2 Static chamber deployed for collection of GHG from rice paddies of Padayatti, Palakkad

2.5.7.2 Estimation of Plant-mediated Transport of GHG

The experiment was carried out to estimate the plant-mediated transport of GHG from the soil to the atmosphere. Plant-mediated GHG was estimated by subtracting the GHG concentration from static chambers accommodated with plants and from those devoid of the rice plant (Thomas et al., 1996)

Plant-mediated transport = GHG plant – GHG no plant

Where GHG plant = mg $m^{-2}h^{-1}$ of GHG where static chamber has desired plant

GHG noplant = mg $m^{-2}h^{-1}$ of GHG where GHG is measured from bare area devoid of roots

To determine the portion of the paddy plant having maximum resistance to lacunal gaseous transport, shoot cutting experiment was carried out. For the experiment, a 56 days old healthy rice paddy plants were selected from the field. After the initial measurements done for comparing the rate of emission with rice plants, plant-mediated transport of GHG was measured by cutting the rice plant 10 cm above the soil. Difference between the intact and cut plant gives the rate of transport of gaseous emissions through the rice plant.

2.5.7.3 Cumulative emission

The daily mean fluxes for each treatment were calculated by averaging the three replicates for each sampling day; these were further integrated into the seasonal cumulative sums using a simple linear approach.

$$\text{Cumulative emission} = \sum_{i=1}^{n} (F_{i+1} + F_i)/2 \times (t_{i+1} - t_i) \times 24 \quad (2)$$

Where F is the GHG emissions (mg m^{-2} d^{-1}), i is the ith measurement, the term $(t_{i+1} - t_i)$ is the days between two consecutive measurements were taken (Ni et al., 2012).

2.5.7.4 Global warming potential (GWP)

The global warming potential (GWP) of different treatments were calculated using the following equation. Based on a 100-year time frame, the GWP coefficients for CH_4 and N_2O are 34 and 298, respectively, when the GWP value for CO_2 is taken as 1 (IPCC 2013).

$$GWP = 34\times CH_4 + CO_2 + 298\times N_2O \text{ kg } CO_2 \text{ equivalent ha}^{-1} \quad (3)$$

2.5.7.5 Net Ecosystem Exchange (NEE)

A net ecosystem exchange of CO_2 (NEE) could be calculated using the equations (Zheng et al., 2008) as follows:

$$NEE = Rs + Ra - GPP \quad (4)$$

$$Rs = Rr + RH \quad (5)$$

$$NPP = GPP - Ra - Rr \quad (6)$$

Combining equations (1) - (3), NEE could be then calculated also as

$$NEE = RH - NPP \quad (7)$$

where NPP was the net primary productivity (kg C ha^{-1}); GPP was the gross primary productivity(kg C ha^{-1}); Ra was the above ground respiration of the plants (kg C ha^{-1}); Rs was the total soil respiration (kg C ha^{-1}); Rr was the root respiration of the Plants (kg C ha^{-1}); and R_H was the microbial heterotrophic respiration of soil (kg C ha^{-1}) which was concerned approximately equal to total CO_2 fluxes from inter-row collars without covering crop growth (Raich and Tufekcioglu. 2000).

By using Equation (4), C flux from the atmosphere to the soil-plant system could be calculated with the measured NPP and R_H. The NPP was simply derived from biomass harvested and determined by the maximum biomass (W max) at maturity from the plots where CO_2 emissions were measured (Zou et al., 2005). Then, NPP was estimated following the equation proposed by Osaki et at. (1993) as:

$$NPP = 0.446 \times W\,max - 0.00067 \quad (8)$$

2.5.7.6 Net Ecosystem Carbon Balance (NECB)

To estimate C balance in flooded rice ecosystem, input and output components of C were considered. The difference between these two components gave the net C balance of the ecosystem was estimated by the modified formula as given by Smith et al. (2008)

$$\mathbf{NECB = [(St + Rb + Rd + Ab + NEP) - (Sw + St + Rb + CH_4\text{-}C + DOC) \quad (9)}$$

Where,

1) St = Stubble biomass (Mg C ha^{-1})
2) Rb = Root Biomass (Mg C ha^{-1})
3) Rd = Rhizodeposition (Mg C ha^{-1})
4) Ab = Algal Biomass (Mg C ha^{-1})
5) NEP is the net ecosystem production calculated using the equation (8) and expressed in Mg ha^{-1}
6) Sw = Straw biomass (Mg C ha^{-1})
7) St = Stubble biomass (Mg C ha^{-1})
8) Rb = Root Biomass (Mg C ha^{-1})
9) CH_4 C = Cumulative methane (Mg C ha^{-1})
10) DOC = C loss as dissolved organic (Mg C ha^{-1})

2.6 DATA ANALYSIS

Statistically transformed and normalized data were used for analysing the significant difference in the environmental parameters and GHG fluxes. Pearson rank correlation, One-way ANOVA, general linear model (GLM) and Tukey's post hoc test were performed to find out the significance and variations among the data. Statistical analysis such as 2 Way ANOVA (Analysis of Variance), standard deviation and the correlation was done based on SPSS 16.0 software packages for Windows for testing the presence of significant differences and correlation among the parameters between stations and between seasons. Non-linear and Gaussian fit regression models were also carried out. Mean variation in the data is expressed as standard error. Data in the tables and figures are presented as mean ± standard errors. All the statistical procedures were performed using software packages SPSS 16.0. Tables and graph were prepared in Sigma Plot 12.5, and Principle component analysis (PCA) was performed and was interpreted graphically by constructing biplot using R 3.5 software. Principal component analysis (PCA) was done on environmental data to analyse the variation in environmental characteristics across the study area. This analysis uses an ordination plot to project the points of more similarities closer together while less similar samples further apart (Clarke and Warwick 2001).

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Chapter - 3

ENVIRONMENT VARIABLES AND SOIL CARBON DYNAMICS IN PADDY WETLANDS

3.1 INTRODUCTION

Carbon is an essential component of soil attributed to its quality and productivity. Globally, terrestrial soils are the major reservoir of atmospheric carbon (CO_2), storing approximately 1500 Pg of organic carbon (OC). Roughly three times the amount of carbon in vegetation and twice the amount (750 Pg) in the atmosphere (Baldock, 2007; IPCC, 1996; Lal, 2009; Liu et al., 2006). Similarly, inorganic component of the carbon stock is also stored in soils in the form of $CaCO_3$ and is estimated to store nearly 700 Pg to 1000 Pg (Godoi et al. 2009). Recently carbon storage in terrestrial soils gain global importance because of the functions it plays in improving the physical and chemical environments of the soil by holding moisture, supporting plant growth with nutrients and in the global carbon cycle by mitigating atmospheric levels of GHG, with special reference to CO_2 especially in an agro-ecosystem (Reichstein et al. 2013).

Carbon storage in soils is the balance between the input (leaf and root litter) and losses from decomposition and mineralization processes (heterotrophic respiration) (Milne et al. 2007). In the terrestrial ecosystems, atmospheric CO_2 is fixed by plants and autotrophic microorganisms through photosynthesis and thereby transformed to organic compounds locked away from the atmosphere in the soil as soil organic carbon (SOC), a process called carbon sequestration (Kayranli et al. 2010). However, these processes in soils are more significant because it takes thousands of years of organic carbon in the soil to renew itself (Lal, 2004). As the soil C pool is twice the amount of atmospheric C, even minor changes in the SOC pool can have a critical effect in the global C cycle, influencing the atmospheric concentration of GHG and thereby global climate change (Davidson et al. 2000; Galloway et al. 2004; Smith 2004; Davidson and Janssens 2006). Recent reports on SOC stock change has made it evident that there is a rapid and significant decline of SOC as result of various anthropogenic activities. Essential factors controlling SOC levels include climate, hydrology, parent material, soil fertility, biological activity, vegetation patterns and land use.

Among agricultural systems, paddy wetlands are essential ecosystems covering around 153 million hectares. Globally harvested area of these paddies cover areas of 146 million ha in Asia which accounted for 89% of the total harvested area across the world in 2013 (FAOSTAT, 2015). Globally paddy wetlands are identified as crucial ecosystems capable of sequester 466–2011 Gt of carbon as well as they act as a source of carbon contributing to emissions of major GHGs (Smith et al. 2008). The potential of agriculture on SOC sequestration in Indian soils ranges between 12.7 and 16.5 Tg C y^{-1} (Lal, 2002; Bhattacharyya et al., 2013).

Carbon sequestration in paddy wetlands depends upon the balance of C inputs from photosynthesis and C gases, mostly in the form of CO_2 with some other non-CO_2 losses. Therefore the processes of autotrophic and heterotrophic respiration control ecosystem carbon fluxes. CO_2 fluxes can be differentiated into three types: (1). Soil respiration includes root, anaerobic and aerobic microbial respiration, (2). Ecosystem respiration: additionally includes aboveground plant respiration, and (**3**). Net ecosystem exchange (NEE) is the difference between photosynthesis and ecosystem respiration.

Even though paddy wetland ecosystems have a considerable potential for sequestering CO_2 from the atmosphere (Bernal and Mitsch, 2012; Mitsch et al., 2013), they can quickly become a source of atmospheric C contributing significantly to global flux of 68–75 Pg CO_2–C $year^{-1}$ (Smith et al., 2008). Most SOC entering the soil surface is rapidly consumed, and some of it is respired by heterotrophic organisms primarily occurring in the rooting zone (top 10–20 cm).

This rapid mineralization quickly returns CO_2 to the atmosphere influenced by various environmental factors.

Terrestrial soils are the largest sink of the global terrestrial C cycle. Approximately half of all soil organic carbon (SOC) in managed ecosystems has been lost to the atmosphere during the last two centuries, and it is accepted that this loss has been a major factor leading to increased atmospheric CO_2 and soil degradation (Schlesinger, 1991; Lal, 2004). The relevance of soil CO_2 emissions in the global carbon budget has been pointed out in numerous studies. Various studies had identified significant factors regulating the C sequestration processes in paddy wetlands So far, few reports on soil CO_2 emission have been available in subtropical regions.

Among the environmental factors, soil temperature and moisture conditions are frequently addressed as those closely related to soil respiration. Soil temperature and moisture conditions in the surface 10 cm were significantly related to CO_2 emissions (Omonode, Vyn, Smith, Hegymegi, & Gál, 2007., Goulden et al., 2004). A reduction in respiration during the dry season was an important cause of this seasonal pattern. Erickson et al. (2011) studied the effect of temperature and precipitation on carbon storage and trace gas flux from crop land soils, since changes in temperature, precipitation, and atmospheric CO_2 concentration will affect NPP, C: N inputs to soil and soil carbon decomposition rates (Saito et al. 2005) Thus terrestrial ecosystem carbon fluxes both respond to and strongly influence the atmospheric CO_2 increase leading to climate change (Cao and Woodward 1998a).

Bhattacharyya et al., (2013) reported the influence of various environments factors, ranging from tropical to temperate regions, with varying climatic, edaphic and biological conditions and different agricultural management practices that naturally affect the rates of CO_2 exchange. Soil properties influencing the GHG emissions include texture, structure, moisture content, temperature, pH, salinity, redox potential, pore size distribution, SOC, N concentrations and management practices. The SOC content in wetland soils is also affected by natural conditions, including pedogenesis (Riha et al., 1986) and groundwater fluctuations (Johnston et al., 2001). Also, human activities (including land-use changes) play a critical role in SOC dynamics (Xiong et al., 2002) cultivation of soil, by plowing, tillage or other soil management methods may enhance the decomposition of SOC and CO_2 production (Lal 2004; Chen et al. 2007). The combined application of rice straw and an inorganic fertilizer was most effective in sequestrating soil organic carbon (1.39 Mg ha^{-1}), resulting in higher grain yield (Bhattacharyya et al. 2012). In agricultural soils intensive management practices, like deep ploughing, land use changes from both pasture to rotation or pasture to crop, crop residue removal, erosion, causes SOC depletion (Lal, 2002; Vleeshouwers and Verhagen, 2002).

Degraded soils can be rejuvenated, primarily by adopting management practices that lead to an increase in the size of the SOC pool. Such practices should not only improve soil quality but may help mitigate climate change by removing atmospheric carbon dioxide (CO_2) and transferring it to a more stable SOC pool. Improved soils and crop management could potentially remove large quantities of CO_2 through soil carbon sequestration in the form of SOM. Examples of soil C sequestration strategies include reduced tillage or no-tillage, use of cover crops in the rotation, land use change from arable to permanent crops, restoration of degraded lands, reduction of fallow periods (Paustian et al., 1997). The residence time of this SOC is also much longer than in biomass, which constitutes an excellent C sink. The SOC parameter is normally employed as an indicator of soil quality and can accumulate in the soil for decades.

In this context, the environment variables influencing soil carbon dynamics and sequestration were investigated in addition to soil C and N stock assessments from Padayatti agro wetland ecosystem to have a better understanding of the carbon storage s especially in regional scale for mitigation options.

3.2 LITERATURE REVIEW

3.2.1 International Scenario

Islam and Islam (1973) was the first report the chemistry of submerged soils and growth and rice yield from different parts of Bangladesh showing variations in the environmental parameters like pH, Eh, water-soluble phosphorus, Calcium, Magnesium, Potassium, and sodium. Soil chemistry of paddy soils from tropical Asia concerning factors affecting paddy growth was reported by Kawaguchi and Kyuma (1974). Armentano (1980) reviewed world's wet organic soils in relation to the global carbon cycle and estimate the consequences of drainage for the global carbon exchange of these soils. Brejda et al. (1981) estimated the surface soil organic carbon content at a regional scale using the National Resource Inventory. The available nitrogen from soil in relation to fraction of soil nitrogen and other soil properties was studied by Warren and Whitehead (1988).Influence of environmental parameters on like soil temperature, phenology, fertilization and water level on methane flux is studied by Schütz et al. (1990); Singh et al. (1996). Role of carbon cycle and probable responses to climatic warming from Northern peatlands are studied by Gorham (1991) and reported that boreal and subarctic peatlands comprise a carbon pool of 455 Pg that has accumulated during the postglacial period at an average net rate of 0.096 Pg y^{-1}. Bouwman (1991) studied the agronomic aspects of wetland rice cultivations like manure addition and material with varying C:N ratios and associated wetland emissions. Gaston et al. (1993) reported the potential effect of no-till management on carbon in the agricultural soils of the former Soviet Union whereas Osaki (1993) studied carbon-nitrogen interaction model in field crop production. Carbon biogeochemistry and climate change were studied by Sarmiento and Bender (1994). Bachelet et al. (1995) studied the balancing the rice carbon budget in China using spatially-distributed data and calculated the net primary production (NPP) of rice fields in China. However the carbon in tropical wetlands was studied by Neue et al. (1997). The effect of soil nitrogen, carbon and moisture on methane uptake by dry tropical forest soils was studied by Singh et al. (1997). The impact of C sequestration in forest derived soils of eastern corn belt was studied by Dick et al.(1998). However Haynes and Naidu (1998) reviewed the Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions. The net primary and ecosystem production and carbon stocks of terrestrial ecosystems and their responses to climate change was studied by Cao and Woodward (1998) and also reported dynamic responses of terrestrial ecosystem carbon cycling to global climate change. The influence of management on soil carbon stock using the ICBM model in agricultural fields was studied by Kätterer and Andrén (1999). The carbon balance of tropical temperate and boreal forests was studied by Malhi et al. (1999). Hou et al. (2000) has studied the Methane and Nitrous oxide Emissions from a rice field in relation to Soil redox and microbiological processes where as Kuzyakov et al. (2000) reviewed the mechanism of priming effects. However the Respiration as the main determinant of carbon balance in European forests was studied by Valentini et al. (2000). The soluble nitrogen concentration in paddy soils and its dynamics was studied by Murphy et al. (2000). The Potential nitrogen immobilization in grassland soils across a soil organic matter gradient was reported by Whiting and Chanton (2001). Jäckel et al. (2001) studied the effect of moisture, texture and aggregate size of paddy soil on production and consumption of CH_4. Simulation of C and N mineralization during crop residue decomposition: a simple dynamic model based on the C: N ratio of the residues was reported by Nicolardot et al. (2001). Saunders and Kalff (2001) studied Nitrogen retention in wetlands, lakes, and rivers. Analysis of carbon sinks in cropland soils and the emission of greenhouse gases from paddy soils: A review of work in China was done by Liping and Erda (2001). A meta-analysis was conducted by Johnson and Curtis (2001) on Effects of forest management on soil C and N storage. West and Marland (2002) studied the Net carbon flux from agricultural ecosystems: methodology for full carbon cycle analyses. Whereas Eve et al. (2002) studied national-scale estimation of changes in soil carbon stocks on agricultural lands. Net carbon flux from agricultural ecosystems was studied by West and Marland (2002). Lal (2002) studied Soil carbon sequestration in China through agricultural intensification, and restoration of degraded and desertified ecosystems and reported potential of soil C sequestration in China is 105–198 Tg C y^{-1} of SOC and 7–138 Tg C y^{-1} for soil inorganic carbon. Albrecht and Kandji (2003) reviewed the carbon sequestration in tropical agroforestry systems. Song et al. (2003) studied the carbon dynamics of wetland in the Sanjiang plain which reveals that wet and warm conditions during the early spring led to the greater value of CH_4 emission flux. Characterizing redox status of paddy soils with incorporated rice straw was done by Tanji et al. (2003). However, Springob and Kirchmann (2003) studied bulk soil C to N ratio as a simple measure of net N mineralization from stabilized soil organic matter in sandy arable soils. Gross nitrogen mineralization, immobilization, and nitrification rates as a function of soil C:N ratio and microbial activity was studied by Bengtsson et al. (2003). Bell et al. (2003) studied the priming effect and C storage in semi-arid to no-till spring crop rotations and suggests C inputs have a greater effect on mineralization of residual C compared to disturbance and endogenous metabolism appears to be the source of primed C. Choi and Wang (2004) studied the dynamics of carbon sequestration in a coastal wetland using radiocarbon measurements indicating that salt marshes have been and continue to be a sink for atmospheric carbon dioxide. Because of higher rates of C sequestration and lower CH_4 emissions, coastal wetlands could be more valuable C sinks per unit area than other ecosystems in a warmer world. However Zhang and He (2004) studied long-term changes in organic carbon and nutrients of an Ultisol under rice cropping in southeast China. Lal (2004) reported the total soil carbon sequestration of India as 39 to 49 Tg C y^{-1}. Galantini and Rosell (2006) studied long-term fertilization effects on soil organic matter quality and dynamics under different production systems in semiarid Pampean soils. Zhang et al. (2006) studied soil organic carbon changes as influenced by agricultural land use and management: a case study in Yanhuai Basin, Beijing, China. Kamoni et al. (2007) predicted the soil organic carbon stocks and changes in Kenya between 1990 and 2030. Cerri et al. (2007) predicted soil organic carbon stocks and changes in the Brazilian Amazon between 2000 and 2030 whereas Dawson and Smith (2007) studied the carbon losses from soil and its consequences for land use management and conclude with possible management options to reduce soil carbon loss and identify gaps in knowledge in order to better understand carbon processes in the terrestrial environment. Hutchinson et al. (2007) reported some perspectives on carbon sequestration in agriculture a significant mitigation option in China. Xie et al. (2007) reported the soil organic carbon stocks in China and changes from 1980s to 2000. Kaur et al. (2008) studied the soil organic matter dynamics as affected by long-term use of organic and inorganic fertilizers under maize-wheat cropping system. Thomsen et al. (2008) estimated soil C loss potentials from the C to N ratio as C to N ratio of a soil and its CO_2-C loss during incubation represents a simple but useful measure for predicting soil C loss potentials on a more general level. Nishimura et al. (2008) studied the effect of land use change from paddy rice cultivation to upland crop cultivation on soil carbon budget of a cropland in Japan. The results indicate that land use change from paddy rice cultivation to upland crop cultivation causes significant loss of carbon from cropland soil. However Smith (2008) studied land use change and soil organic carbon dynamics. Grybos et al. (2009) reported increasing pH drives organic matter solubilization from wetland soils under reducing conditions. Bernal and Mitsch (2012) compared the carbon sequestration in temperate freshwater wetland communities. Cui et al. (2013) studied changes in soil carbon sequestration and soil respiration following afforestation on paddy fields in north subtropical China. Whereas the carbon budget of South Asia was studied by Patra et al. (2013) The dynamics of redox control on carbon mineralization and dissolved organic matter along a Chronosequence of paddy soils was studied by Hanke et al. (2013). Morillas et al. (2013) studied wetting and drying events determine soil N pools in two Mediterranean ecosystems; suggest that the changes in wetting-drying cycles expected with global climate change may have a significant impact on the availability and turnover of organic and inorganic N. Adviento-Borbe and Linquist (2016) assessed the fertilizer N placement on CH_4 and N_2O emissions in irrigated rice systems of California. Rodríguez Martín et al. (2016) made an assessment of the soil organic carbon stock in Spain

3.2.2 Indian Scenario

Bhattacharyya et al. (2000) studied organic carbon stock in Indian soils and their geographical distribution. Changes in levels of carbon in soils over years of two important food production zones of India was also reported by Bhattacharyya et al. (2007a) This suggests that the agricultural management practices advocated through the national agricultural research system for the last 25 years did not cause any decline in SOC in the major crop- growing zones of the country. Bhattacharyya et al. (2007b) modeled soil organic carbon stocks and changes in the Indo-Gangetic Plains, India from 1980 to 2030. Whereas soil carbon storage capacity as a tool to prioritize areas for carbon sequestration. Bhattacharyya et al. (2008) explain the role of soils as one of the most important natural resources in enhancing carbon sequestration in soils. Kukal et al. (2009) studied soil organic carbon sequestration in relation to organic and inorganic fertilization in rice-wheat and maize-wheat systems. However, Grace et al. (2012) studied soil carbon sequestration and associated economic costs for farming systems of the Indo-Gangetic plain: A meta-analysis. Mohanty et al. (2013) studied carbon and nitrogen mineralization kinetics in the soil of rice-rice system under long-term application of chemical fertilizers and farmyard manure. Higher values of CO_2, N_2O, and rates of mineralization were recorded under aerobic condition than that under submergence. The amount of N released per unit C mineralization was higher in an aerobic system that may result in greater. Hanke et al. (2013) studied the redox control on carbon mineralization and dissolved organic matter along a chronosequence of paddy soils. Whereas Ray et al. (2014) reported soil and land quality indicators of the Indo-Gangetic

Plains of India. Describing the spatial distribution of soil and land quality with respect to major crops of IGP. Venkanna et al. (2014) studied carbon stocks in major soil types and land systems in the semiarid tropical region of southern India. However, Pal et al. (2015) reported that the carbon sequestration in Indian soils: present status and the Potential. The author also studied the Carbon sequestration and its relation with some soil properties of East Kolkata Wetlands (a Ramsar Site): a spatiotemporal study using radial basis functions (Pal et al. 2016). Gupta et al. (2016) studied the mitigation of greenhouse gas emission from a rice-wheat system of the Indo-Gangetic plains. Whereas Ma et al. (2016) studied the changes in soil organic carbon stocks of wetlands on China's Zoige plateau from 1980 to 2010. Bharali et al. (2017) estimated the Methane emission from irrigated rice ecosystem: relationship with carbon fixation, partitioning, and soil carbon storage.

3.3 RESULTS

3.3.1 Ambient maximum and Minimum Temperature

The ambient temperature varied from the highest value of 39.68°C to the lowest value of 27.61°C with a mean value of 34.40 ± 3.3°C during the study period from 2011-12 to 2013-14 (Fig. 3.1). Seasonally significant variation in the ambient-maximum temperature was observed between crop season (CS) and fallow season (FS) ($p<0.01$). During the period highest temperature was observed in FS compared to that of CS. In CS-I ambient-maximum temperature varied from 27.61 °C to 36.6°C with a mean value of 30.96° ± 2.23 °C, whereas in CS-II ambient-maximum temperature varied from 31.38 to 37.4 °C with a mean value of 34.5 ± 1.6 °C. During FS ambient-maximum temperature ranged from 35.34 °C to 39.68 °C with a mean value of 38.07 ± 1.2°C. The annual ambient-maximum temperature did not differ significantly between the years from 2011 to 2014. During the observation period, the ambient-minimum temperature also followed a similar pattern as that of ambient-maximum temperature. During the period ambient-minimum temperature varied from 21 to 28 °C with a mean value of 24.08 ± 1.3 °C. The seasonal ambient-minimum temperature was lowest in CS-II with a mean value of 23.3 ± 0.9 °C, followed by CS-I with a mean value of 24.3 ± 0.9°C and the highest was observed in FS with a mean value of 24.65 ±1.8 °C.

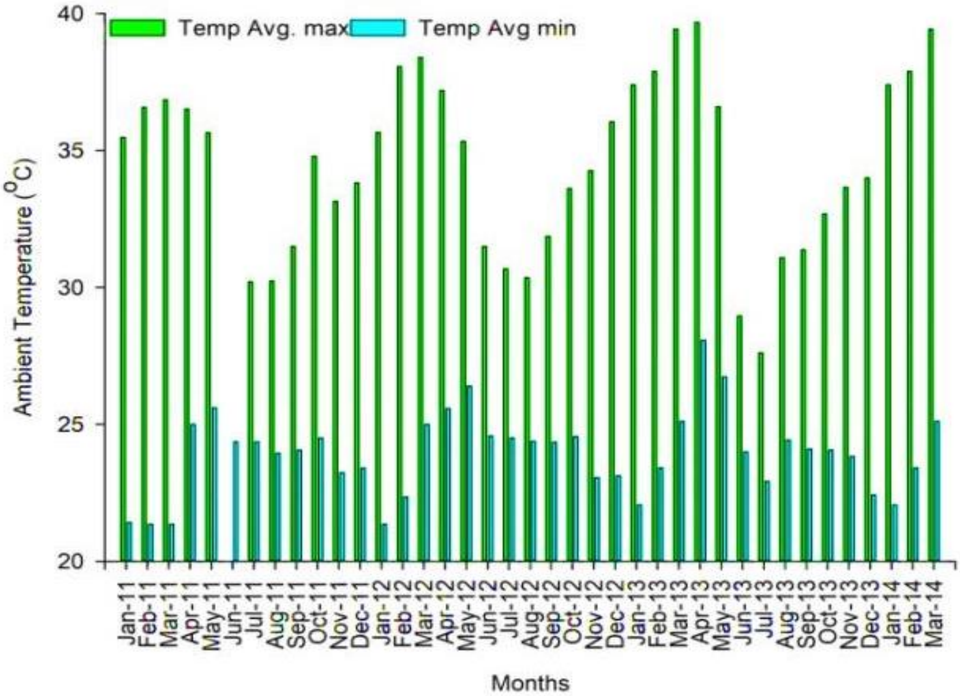

Figure 3.1 Mean monthly ambient-maximum and ambient-minimum temperature variation in the rice paddies of Padayatti during 2011 to March 2014

3.3.2 Diurnal Variations: Ambient temperature, Humidity, and Total solar radiation

Diurnal variation in an ambient temperature varied significantly between day and night cycles with a mean value of 25.16 ± 0.34 °C. Ambient temperature was observed lowest during the early morning hours of 04.00 am with a mean value of 22.5 ± 1.2 °C. With time the temperature gradually increased towards noon reaching the maximum temperature of 32.15 ± 2.4 °C at 02:15 pm. The temperature was observed gradually decreasing towards night reaching the lowest value of 22.8 ± 1.8 °C during 03:45 am hours (Fig. 3.2).

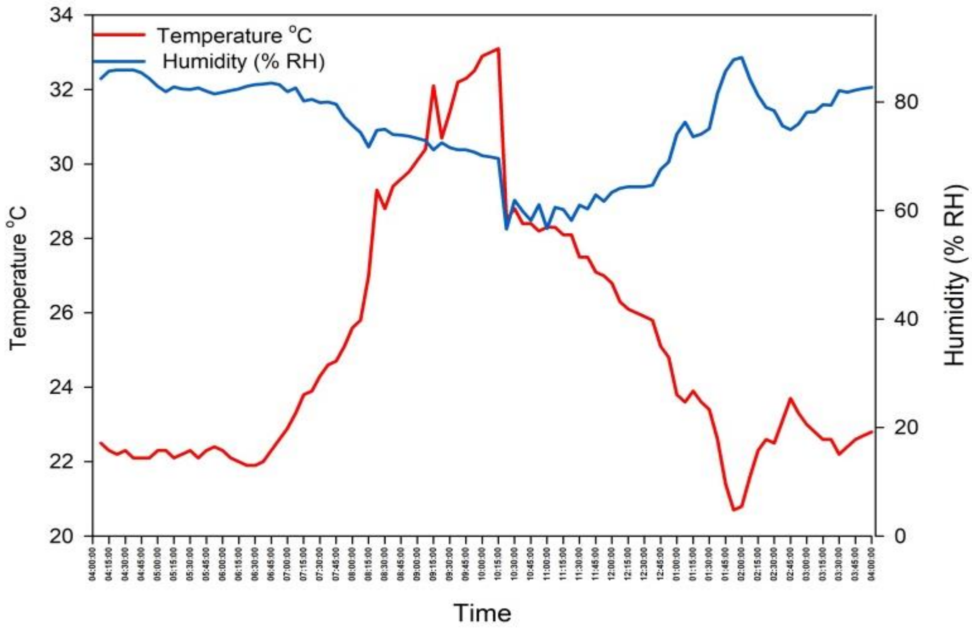

Figure 3.2 Diurnal variation of ambient temperature and humidity from rice paddies of Padayatti Palakkad

Diurnally humidity also varied significantly between day and night cycles. Variation in humidity pattern was inverse to that of ambient temperature (Fig. 3.2). During the study highest value of relative humidity was observed during the early hours of 04:00 am hours with a mean value of 84.3 ± 2.3% RH. However, the lowest % of relative humidity was observed between the afternoon hours of 05 to 06 pm with a mean value of 58.2 ± 3.8% RH which gradually increases towards night.

Diurnal total solar radiation also varied significantly between day and night cycles. Solar flux was observed positive towards day hours ranging from 0.25 to 775W m^{-2} during 6.00 am to 6.00 pm and decreases towards night (Fig. 3.3). During the study the total solar flux started to increase from 06:00 am hours with a mean value of 2±0.12 $Wm^{-2,}$ and it reached the highest value of 775 Wm^{-2} at 12:00 pm. Solar flux eventually started to decrease towards evening hours with a lowest observed value of 2.25 Wm^{-2} during 06:00 pm hours and it decreases towards night to a constant value of 1 Wm^{-2}.

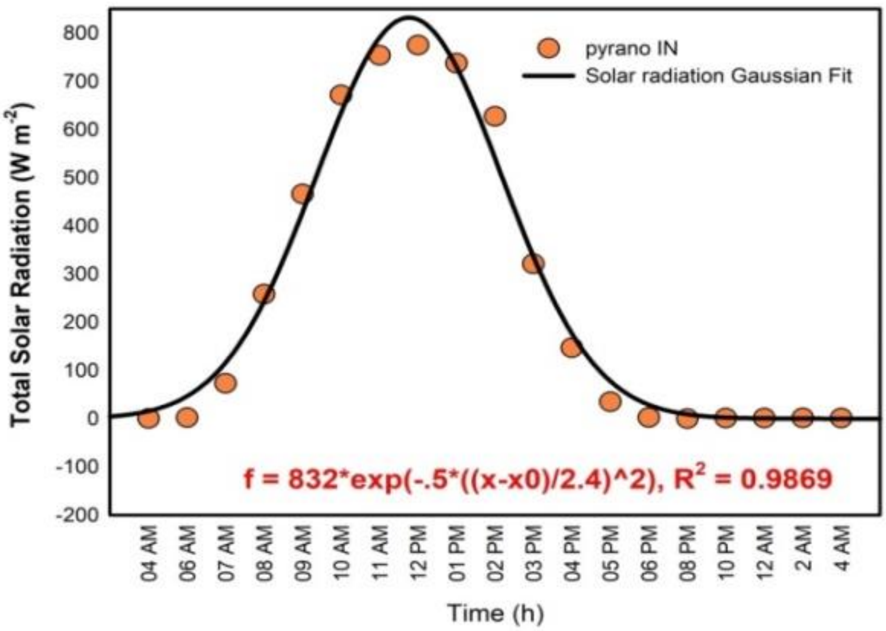

Figure 3.3 Diurnal net solar radiation from rice paddies of Padayatti, Palakkad during 2011-12 to 2013-14

3.3.3 Rainfall

The seasonal distribution of rainfall from the rice paddy wetland of Padayatti during the period from 2011 to 2014 is shown in Fig. 3.4. The average rainfall during the entire study period from 2011 to 2014 was 152± 31.7 mm. During the period the highest annual rainfall was observed during the year 2014 with a mean value of 162.82 ± 61.1 mm. However, the significant seasonal difference in rainfall was observed between CS-I and CS-II ($p< 0.05$). in which highest rainfall was observed during CS-I with a mean value of 290.92±40 mm followed by FS with a mean value of 148.14 ± 71 mm. However, the lowest rainfall was observed during CS-II with a mean value of 28.3 ± 31.79mm.

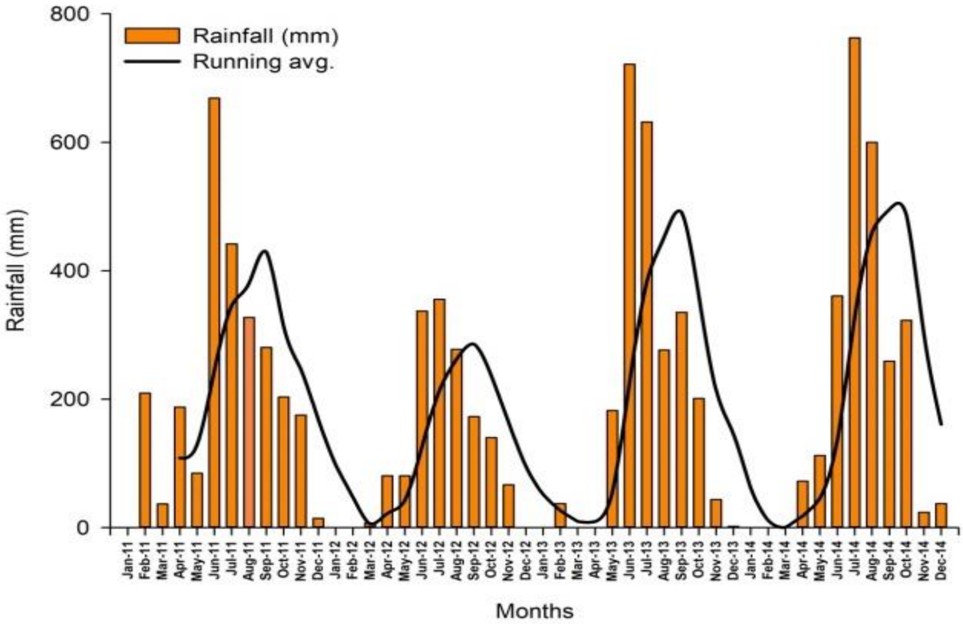

Figure 3.4 Mean monthly rainfalls in the rice paddies of Padayatti, Palakkad during 2011 to 2014

3.3.4 Soil surface Temperature

The average soil surface temperature (5cm) during the study period varied from 21 to 36 °C with a mean value of 26.7 ± 3.3 °C (Fig. 3.5). Seasonally, a significant difference ($P<0.01$) in soil temperatures were observed between CS and FS, with the highest observed temperature in FS with a mean value of 30.35 ± 3.3 °C. However, variations in soil temperature were observed between the crop growing seasons of CS-I and CS-II in which highest temperature was observed in CS-I with a mean value of 26.21 ± 1.8 °C. Whereas the lowest value was observed in CS-II, with a mean value of 24.27 ± 1.96 °. Soil temperature was observed positively correlated with air temperature ($r = 0.401$, $p<0.05$) and negatively correlated with soil moisture content ($r = -0.676$, $p<0.01$).

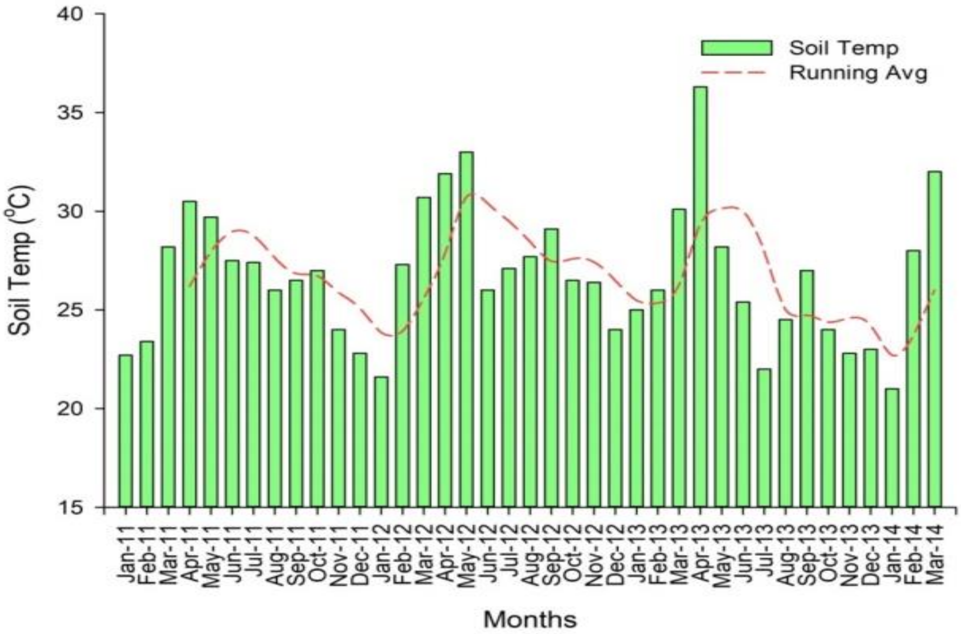

Figure 3.5 Mean monthly soil temperature variation in the rice paddies of Padayatti, Palakkad during 2011-12 to 2013-14

3.3.5 Soil Moisture Content

Soil moisture content (SMC) in Padayatti paddy wetlands differ significantly between seasons ($p<0.01$), however, it lacks annual and spatial variations. During the entire study period, significant seasonal variations ($p<0.01$) in SMC (%) was observed between crops growing and summer fallow seasons. During 2011, SMC was observed higher in CS-I, followed by CS-II and lowest during FS with mean values of 49.02 ± 2.35%, 44.90 ± 1.56% and 12.04 ± 6.91% respectively. In 2012 highest value of SMC was observed in CS-II, followed by CS-I and lowest in FS. During this period SMC varied from the highest value of 48.75%to the lowest value of 31.48 % with a mean value of 42.60% in CS-I while it varied from 53.48 % to 38.79 % with a mean value of 18.05 ± 48.05 % in CS-II. During the fallow seasons, SMC varied from 16.19 to 8.23% with a mean value of 12.86%. During the year 2014, SMC was observed highest in CS-I followed by CS-II and lowest in FS respectively. In CS-I, SMC varied from 14.76 to 6.91 % with a mean value of 10.88 ± 3.9%, whereas in CS-II SMC varied between 52.48 to 37.63

% with a mean value of 42.99 ± 3.2 %. However, in FS it varied from the highest value of 14.76 % to the lowest value of 6.91 %with a mean value of 10.83% (Fig. 3.6). In the present study, SMC was found highly dependent on irrigation and flooding pattern as part of the agricultural and field management operations.

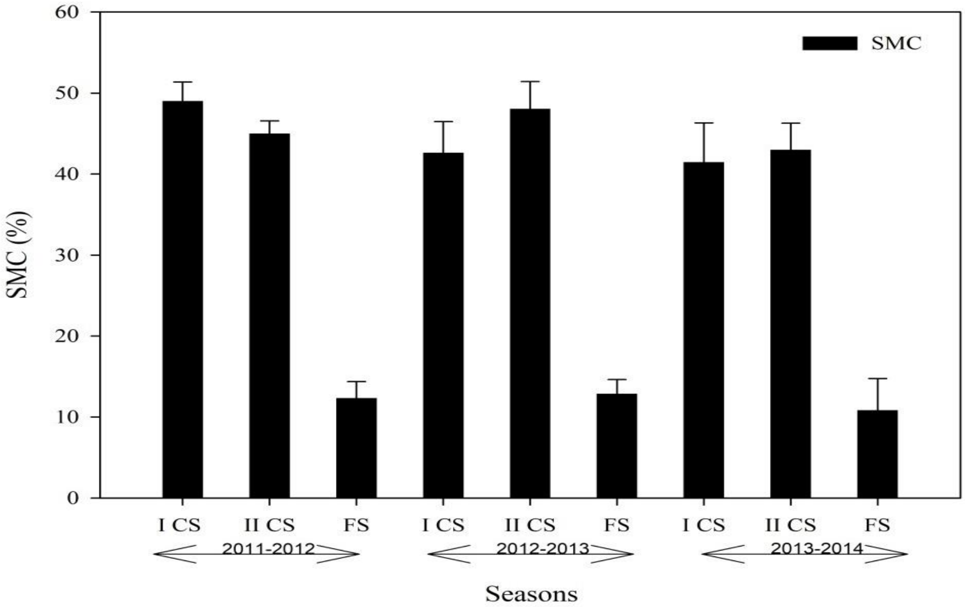

Figure 3.6 Seasonal variations in soil moisture content (SMC) of rice paddies of Padayatti, during 2011-12 to 2013-14

3.3.6 Soil Texture

Soil textural properties of Padayatti wetland showed significant ($p<0.05$) seasonal variation between sand, clay, and silt fractions. However, it lacks seasonal and annual variations. Based on the sand silt and clay fractions soils of Padayatti are classified into silty loam, clay loam, and loam fractions during the study period (Fig. 3.7). In St.1 the texture of the soil observed was silt loam with sand silt and clay in the order of 22.27%, 52.21%, and 25.5 % respectively. While in St.2 it was in the order sand (22.94%), silt (51.76%) and clay (25.94%). In St.3 it varied between sand (21.3%), silt (51.65%) and clay (27.01%). Among stations, St.4 and St.5 are classified as clay loam with sand, silt and clay % in the order 27.86%, 44.09%and 28.03 % in St.4 and 26.54%, 47.2%and 26.4% St. 5.

Textural characteristics of St.6 and St.7 is of loam in nature with sand, silt and clay in the order 34.05%, 42.2% and 23.2% in St.6 and 33.05%, 41.25% and 26.1% in St.7 respectively.

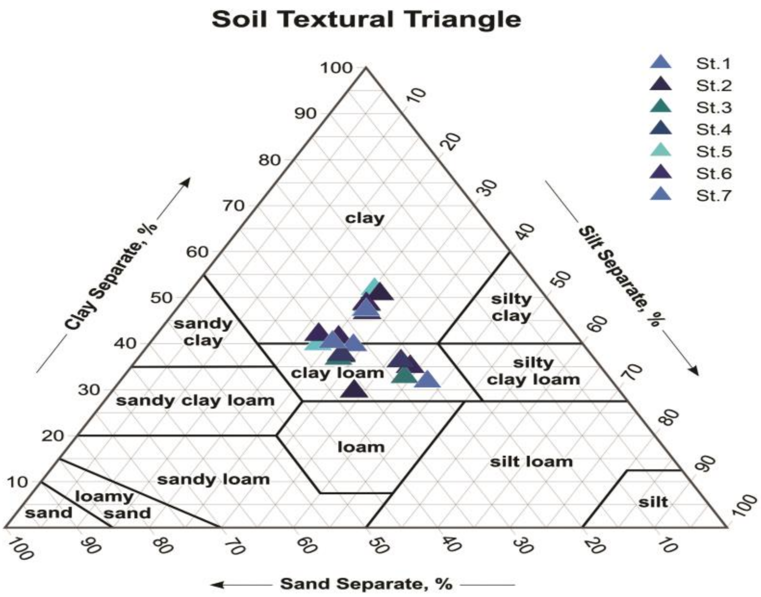

Figure 3.7 Soil textures of the Padayatti rice paddy during the study period

3.3.7 Soil pH and Eh

The soil pH during the study period varied from 5.12 to 6.84 with an average value of 6.06 ± 0.55 (Fig. 3.8). During the period, soil pH lacks significant variation both seasonally and annually. In CS-I, pH varied from the lowest value of 5.15 to the highest value of 6.76 with a mean value of 6.02 ± 0.57. Whereas in CS-II, pH varied from the lowest value of 5.55 to 6.84 with a mean value of 6.18 ± 0.47.However, in FS pH varied from 5.12 to 6.55 with a mean value of 5.9 ± 0.64. Annually highest pH was observed in 2011-12 and 2012-13 with an average value of 6.14 ± 0.54 and 6.16 ± 0.6 respectively. Lowest pH was observed in the year 2012-2014 with a mean value of 5.85 ± 0.52. However, pH had a significant negative correlation with DPW significant at p<0.05, r = -596.

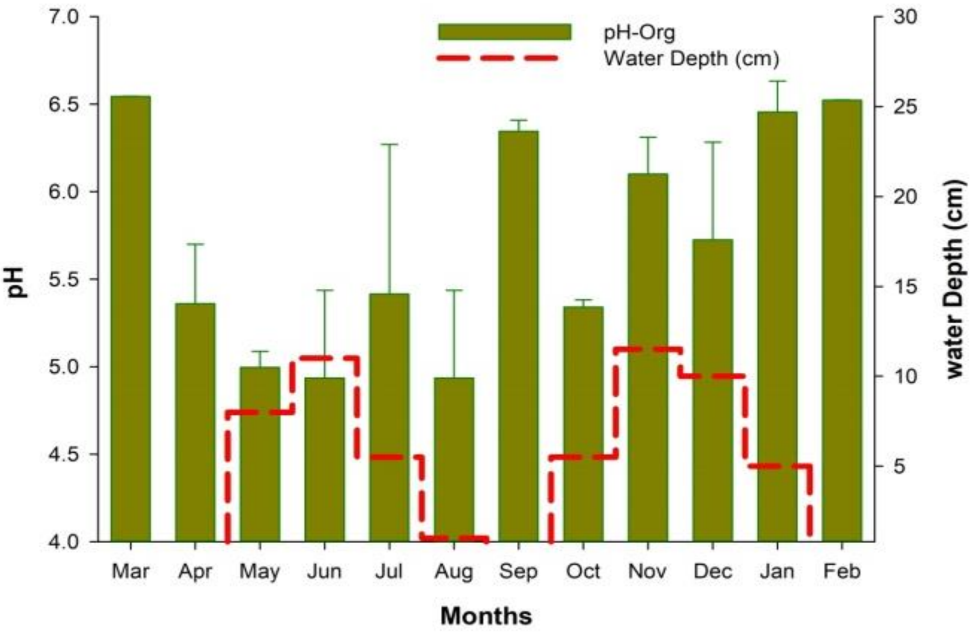

Figure 3.8 Mean monthly pH variation in the rice paddies of Padayatti, Palakkad during 2011-2012 to 2013-2014

The soil Eh during the study period varied from -339 mV to 126 mV with an average value of -89.65± 14.5 mV (Fig. 3.9). During the observation period, soil Eh varied significantly with flooded CS and dry FS ($p < 0.05$). In CS-I, Eh varied from -339 mv to 50 mV with a mean value of -71.14 ± 21.4 mV. Whereas in CS-II, the Eh was observed varying from -313 mV to 26 mV with a mean value of -166.8±19.55 mV. However, in contrast to the flooded CS, Eh was observed positive during the dry FS with a mean value of 11.94 ± 20.4 mV. In the present study, Eh was observed positively correlated with air ($p < 0.01$) and soil temperatures ($r = 0.602$, $p < 0.01$) however Eh was negatively correlated with soil moisture content($r = -0.692$, $p < 0.01$).

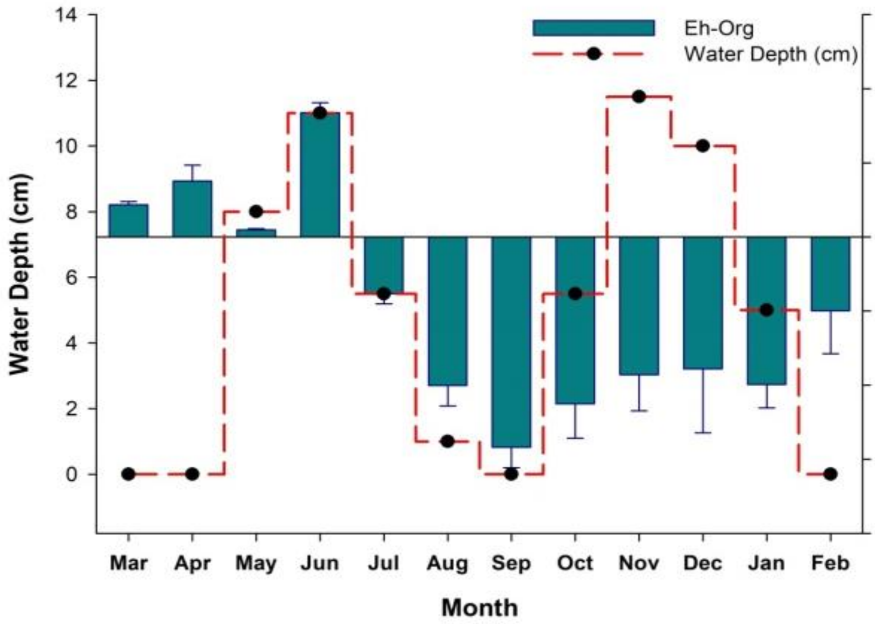

Figure 3.9 Mean monthly Eh variation in the rice paddies of Padayatti, Palakkad during 2011-12 to 2013-14

In the present study, soil pH was observed decreasing towards increasing soil depth (Fig. 3.10). In the top 0 to 5 cm of the soil profile, pH was observed with a mean value of 6.53 ± 0.51 which slightly decreased to 6.5 ± 0.14 towards 05 to 10cm. In the 10 to 15 cm of the soil profile pH further decreased to a mean value of 6.29 ± 0.18 and it remained in 6.11± 0.24 in the 15 to 20 cm profile of the soil. Depth wise profile of soil Eh (Fig. 3.10) showed a decreasing trend towards 0 to 5 and 5 to 10 cm of soil profile with a mean Eh value of -321 ± 1.35 and -385 ±0.584 respectively. However it increased to -329 to -284 mv in the 10to 15 and 15 to 20 cm profile of the soil.

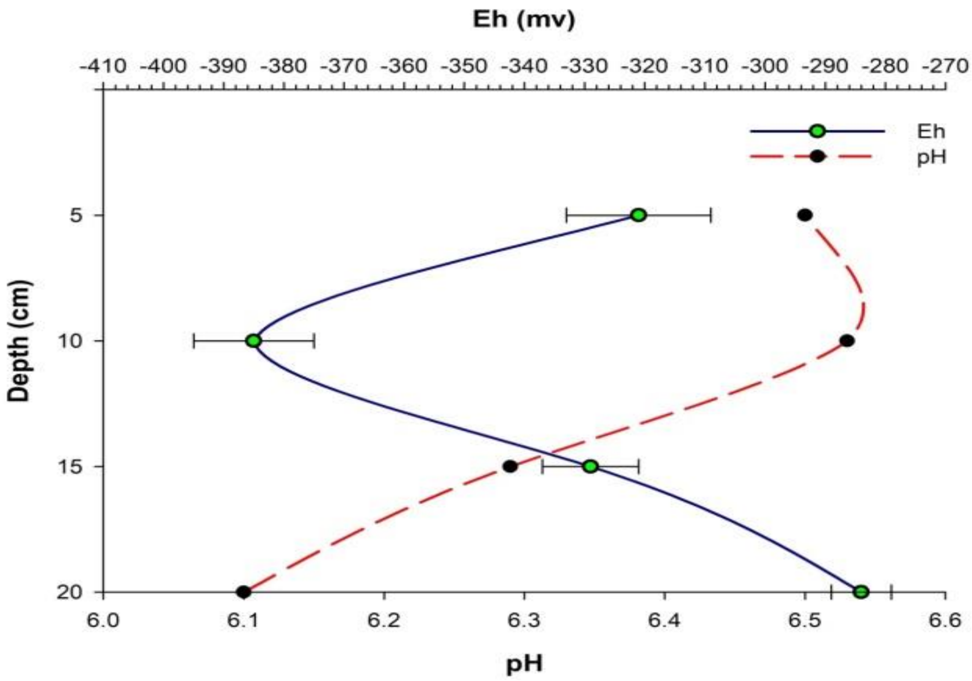

Figure 3.10 Soil profile showing depthwise distribution of pH and Eh from rice paddies of Padayatti, Palakkad during 2011-12 to 2013-14

3.3.8 Sodium, Potassium, and Calcium

The average concentration of sodium in the soil of Padayatti wetland was 0.441 ± 0.11 mg g^{-1}(Fig. 3.11). The Na concentrations in soils lack significant annual variations and it was 0.438 ± 0.13 mg g^{-1} in 2011-12 and 0.447 ± 0.84 mg g^{-1} in 2012-13 and that of 0.42 ± 0.11 mg g^{-1} in 2013-14. Seasonally, the highest concentration of Na was observed in FS while it lacks significant variation between seasons. Among crop, seasons mean value of Na was 0.453 ± 0.14 mg g^{-1} in CS-I whereas it was 0.416 ± 0.076 mg g^{-1} in CS-II and 0.464 ± 0.12 mg g^{-1} in FS. Spatially, the highest concentration of Na was observed in St.5 (0.511 ±0.21 mg g^{-1}) whereas lowest concentration was observed in St. 6 with a mean value of 0.34 ±0.14 mg g^{-1}.

The average concentration of K in the rice paddy soils of Padayatti was 0.69 ± 0.479 mg g^{-1} (Fig. 3.11). Annually K varied from a mean value of 0.68 ± 0.49 mg g^{-1} during the year 2011-12, whereas it was 0.691 ± 0.46 mg g^{-1} in 2012-

2013 and 0.65 ± 0.47 in 2013-2014 respectively. Among seasons highest concentration of K was observed in CS-I (0.8 ±0.65 mg g^{-1}) and lowest in CS-II (0.548 ± 0.26 mg g^{-1}). Spatial distribution of K among seven stations showed the highest value in St. 1 (0.88 ± 0.6 mg g^{-1}) and lowest value in St. 5 (0.20 ± 0.14 mg g^{-1}). The concentration of K in paddy soils lack significant variation annually, seasonally and spatially during the present study.

The average concentration of Ca from the rice paddy soils of Padayatti was 2.75 ± 1.06 mg g^{-1} (Fig. 3.11). The highest concentration of Ca was observed during 2012-2013 (2.77± 1.02 mg g^{-1}) whereas lowest concentration was observed during the year 2013-2014 (2.75 ± 0.06 mg g^{-1}). Seasonal variation in the concentrations of Ca was observed higher in CS-1 with an average value of 3.07 ± 1.1 mg g^{-1}. However, the lowest value of Ca was observed in CS-II with an average concentration of 2.4± 1.01 mg g^{-1}. Spatially, among the seven stations, the concentration of Ca was observed highest in St. 5 (3.1 ± 0.14 mg g^{-1}), and a lowest value that was observed in St. 4 with a mean value of 23.± 0.93 mg g^{-1}.

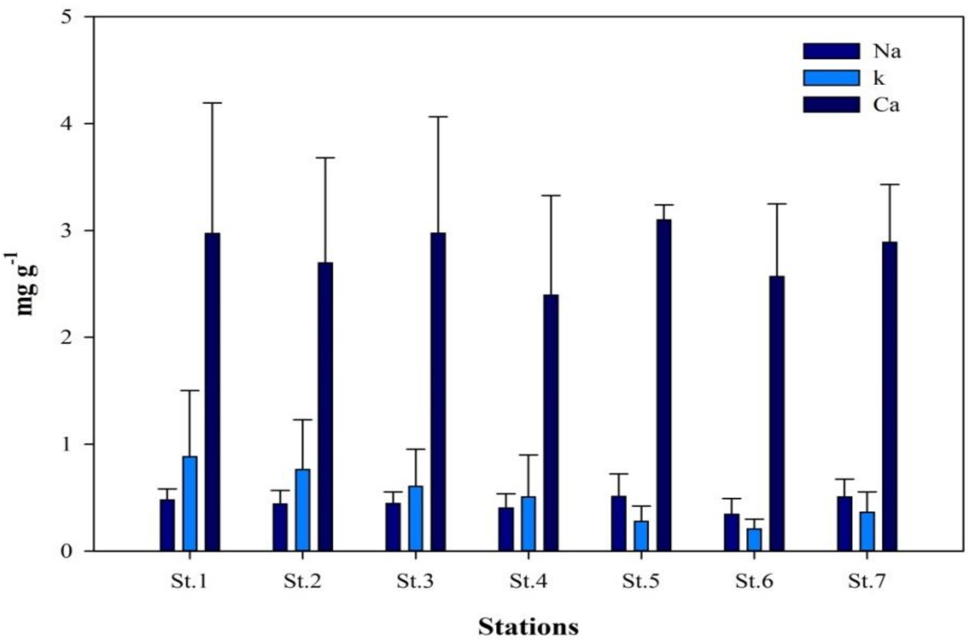

Figure 3.11 Mean spatial distribution of Na, K and Ca from rice paddies of Padayatti, during 2011-12 to 2013-14

3.3.9 Available Phosphorus

The average concentration of P in the rice paddy soils of Padayatti was 75.24 ± 56 mg g^{-1}. The mean value of P during 2011-2012 was 51.92 ± 23.69 mg g^{-1} ,and it was 121.88 ± 33 during 2012-2013. However, it was 62.58 ± 48 mg g^{-1} during 2013-2014. Seasonally, concentrations of P varied with the highest value of 93.63 ± 30 mg g^{-1} in FS and the lowest value of 66 ± 54 mg g^{-1} during CS-II. Among stations, the highest concentration of P was observed in St. 1 with a mean value of 81.89 ± 65.13 mg g^{-1} and lowest in St.5 with a mean value of 54.35 ± 24.81 mg g^{-1} **(**Fig. 3.12).

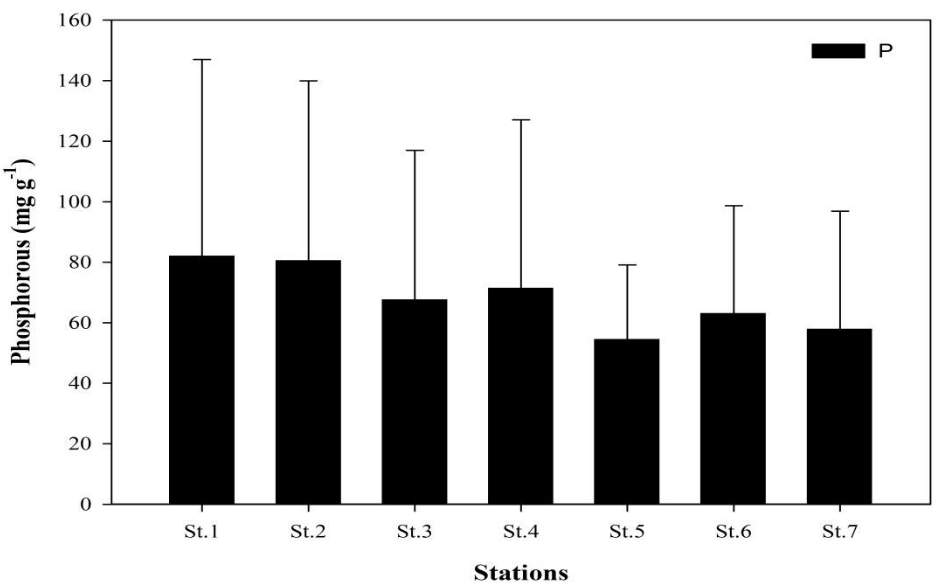

Figure 3.12 Mean spatial distributions of Phosphorous rice paddies of Padayatti during 2011-12 to 2013-14

3.3.10 Total Nitrogen

The surface distribution of TN (Fig. 3.13) differs significantly between seasons and stations, while its lacks significant annual variations. Seasonally, a significant difference in TN was observed between CS and FS. The highest concentration of TN was observed in CS-I ranging from 2.41 to 3.57 g Kg^{-1} with a mean value of 3.004 ± 0.13 g Kg^{-1}. Whereas lowest value was observed in FS, ranging from 1.74 to 2.87 g Kg^{-1} with a mean value of 2.30 ± 0.124 g Kg^{-1}. TN followed a clear seasonal pattern with the lowest value in the FS which increased towards CS-II and then decreases towards the FS. In contrast to seasonal variation, TN lacks significant annual variation ranging from the lowest value of 2.59± 0.18 g Kg^{-1} in 2011-2012 to the highest value of 2.76 ± 0.11 g Kg^{-1} in the year 2013-2014. Spatially TN showed significant variation ($p < 0.05$) ranging from the lowest value in St.1 (2.05 ± 0.12 g Kg^{-1}) to the highest concentration in St.5 (2.9 ± 0.07 g Kg^{-1}) (Fig. 3.14).

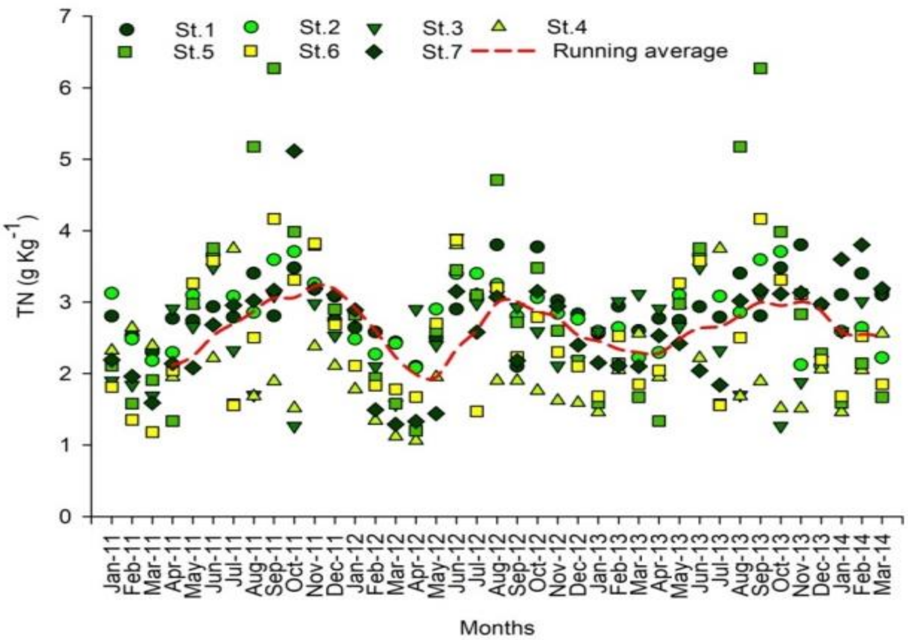

Figure 3.13 Temporal variations in TN from the rice paddies of Padayatti during 2011-12 to 2013-14

The surface distribution of soil TN stock was showed no significant variations between crop seasons and years. Annually during both the years 2011-12 and 2013-14 showed a similar trend in TN stock with a mean value of 11.5 ±1.22 Mg ha^{-1} and 11.07 ± 0.74 Mg ha^{-1} respectively. However, the lowest TN stock value was observed in 2012-2013 with a mean value of 11.53 ±0.98 Mg ha^{-1}. Seasonally TN lacks significant variations where highest TN stock values were observed in CS-I (4.17 ± 0.188 Mg ha^{-1}) followed by FS (3.63 ± 0.24 Mg ha^{-1}) and lowest was observed during CS-II (3.57 ± 0.13 Mg ha^{-1}). The net TN stock of the rice paddy soils of Padayatti, Palakkad during the observation period from 2011-12 to 2013- 14 was estimated as 34.14 ± 1.72 Mg ha^{-1}.

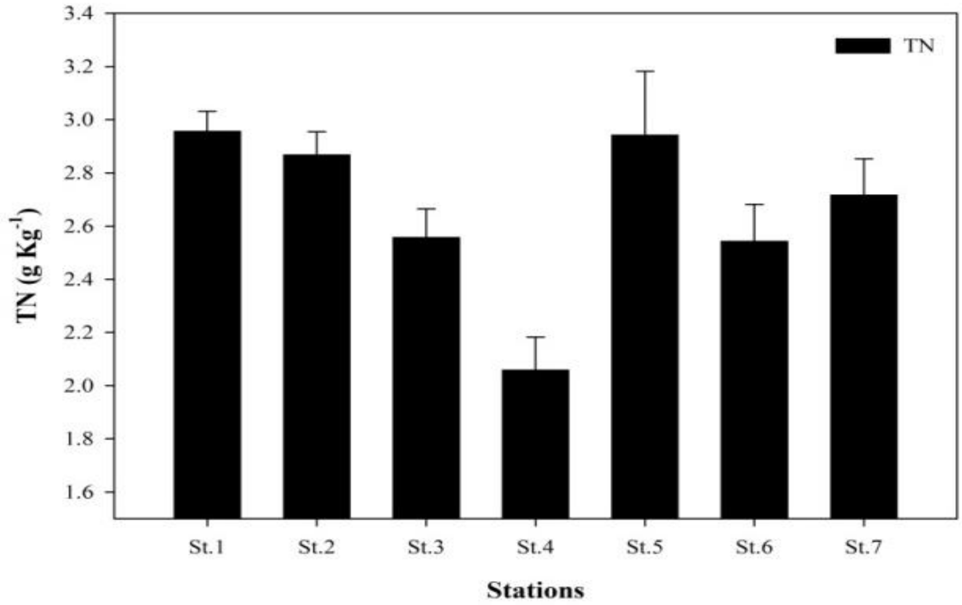

Figure 3.14 Spatial variations in the distribution of TN from rice paddies of Padayatti, during 2011-12 to 2013-14

3.3.11 Available Nitrogen

The mean concentration of AN in rice paddy soils of Padayatti was 0.0471 ±0.03%. The highest concentration of available nitrogen was observed during the year 2011-2012 with a mean value of 0.0481 ± 0.04 %, and the lowest value of 0.045 ± 0.08% was observed during 2013-2014. Among the seasons, concentrations of available nitrogen were observed lowest in FS with a mean value of 0.039 ± 0.012 %, and the highest value was observed in CS-II with a mean value of 0.05 ± 0.02%. Spatially highest concentrations of available nitrogen were observed in St.1 with a mean value of 0.057 ± 0.07 % whereas the lowest value of 0.027 ± 0.03 was observed in St.7 (Fig. 3.15).

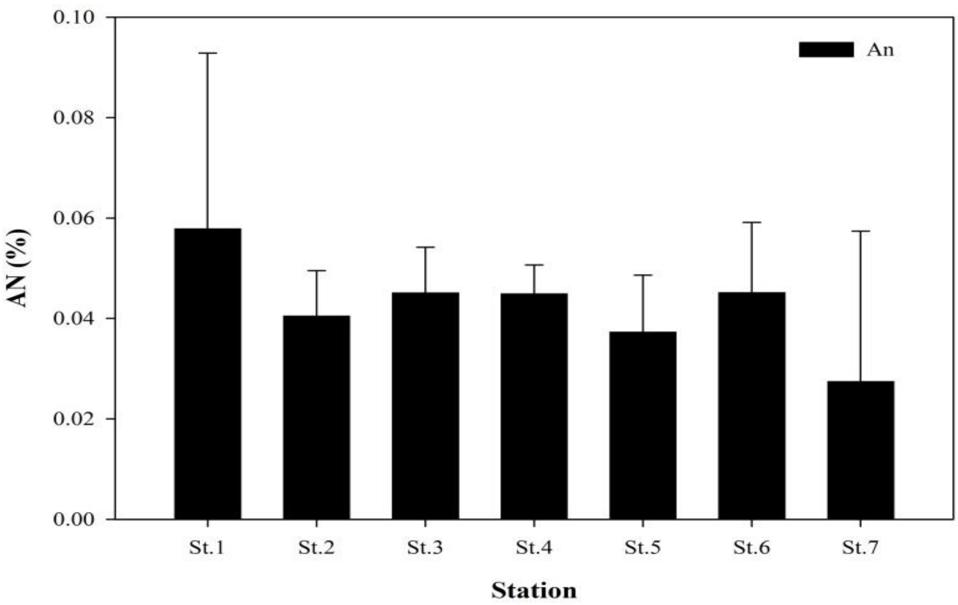

Figure 3.15 Mean spatial distribution of available nitrogen of rice paddies of Padayatti during 2011-12 to 2013-14

3.3.12 Soil Organic Carbon (SOC)

The surface distribution of SOC in the rice paddy soils of Padayatti varied temporarily, spatially and annually during the observation period (Fig. 3.16). Seasonally SOC concentration was 5.57 ± 0.14 g Kg^{-1}, 5.42 ± 0.13 g kg^{-1} and 5.93 ± 0.15 g Kg^{-1} in CS-I, CS-II and in FS respectively with a seasonal significant difference among CS and FS ($r = 0.07$, $p< 0.05$). During the period the highest concentration of SOC was observed in the FS ranging from 5.6 to 6.22 g Kg^{-1} with a mean value of 5.93 ± 0.15 g Kg^{-1}. However, the lowest value was observed CS-II ranging from 5.15 to 5.68 g Kg^{-1} with a mean value of 5.42 ± 0.135 g Kg^{-1}. Annual variation in SOC was significant at $p<0.05$ level in which highest concentration of SOC was observed during 2011-12 followed by 2012-13 and the lowest concentration was observed in 2013-14 respectively. Annually highest concentration of SOC was observed during the year 2011-2012 with values ranging from 5.62 to 6.15 g Kg^{-1} with a mean value of 5.88 ±0.135 g Kg^{-1}. The year 2013-2014 showed the lowest concentration in SOC ranging from 4.98 to 5.57 g Kg^{-1} with a mean value of 5.25 ± 0.158 g Kg^{-1}. Spatially SOC varied significantly with stations ($p<0.01$).During the period highest concentration SOC was observed in St. 7 with a mean value of 6.4 ± 0.29 g Kg^{-1}, whereas, the lowest concentration of 4.9 ± 0.21 g $Kg^{-1}$was observed at St.4 (Fig. 3.17).

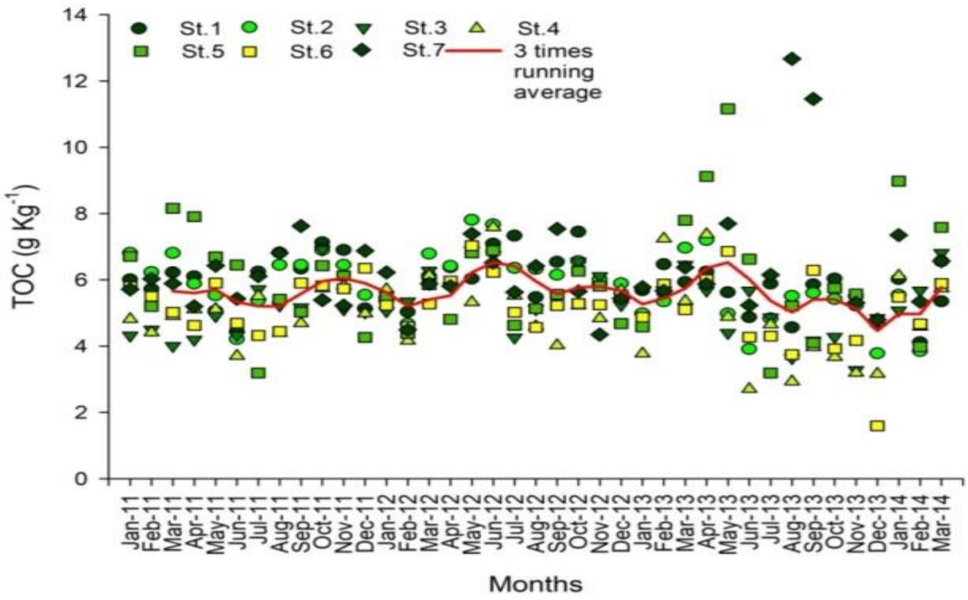

Figure 3.16 Mean temporal distribution of SOC from rice paddies of Padayatti during 2011-12 to 2013-14

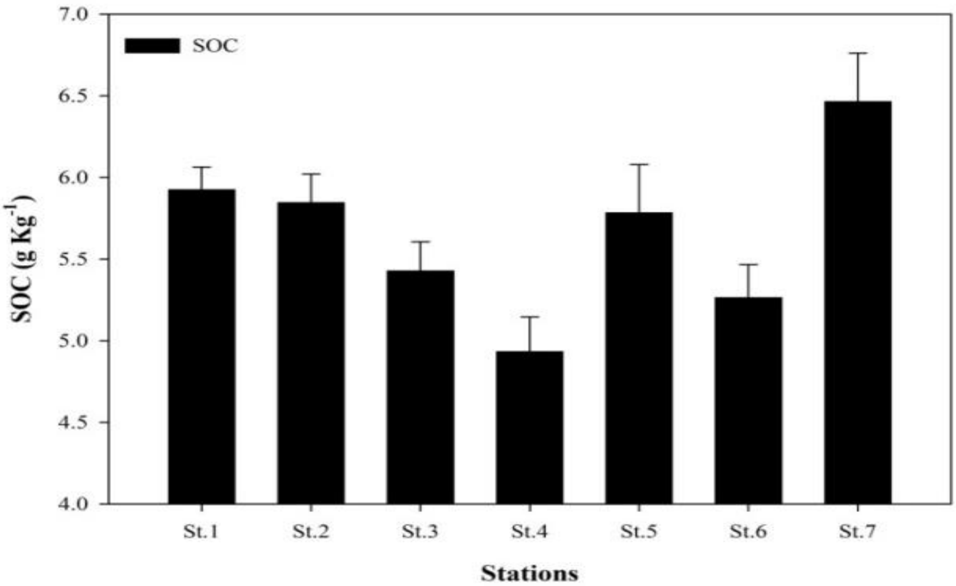

Figure 3.17 Mean Spatial variation of SOC in the rice paddies of Padayatti during 2011-12 to 2013-14

The annual and seasonal distribution of SOC stock among rice paddies of Padayatti, Palakkad did not differ significantly during the observation period (Table 3.1). Annually SOC stock was found higher in 2011-2012 with a mean value of 25.13 ± 1.44 Mg ha^{-1}. However, there was a decrease in the SOC stock in the subsurface soil depths of 0-15cm during the successive years of rice cultivation with a mean value of 24.68 ± 0.91 Mg ha^{-1} in 2012-2013. The lowest SOC stock was observed in 2013-2014 with an average value of 23.50 ± 2.08 Mg ha^{-1}. On a seasonal basis of rice cultivation highest SOC stock was observed in FS with a mean value of 8.48 ± 0.30 Mg ha^{-1} followed by CS-I (8.21 ± 0.32 Mg ha^{-1}) and lowest SOC stock was observed in CS –II (7.73 ± 0.30 Mg ha^{-1}). The net organic carbon stock of the rice paddy soils of Padayatti, Palakkad during the observation period from 2011-12 to 2012-14 was estimated as 8.145 ± 0.18 Mg ha^{-1}.

3.3.13 Soil Inorganic Carbon (SIC)

Soil inorganic carbon varied both temporally, spatially and annually during the observation period (Fig. 3.18). Seasonally, the highest concentration of SIC was observed in CS-I ranging from 6.65 to 7.73 g Kg^{-1} with a mean value of 7.19 ± 0.27 g Kg^{-1}. However, the lowest concentration of SIC was observed in the FS ranging from 5.2 to 6.3 g Kg^{-1} with a mean value of 5.81 ± 0.29 g Kg^{-1}. During the crop growing seasons, SIC started to increase from May in CS-I and had its higher concentration in October during CS-II, and it decreased toward FS. Annually significant variations ($p<0.01$) in SIC was observed with the highest concentration in the year 2012-2013 with a mean value of 8.35 ± 0.263 g Kg^{-1} and lowest concentration towards 2013-2014 with a mean value of 3.49 ± 0.31 g Kg^{-1}. Spatial distribution of SIC also showed significant variation ($p<0.05$). Spatially highest concentration was observed in St.5 (8.06 ± 0.62 g Kg^{-1}) whereas lowest was reported in St.3 (6.13 ± 0.5 g Kg^{-1}) (Fig. 3.19).

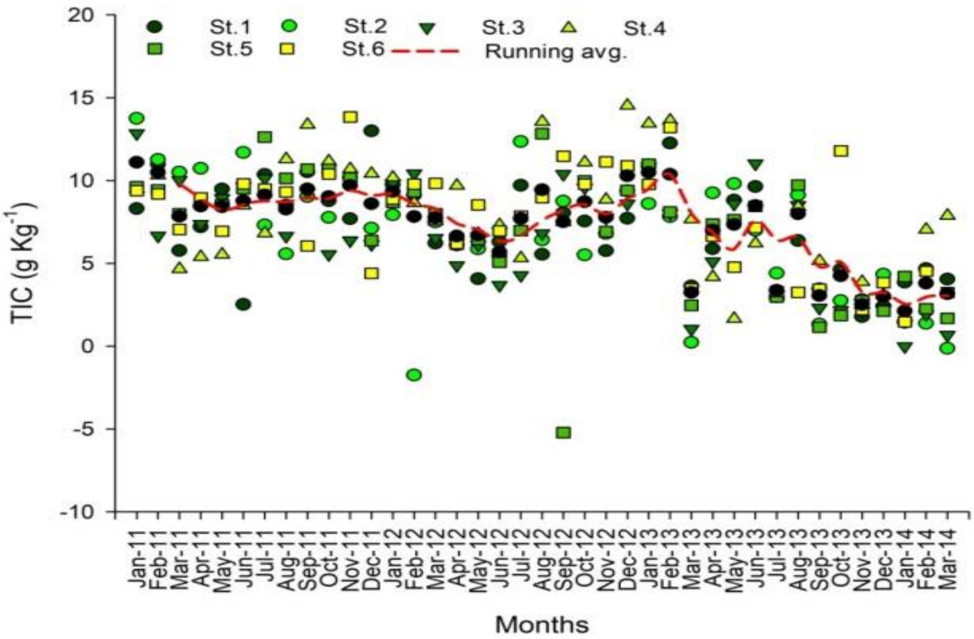

Figure 3.18 Mean temporal distribution of SIC of the rice paddies of Padayatti during 2011-12 to 2013-14

The one way ANOVA of sub-surface SIC stock showed significant annual variation ($p< 0.05$). The annual SIC stock was observed decreasing during the period from 2011-12 to 2013-14 (Table 3.1). The SIC stock was observed moderately stable during the period 2011-12 and 2012-13 with a mean value of 11.7 ± 0.53 and 11.72 ± 0.82 Mg ha^{-1} respectively. However, a significant decreasing trend in SIC stock was observed during the cultivation period 2013-2014 with a mean value of 63.2 ± 0.84 Mg ha^{-1}. Seasonally SIC stock lack significant differences with a mean value of 10.18 ± 0.92 Mg ha^{-1} in CS-I, 10.22 ± 1.32 Mg ha^{-1} in CS-II and 9.3 ± 0.60 Mg ha^{-1} in FS respectively. Overall the net SIC stock of the rice paddy soils of Padayatti during the observation period from 2011-12 to 2012- 14 was estimated as 89.26 ± 9.49 Mg ha^{-1}.

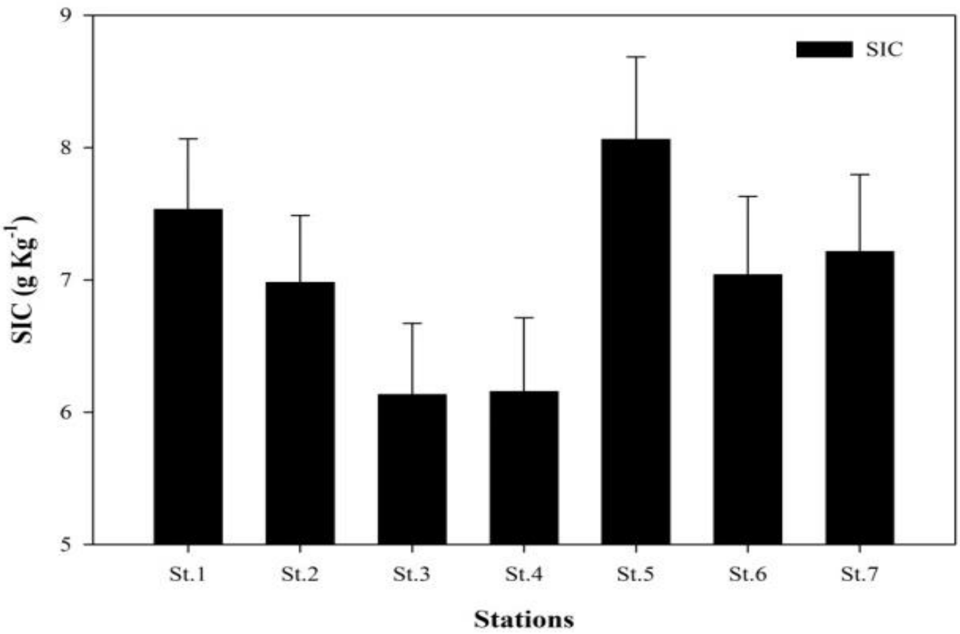

Figure 3.19 Spatial distribution of SIC from rice paddies of Pdayatti during 2011-12to 2013-14

3.3.14 Soil Total Carbon

The surface distribution of TC during the entire study period varied form 6.94 to 16.37 with a mean value of 12.67 ± 0.49 g Kg^{-1}. During the period significant annual and spatial variations were observed while TC lacks seasonal variations (Fig. 3.20.). Seasonally TC varied with a mean value of 13.19 ± 0.34 g kg^{-1}, 12.38 ± 0.42 g $kg^{-1}$and 12.46 ± 0.36 g kg^{-1} in CS-I, CS-II, and FS respectively. During the study period, TC was highest in crop growing seasons and was decreasing towards FS which remain in the same status until the next CS. During the observation period, fluctuations were observed with respect to crop cycles.

Annual distribution of TC showed a significant ($p<0.01$) decline in its concentration towards the year 2013-2014; however consistency in its concentrations was maintained during the period 2011-2012 and 2012-2013. During 2011-2012 , TC varied from 19.05 to 10.01 g Kg^{-1} with a mean value of 14.109 ± 0.22 g Kg^{-1}. Whereas in 2012-2013 it ranged between 19.30 to

6.4 g Kg^{-1} with a mean value of 14.13 ± 0.285 g Kg^{-1}. However a significant ($p<0.01$) decline in the concentrations of TC was observed during 2013-2014, both temporarily and spatially which varied from 15.91 ± 4.8to 3.7± 13 g Kg^{-1} with a mean value of 8.82 ± 0.33 g Kg^{-1}. Spatially TC was observed varying significantly ($p<0.05$) with stations with the highest concentration in St.7 ranging from 7.5 to 19.05 g Kg^{-1} with a mean value of 13.84 ± 0.59 g Kg^{-1} and lowest in St.4 ranging between 5.29 to 15.65 with a mean value of 11.08 ± 0.56 g Kg^{-1} (Fig. 3.21).

The subsurface soil TC stock was found decreasing toward continuous paddy cultivation with the lowest TC stock values in the year 2013-2014 compared to 2011-12 and 2012-13. (Table 3.1). One way ANOVA showed significant ($p<0.01$) annual variation in TC stock with the highest mean value in 2012-2013 (20.22 ± 0.74 Mg ha^{-1}) followed by 2011-2012 (20.08 ± 0.46 Mg ha^{-1}). Whereas lowest TC stock was observed during the period 2013-2014 with a mean value of 13.84 ± 0.94 Mg ha^{-1}. Seasonally TC stock lacked significant differences and was observed consistent with cropping seasons with major variations. The seasonally highest TC stock was observed in CS-I (18.62 ± 0.94 Mg ha^{-1}) followed by CS-II (17.88 ± 1.4 Mg ha^{-1}) whereas lowest was in FS with a mean value of 17.63 ± 0.94 Mg ha^{-1}. The net TC stock of the rice paddy soils of Padayatti during the observation period from 2011-12 to 2012- 14 was estimated as 18.54 ± 3.9 Mg ha^{-1}.

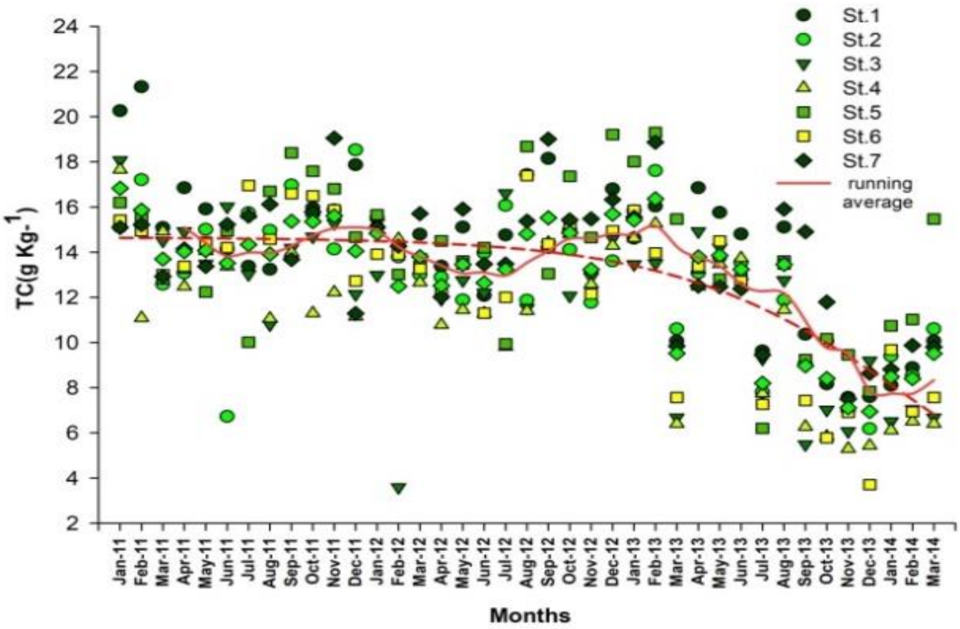

Figure 3.20Mean distribution pattern of total C from rice paddies of Padayatti during the period from 2011-2012 to 2013-2014

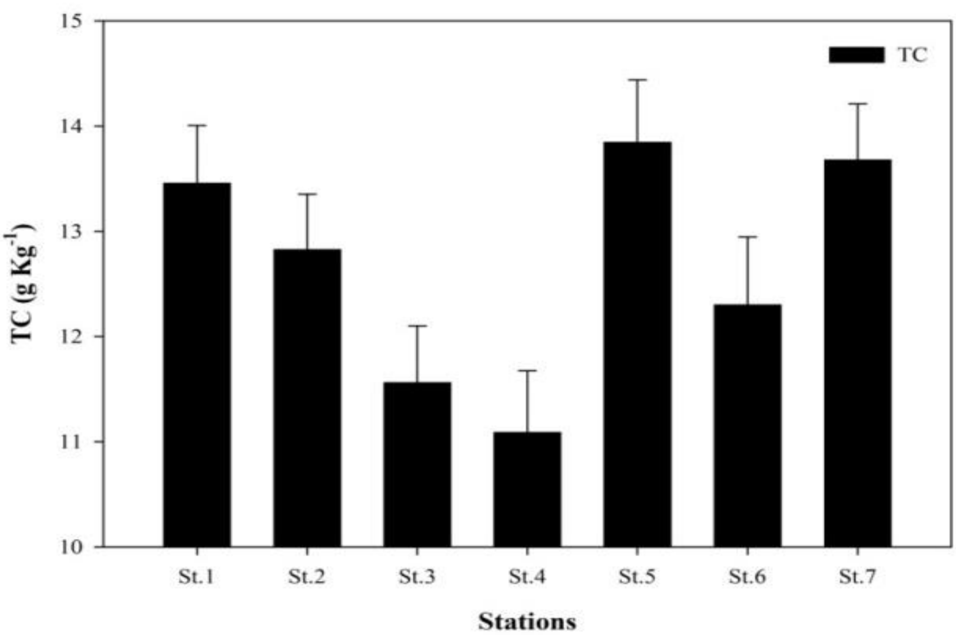

Figure 3.21 Spatial distribution of TC from rice paddies of Padayatti during 2011-12 to 2013-14

Table 3.1 Distribution of C and N stock during different crop seasons in rice paddies of Padayatti, Palakkad from 2011-12 to 2013-14

Year	Seasons	SOC Stock	SIC Stock	TC Stock	TN Stock
2011-2012	CS-1	8.483 ± 0.53	11.651 ± 1.23	20.133 ± 0.81	4.469 ± 0.24
	CS-II	8.299 ± 0.29	13.114 ± 0.33	21.413 ± 0.49	3.723 ± 0.38
	FS	8.349 ± 0.62	10.348 ± 0.46	18.697 ± 0.48	3.348 ± 0.59
2012-2013	CS-1	7.680 ± 0.32	11.853 ± 0.63	20.326 ± 0.82	3.956 ± 0.31
	CS-II	7.849 ± 0.36	13.333 ± 0.93	21.183 ± 0.79	3.348 ± 0.14
	FS	9.152 ± 0.24	10.000 ± 2.09	19.152 ± 2.03	3.768 ± 0.30
2013-2014	CS-1	8.472 ± 0.80	07.043 ± 1.63	15.413 ± 1.85	4.104 ± 0.43
	CS-II	7.070 ± 0.73	04.241 ± 0.66	11.064 ± 0.59	3.645 ± 0.14
	FS	7.960 ± 0.56	07.691 ± 1.58	15.053 ± 1.45	3.785 ± 0.40

3.3.15 C:N Ratio

The surface distribution of C:N ratio varied significantly between seasons, with stations and between consecutive years (Fig. 3.22). Seasonally, a significant difference in C:N ratio was observed between FS and CS. During the period C:N ratio was found higher in FS with a mean ratio of 5.62 ± 0.22. Annually C:N ratio varied significantly with the highest ratio in 5.91± 0.206 in 2011-2012 followed by 2012-2013 (5.66 ± 0.206) and 2013-2014 (3.5 ± 0.241) respectively. Spatially C:N ratio varied significantly between stations. During the period St.5 exhibited highest C:N ratio with a mean ratio of 5.8 ± 0.32 and the lowest ratio in St.2 with a mean ratio of 4.42 ± 0.32 (Fig. 3.23).

Statistical analysis where made to study the significant relationship between parameters and the detailed result are shown in table no. 3.3

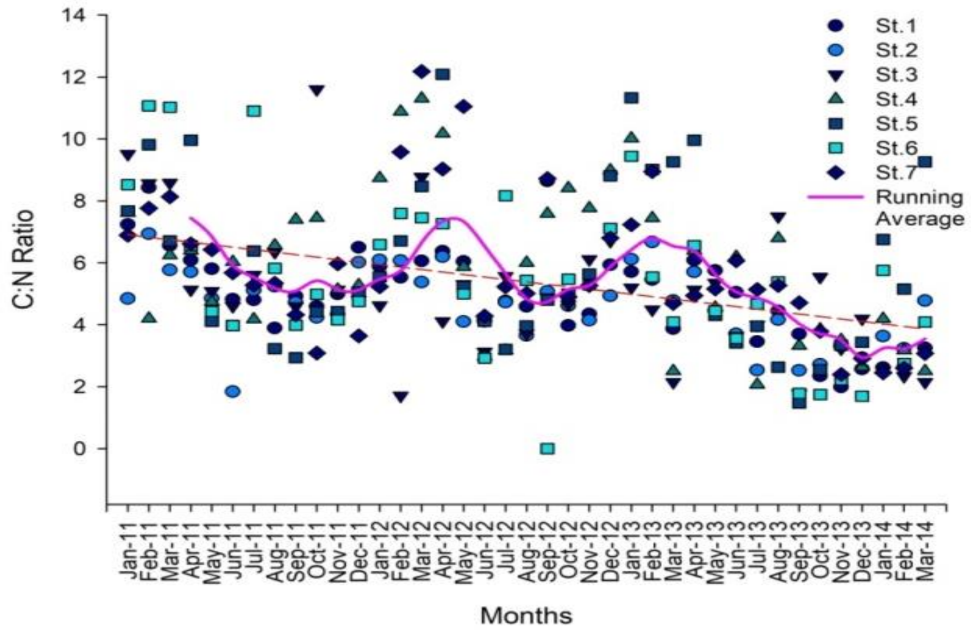

Figure 3.22 Temporal distribution of C:N ratio from rice paddies of Padayatti, Palakkad during 2011-12 to 2013-14

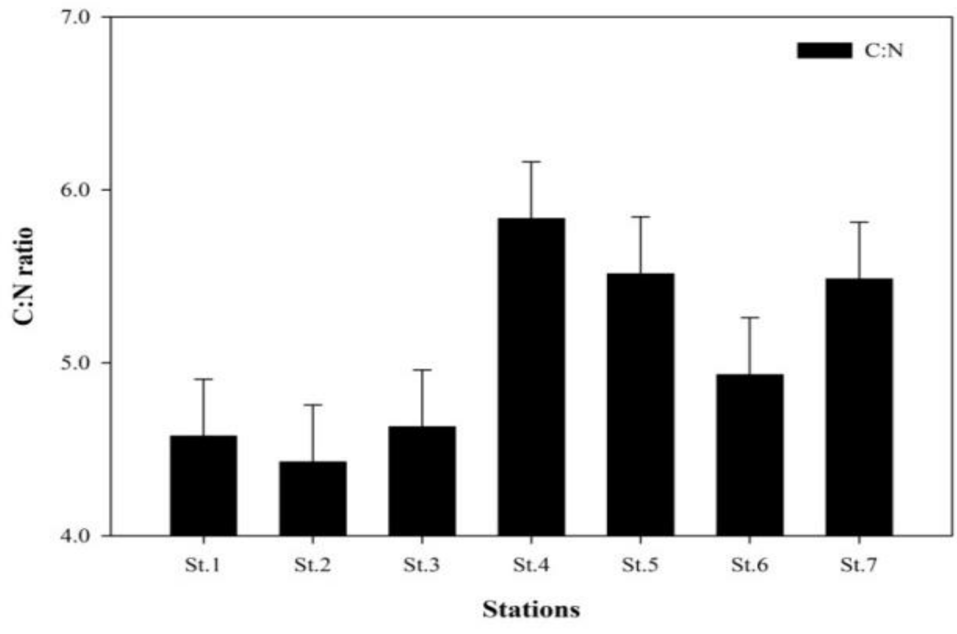

Figure3.23 Spatial distribution of C:N ratio in rice paddies of Padayatti, Palakkad during 2011-12 to 2013-14

Table 3.2 Correlation analysis showing relationship between environmental variables

Env. Variables	Air. max	Air.min	Rainfall	Soil Temp	SMC	pH	Eh	TOC	TIC	TC	TN	C:N	An	Na	K	Ca	P
Air.max	1																
Air.min	0.137	1															
Rainfall	-.594**	.383*	1														
Soil Temp	.401*	.561**	-0.182	1													
SMC	-.712**	-.391*	0.259	-.676**	1												
pH	0.032	-.490**	-0.266	-0.109	0.251	1											
Eh	.530**	.640**	0.023	.613**	-.700**	-0.335	1										
TOC	0.162	.362*	-0.113	.515**	-0.31	-0.055	.354*	1									
TIC	-0.126	-0.009	0.043	-0.008	0.22	0.252	-0.142	0.15	1								
TC	-0.079	0.079	0.012	0.117	0.131	0.222	-0.047	.382*	.971**	1							
TN	-.515**	0.136	.520**	-0.257	.389*	-0.009	-0.287	0.117	0.031	0.057	1						
C_N	0.283	0.021	-0.305	0.318	-0.206	0.095	0.164	0.253	.694**	.710**	-.601**	1					
An	0.052	-0.045	0.071	-0.117	0.163	0.228	-0.236	0.273	0.175	0.337	0.329	-0.122	1				
Na	-0.035	0.179	0.19	0.183	-0.214	-0.422	0.405	-0.044	-0.272	-0.337	-0.299	0.206	-0.336	1			
K	-0.164	0.305	0.375	0.192	-0.195	-0.461	0.419	0.103	-.498*	-.527*	-0.079	-0.036	-0.16	.797**	1		
Ca	-0.236	.517*	0.432	0.331	-0.191	-0.074	0.399	0.417	-.545*	-0.428	0.198	-0.307	-0.016	0.322	0.429	1	
P	.700**	-0.445	-.635**	-0.066	-.484*	0.076	0.048	-0.248	-0.056	-0.186	-.575*	.533*	-0.103	0.046	-0.107	-0.115	1

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

3.3.16 Principal Component Analysis (PCA)

Principle component analysis (PCA) of the environmental parameters of Padayatti, agro wetland ecosystem showed that the axis Dim1, 2 and 3 obtain large eigenvalues contributing to greater than 74.5% of cumulative % variance (Table 3.2). The variables TC, SIC, SOC, C:N Eh, soil temp, air-max and air-min has the positive load towards Dim1. The negative loading towards Dim1 was attribute mainly by TN, pH, and SMC.

Table 3.3 Variable loadings for Dim1,Dim 2,Dim 3, Dim4 and Dim5

Variables	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
T_Carbon	0.204	0.915	0.310	-0.004	-0.063
TI_Carbon	0.103	0.929	0.191	-0.173	0.105
TO_Carbon	0.450	0.074	0.542	0.463	-0.500
T_Nitrogen	-0.575	-0.114	0.689	0.301	0.113
C:N	0.544	0.750	-0.239	-0.201	-0.118
pH	-0.168	0.494	-0.321	0.657	0.385
Eh	0.761	-0.345	0.088	0.013	0.081
MC	-0.854	0.245	0.174	-0.135	-0.023
Soil_Temp	0.807	-0.011	0.231	0.071	0.312
Air_Max	0.698	-0.134	-0.440	0.223	-0.089
Air_Min	0.547	-0.241	0.635	-0.248	0.274

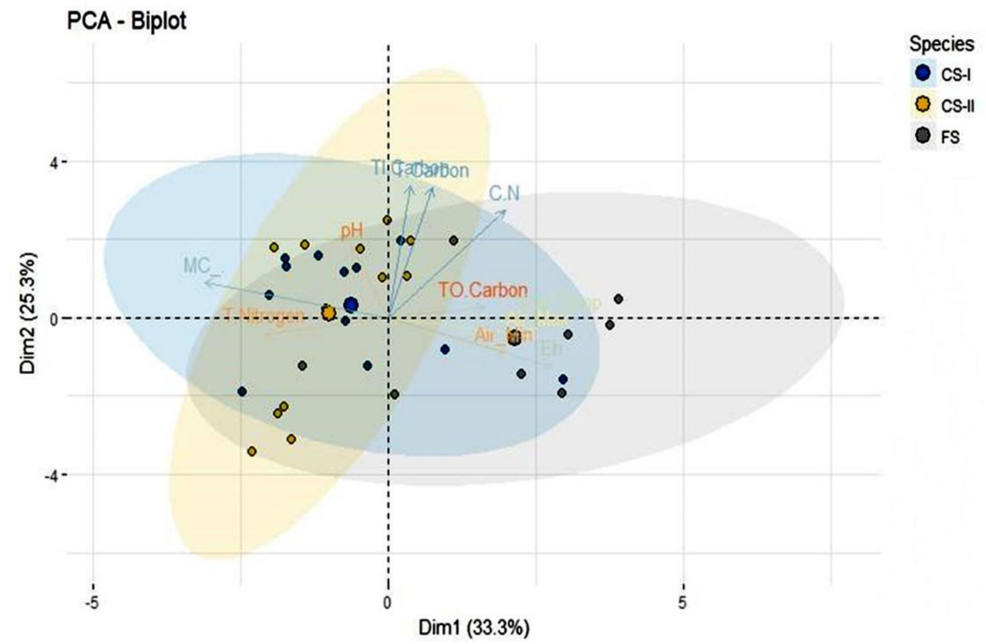

Figure 3.24 Scores and loadings from principal component analysis (PCA) biplot from three seasons showing the relationship between environmental parameters from Padayatti paddy wetland during 2011-12 to 2013-14

3.3.17 Partitioning of net ecosystem carbon and the NEE of the rice ecosystem

a) Carbon Input

The major components which add carbon inputs to an ecosystem are (a) NEP, (b) addition of C inputs from stubble and root biomass (previous season crop residue left in the field), (c) rhizodeposition plus algal biomass and (d) manure inputs as compost. Partitioning of net ecosystem carbon and the NEE of the rice ecosystem was calculated for the year 2013-2014.

In the present study, the net ecosystem production (NEP) of the Padayatti was +1.595 Mg C ha^{-1}in CS-I and it was +1.945 Mg C ha^{-1} in CS-II respectively (Table 3.4). Carbon inputs in the form of crop residues, rice stubble, and root biomass were estimated as 1.16Mg C ha^{-1} in CS-I and 1.31 Mg C ha^{-1} in

CS-II respectively. The rhizodeposition for the period was estimated by using a conversion factor of 15% of total above ground biomass at harvest, and the values are 0.0426 in CS-I and 0.0472 in CS-II respectively. The factor value of 0.70 Mg C ha^{-1} for C load of aquatic algal mass in tropical rice was used for C input. The manures added to the paddy field during the present study constitute 0.33 and 0.32Mg C ha^{-1} during CS-I and CS-II respectively. From adding up all the respective C input components 3.832 Mg C ha^{-1}in CS-I and 4.33 in CS-II was calculated to be added to the system (Fig. 3.24).

b) Carbon release from the system

In the present study, C was lost from the system due to several farm practices and crop biochemical and physiological processes were quantified. Carbon is usually removed from the system mainly by means of (a) harvest of crop biomass, (b) DOC, and (c) CH_4.

The C removal after harvest through rice grain, straw, stubble, and root were 2.72Mg C ha^{-1} in CS-I and 2.968 Mg C ha^{-1} in CS-II. The cumulative CH_4 constitute 0.07and 0.151Mg C h^{-1} for CS-I and CS-II whereas DOC constitutes 0.078 and 0.077 Mg C h^{-1} during CS-I and CS-II respectively. Therefore, C loss from the system was estimated as 2.87 and 3.19 Mg C $h^{-1}$for CS-I and CS-II respectively. As crop residue and stubble burning was not a regular farm practice in the study area, the gaseous C loss due to biomass burning was not included during balancing the input and output C flux components in the net ecosystem carbon balance (NECB) model. From the results, it was estimated that the system has the potential to store C at the rate of 0.957 Mg C h^{-1} in CS-I and 1.1368 in Mg C h^{-1} respectively.

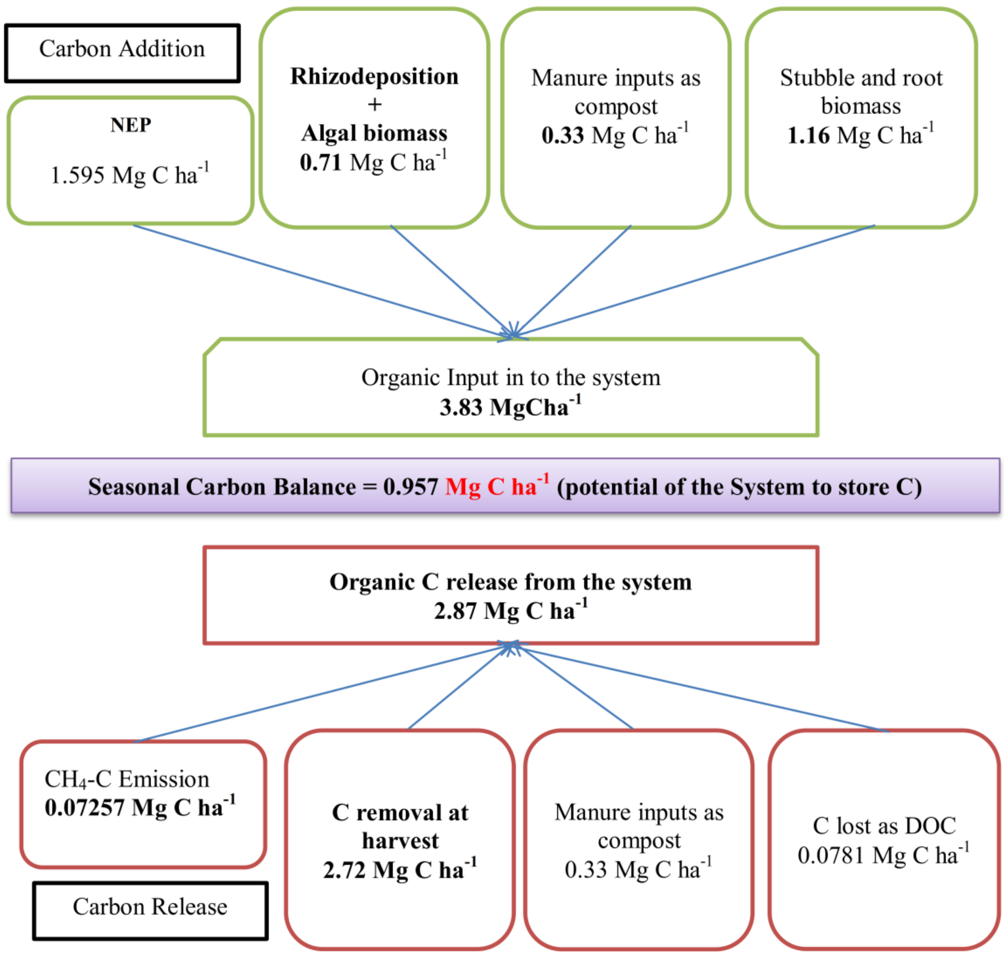

Figure 3.25 (a) Schematics of carbon balance in tropical low land rice ecology in CS-I, 2013–14

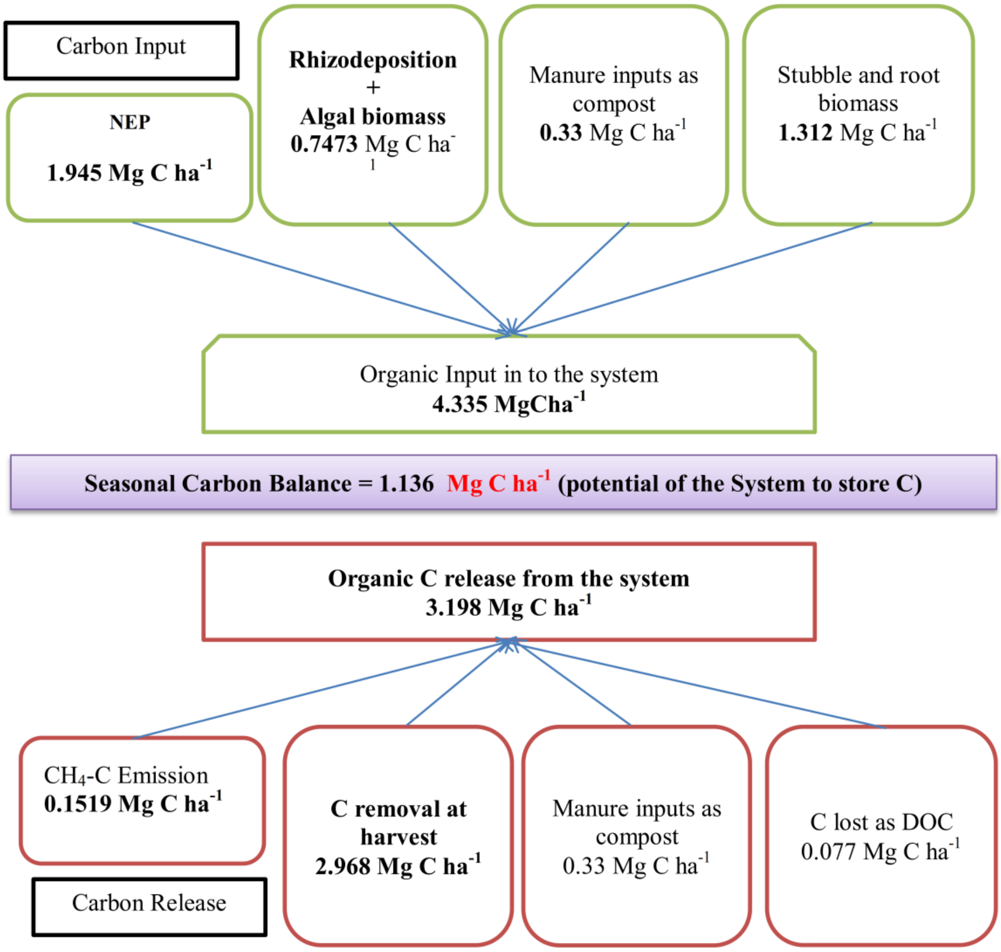

Figure 3.25 (b) Schematics of carbon balance in tropical low land rice ecology in CS-II, 2013–14

Table 3.4 The rate of NEE, NPP and Rh in different paddy plant growth stages during 2013-2014

Seasons	Months	NPP (Kg C ha^{-1})	Rh (Kg C ha^{-1})	NEE (Kg C ha^{-1})	NEP (Kg C ha^{-1})
FS	Mar-13	-0.00067	33.926	33.927	-33.927
	Apr-13	-0.00067	39.924	39.924	-39.924
	May-13	-0.00067	612.002	612.002	-612.002
CS-I	Jun-13	214.079	159.42	-54.659	54.659
	Jul-13	1355.839	284.394	-1071.45	1071.45
	Aug-13	1534.239	152.82	-1381.42	1381.42
	Sep-13	1945.165	350.15	-1595.02	1595.02
CS-II	05-Oct-13	239.055	2.352	-236.703	236.703
	17-Oct-13	677.919	5.928	-671.991	671.991
	23-Oct-13	1095.375	69.36	-1026.02	1026.02
	11-Nov-13	1462.879	232.73	-1230.15	1230.15
	23-Nov-13	1712.639	236.88	-1475.76	1475.76
	30-Nov-13	1819.679	97.9922	-1721.69	1721.69
	09-Dec-13	1926.719	97.56	-1829.16	1829.16
	18-Dec-13	1962.399	104.11	-1858.29	1858.29
	28-Dec-13	1998.079	179.5	-1818.58	1818.58
	08-Jan-14	2069.439	126.28	-1943.16	1943.16
	16-Jan-14	2176.479	75.354	-2101.12	2101.12
	30-Jan-14	2205.023	511.72	-1693.29	1693.29
	Feb-14	2268.783	323.904	-1944.88	1944.88

3.4 DISCUSSION

Flooded rice paddies are unique ecosystems regulated by complex micro-meteorological, physiological and soil biological processes (Martins et al. 2016). According to Thornthwaitesclimatic classification, Padayatti rice paddy wetland experiences a humid as well as an arid climatic condition due to its specific geographical location along with the presence of Palakkad gap(Raj and Azeez 2010).The specific geographic location of Palakkad along with its high ambient temperature makes it distinct from the rest of the districts of Kerala in many aspects. Generally, Palakkad experiences oppressive summer during the month of March to May where the ambient temperature was near to 40 °C. These extreme summer months make Palakkad especially Padayatti free from rice paddy cultivation due to water scarcity. Thus the increased ambient and soil temperature in the summer fallow season make it significantly distinct from both the crop growing seasons. The area receives maximum rainfall during the southwest monsoon (June to September) followed by the northeast monsoon (November to December) where as rest of the months receive only a little rainfall. Generally, the total annual rainfall of Palakkad was lower compared to that of other districts of Kerala (Krishnakumar et al., 2009).Therefore the peculiar geographic conditions and seasonal variation determine the temperature distribution in the study area. Diurnal variation in ambient temperature depends upon the availability of solar radiation and its day and night cycling(Chen et al. 2015).Variations in temperature are also influenced by wind patterns (Chen et al. 2016), physiology of the vegetation, such as the canopy/stomatal conductance, photosynthetic and chlorophyll rates etc. (Maruyama and Kuwagata 2008). Where as the diffusional transport of greenhouse gases from the paddy soil is significantly influenced by temperature(Mikkela et al. 1995).

Soil temperature of the study area co-varied with the air temperature and the correlation analysis showed significant positive correlation to air temperature. However, a significant negative correlation was observed between ambient temperature and SMC. This shows that variation in air temperature and moisture content plays a significant role in soil temperature though they are growing in flooded conditions (Takata et al. 2008). Soil moisture content in Padayatti wetland differs significantly between seasons and it lacks annual and spatial variations. The moisture content was higher in crop growing seasons compared to summer fallow and this seasonal variation in SMC was related to rainfall and the soil temperature. Higher rainfall during the crop growing seasons resulted in the increase of SMC whereas elevated temperature leads to decline in SMC during FS. The correlation analysis also showed significant positive correlation between rainfall and negative correlation to air temperature which was similar to the observation of (Hamerlynck et al. 2013). Agricultural and field management operations such as irrigation and flooding pattern also affect the distribution of SMC in Padayatti wetland. The continuous irrigation and flooding could be the reason for the insignificant annual and spatial variations.

The soil texture is a basic property that is useful in deriving several physical and chemical soil quality parameters. The soils of Padayatti wetlands were silty loam, clay loam, and loam and the percentage composition showed that silt content was higher during the study period which was similar to other wetlands of Kerala (Sheela, 1988 Hameed, 1975).However Thomas (2003) and Hameed (1975) reported that clay texture predominates in most localities of Kole wetland. According to Trask (1953) fine-grained sediments contains more organic matter than coarse sediments. The hydraulic equivalence of clay and organic particles (Calvert and Pedersen 1992) and the higher surface area to volume ratios of fine-grained particles (Keil et al. 1994, Mayer 1994) were the reason behind it. Soil texture may also be an important factor affecting the mineralisation response to due to its role in the stabilisation of soil organic matter(Harrison-Kirk et al. 2013). The moisture release characteristics of soil are also related to pore size distribution (Liu et al. 2006). It was also reported that genetic structure of some of the bacterial community is related to soil physico chemistry and is dependent on soil texture(Guigue et al. 2015). Soil texture may control SOC decomposition, and its content may give an idea of the degree of protection conferred by a particular soil(Xu et al. 2016). The predominance of finer sediments (clay and silt) than coarse sediments (sand) in Padayatti agro wetland ecosystem could be a reason for higher organic matter in the study area.

Soil pH in paddy soils is an important index that affects a wide range of agronomical and environmental functions of soils (Funakawa et al. 2008). It is also an ecologically important variable that acts as an indicator of soil processes which influence the availability of plant nutrients and soil microbial ecology (Husson 2013). In the present study, pH was observed in the range near acidic to neutral with a mean value of 6.06 ± 0.57 which was comparable to most of the arable ecosystems including paddy fields (Hadi et al. 2010). It was inferred from many studies that cultivated crops can grow well on soils that are slightly acidic to near neutral and only a few species can develop at a pH below 4.5 or above 9 (Springob and Kirchmann 2003). During the study, the submergence of the paddy field was observed to influence the soil pH. The pH was observed negatively correlated with DPW, significant at $p < 0.05$ with an $r = -0.596$ (Fig.3.8). During the initial submergence of the field during May, soil pH slightly decreased and then gradually increased and maintained a stable pH in the range 5.3 to 6.1. The initial decrease in pH of 0.5 units in Padayatti was associated with high organic matter (Li et al. 2005). The magnitude of variation of pH in agriculture soil is related to the amount of organic matter added and easily-decomposable organic matter retard the increase in pH during its intensive decomposition(Ghimire et al. 2017). Whereas application of inorganic fertilizer significantly decreased soil pH value, while amendment with organic manure showed less effect on soil pH value(Ge et al. 2010) because the organic carbon in wetlands buffers the soil to neutrality (DeLaune and Reddy 2005). In the present study, the direct application of organic manure in FS and the organic residues of each crop season make the availability of organic matter in the paddy field throughout the season and this may be the reason for lower pH in padayatti. The low iron content in the paddy soils is also reported which also influence the decrease in soil pH. The subsequent increase in pH on submergence was associated with reduction process of soil. The Eh was observed to decrease with submergence in the range -152 to -568 mV. Redox conditions has significant effects on the pH of individual soils, because of H^+ consumption during reduction reactions (nitrate reduction, but little Fe reduction) (Hanke et al. 2013). In paddy soils pH appears to be a better indicator of CH_4 emission as methanogenic bacteria are pH sensitive and most of them grow over a relatively narrow pH range of about 6–8 (Vijay and Bijoy Nandan 2016). pH also regulates the denitrification and ammonification rates and N_2O and NO emissions from paddy soils.

About 75% of the rice is grown on paddy soils which are kept submerged during the growing season(Le Mer and Roger 2001). As a result of continuous flooding, anoxic conditions accompanied by low redox potentials are characteristic for paddy soil ecosystems.As paddy soilsexperience wide range of hydrological variations from drying to flooding, severe changes occur in its physicochemical characteristics(Ford et al. 2007). Soil redox potential (Eh) is the measure of electron activity of the soil and is one of the most important electrochemical properties of the soil affected by the dynamic changes when paddy fields are subjected to hydrological fluctuations. Eh predicts the ionic distribution between chemical species which may interact with the transfer of electrons, such as ferrous and ferric iron or nitrite and nitrate nitrogen. During the present study Eh ranged from -339 mV to 126 mV with an average value of -89.65 ± 14.5 mV. According to soil Eh classification (Husson 2013), a reduced to highly reduced conditions are prevailing in the study area of Padayatti during the observation period. Generally, the redox potential of 0 mV indicates a highly reduced soil status where oxygen and nitrate are not likely to be present and the bioreducable iron and manganesecompounds are in a reduced condition(Tanji et al. 2003). However, sulfate will be in a stable state under the same situation(Yao and Conrad 2001). A redox potential of +400 mV indicates oxidised state of the soil with the presenceof oxygen(Mansfeldt 2003). During the present study, significant seasonal variation was observed between submerged crop seasons and dry summer fallow seasons, indicating submergence of paddy fields had asignificant effect on Eh which was in accordance to the results of (Husson 2013). During flooding the oxygen supply from the air-soil interface was cut off which results in the quick depletion of oxygen in the soil (Jayalath et al. 2016). This results in soil reduction and sets in motion a series of physical, chemical and biological processes that profoundly influence the quality of soil as a medium for the growth of crops such as wetland rice. As paddy systems experience wide hydrological variations from drying to flooding, severe changes in its physicochemical characteristics is also expected. During the flooded anoxic condition microbial reduction processes sequentially use NO_3^-,Mn_4^+,Fe_3^+,SO_4^{2-} as electron acceptors, accompanied by the emission of the trace gases N_2O, N_2, H_2S, and CH_4 due to reduction induced increasing pH and NH_3(Kögel-Knabner et al. 2010). In iron rich soils, anoxic flooded conditions provide the physio-chemical environment for the formation of black ferrous sulphides (Bloomfield 1969; Brümmer 1974) and lead to the anoxic decomposition of organic matter, resulting in the production of methane by methanogenic archaea (Ponnamperuma 1972; Liesack et al. 2000). However, the prolonged dry seasons alter soil character in paddy soils by promoting oxidation, shrinkage, and compaction of well-developed organic layer leading to a reduction in the SOC stock of the soil (Zhang et al. 2012). Various authors have also reported marked differences in Eh and pH as a function of soil depth (Mansfeldt 2003). Depending on the hydrological regime and input of electron donors and acceptors steep Eh gradient was observed.

K^+, Na^+, and Ca^+ are major essential macro nutrients present in the soil which helps to maintain electro neutrality at the soil-root interface of the paddy plants. Potassium is an essential nutrient for plant growth and is the third most important fertilizer element (after N and P). The average concentration of available potassium in the soil of Padayatti wetland was 0.672 mg g^{-1} during the study period which is comparable with paddy fields of California Sacramento valley have a similar K levels especially the plant available potassium in organic soils (Drinkwater et al., 1995). Ravikumar & Somashekar (2013) also reported low exchangeable potassium from Varahi River basin, Karnataka with a mean value of 0.023 meq/100g. During the adequate supply of K^+ crops remove K^+ at a high rate which is three to four times that of phosphorous. This tendency is termed as 'luxury consumption' because the excess K+ adsorbed apparently does not increase crop yield to any extent. This results in the depletion of K^+ in the soil. However a certain amount of this element is needed for optimum yields and this is termed as 'required potassium'. Much of the unavailable K is bound with other minerals. The K^+ are attracted to and held by negatively charged colloids which make up the cation exchange capacity (CEC) of the soil and an increase of CEC increases the uptake of K+ by plants.

Potassium is absorbed by plants as K+ ion. Plant requirements for this element are typically high. Potassium is involved in large number of physiological processes like including carbohydrate metabolism, enzyme activation, osmoregulation, cation-anion balance, protein synthesis and activation of enzymes. Being a major inorganic solute, it plays a key role in the water balance of plants. Nutrient K is less mobile in soils because of the strong affinity with some exchange sites of clays (Singh and Mishra 2012). Potassium also plays a role in minimizing certain plant diseases and in improving plant quality. Potassium deficiencies have been primarily associated with sandy soils because of the scarcity of K-bearing minerals and low clay contents, organic materials low in K, and high lime soils in which K+ uptake is inhibited by high concentrations of Ca_2+ (Cook and Ellis, 1987).

Three forms of sodium are typically found in the soil: fixed in insoluble silicates, exchangeable in the structures of other minerals, and soluble in the soil solution. In the majority of soils, most of the Na is present in silicates. In highly leached soils, Na may occur in high-albite plagioclases and in small amounts of perthite, micas, pyroxenes, and amphiboles, which exist mainly in the fine sand and silt fractions (Tisdale et al., 1997). In arid and semiarid soils, Na typically exists in silicates as well as soluble salts, e.g., NaCl, Na_2SO4, and Na_2CO_3.

Sodium is a highly important nutrient of an ecosystem. The availability of Na is dependent on the reaction rate between soil solutions and exchangeable phases of Na, which is strongly dependent on the type of clay minerals, present. Even though Na^+ is an essential cation for the plants, soil Na^+ levels can be used as an indicator of degradation of soils by irrigation with ground waters containing residual alkalinity which poses a major threat to agriculture. In the present study the mean level of exchangeable Na^+ observed was 0.442 mg g^{-1} which is comparable to the results of (Bajwa et al., 1983).

Sodium is usually a soil chemical concern when it occurs in excess. Sodium has a dispersing action on clay and organic matter, resulting in the breakdown of soil aggregates and reducing permeability to air and water. Because of the loss of large pores, soils with excessive amounts of Na become almost impervious to water and air, root penetration is impeded, clods are hard, seedbed preparation is difficult, and surface crusting results in poor germination and uneven stands. These detrimental effects of excess levels of exchangeable Na+ are conditioned by soil texture and clay mineralogy (Tisdale et al., 1997). High concentrations of sodium are toxic to some plants. This toxicity may be relatively insignificant in comparison to the restrictions resulting from the associated physical condition of the soil. Poor physical soil condition normally precedes Na toxicity, and high pH usually accompanies the accumulation of Na in soils; however, these problems are less important than the water and micronutrient problems induced by Na accumulation (Bohn et al., 1985).

Calcium is typically the most abundant exchangeable cation in soils.Yields of most agricultural crops is highest when the soil exchange complex is dominated by Ca^{2+}. A Ca-dominated exchange complex usually indicates a near-neutral pH, which is considered optimum for most plants and soil micro-organisms (Bohn et al., 1985).The average concentration of calcium during the study period in Padayatti wetland was 2.887 mg g^{-1}. Ca has been identified as a basic process that initiates the development of sodicity. Despite the importance of Ca2+ as an exchangeable cation, soils derived from limestone can be unproductive; i.e., as the limestone weathers, the Ca_2^+ and HCO_3^- ions are released but are leached out of the system because the soils lack the cation-exchange capacity to retain the Ca_2^+ (Bohn et al., 1985). Calcium is an essential nutrient for plant growth and is absorbed by plants as the ion Ca_2^+. Calcium has an essential role in cell elongation and division, in cell membrane structure and permeability, in chromosome structure and stability, and in carbohydrate translocation (Tisdale et al., 1997)

Phosphorus is the second most important macronutrient available in the biological systems and available P is the main source of plant available phosphorus in agricultural soils. During the present study available P in rice paddy soils of Padayatti was 51.92 ± 23.69 to 121.88 ± 33 mg Kg^{-1} which was comparable to the results of Varahi agricultural plains of Udupi district in the western part of Karnataka state (Ravikumar and Somashekar 2013). The concentration of available P in Padayatti paddy wetlands is observed to be low according to Singh and Mishra (2012). Where areas with concentration of available P less than 12.4 kg ha^{-1} is graded as phosphorous deficient regions. The major factors controlling the P distribution in paddy soils is the P sorption and releases especially under flooded conditions (Cao and Zhang 2004). Flooding and drainage cause chemical changes in soils, which leads to the dynamic release or adsorption of soil P (Gopal 2003). Frequent flooding and drainage can alter pH and Eh in the water soil system and thus affect soil P transformations and its availability in floodwater and pore water. Flooding can decrease Eh, which increases P release due to iron reduction (Kögel-Knabner et al. 2010). However, a secondary reaction between Fe^{2+} (produced by the reduction of Fe3+) and soluble P can decrease soluble P (Ng Kee Kwong et al. 2002).

Soil is an important non-renewable natural resource which captures and stores the basic components SOC and SIC. Among the C fractions, SOC is an important indicator of soil quality that affects ecosystem functioning and food security. Thus a small change in SOC stock could have a large consequence for global carbon cycling and feedback to the climate system. In the present study, the average concentration of SOC from Padayatti agro wetland ecosystem was 5.93± 0.13g Kg^{-1} which was comparable to the results of similar rice paddy systems (Venkanna et al. 2014). Surface soil SOC distribution in the Padayatti rice paddies were comparable to other Indian ecosystems (Tang et al. 2012) but it was lower compared to the topsoils of low land rice soils in tropical Asia.

However, Indian non-cultivable ecosystems especially agroforestry have a significantly higher concentration of SOC (8.35 ± 0.80) than rice paddy systems (Benbi et al. 2012). The SIC distribution in the surface soil layers of Padayatti agroecosystems varied with a mean value of 7.19 ± 0.27 g Kg^{-1}. In the present study, the paddy soils of Padayatti showed an increased concentration of SIC when compared to SOC. This was similar to previous reports showing an increased concentration of SIC in various paddy ecosystems characterized by hot, humid and arid climate (Ray et al. 2014). The TC content of Padayatti varied with a mean value of 12.67 ± 0.38 g Kg^{-1}. TC is the sum total of SOC plus SIC.

The potential of soil to sequester carbon can be assessed by estimating carbon stock such as SOC and SIC stock ofthe area (Zhang et al., 2004). During the entire study period from 2011-12 to 2013-14, the SOC stock varied with a mean value of 73.31 ± 4.4 Mg ha^{-1} whereas SIC was in the range 89.27 ± 9.5 Mg ha^{-1}. The average TC stock of Padayatti was 162.43 ± 9.2 $Mg.ha^{-1}$. The observations of carbon stocks reveal that rice paddy soils of Padayatti has higher concentration of SIC content compared to SOC.This was comparable to the estimates of SOC stock (in the first 0–150 cm) of Indian soils having an increased concentration of SIC (33.98 Pg) compared to SOC (29.92 Pg) than that of SIC (Pal et al. 2015). In Indian soils, SIC concentration is observed with increased concentration and are affected by dry climatic conditions that cause more calcareousness in the sub soil. The presence of $CaCO_3$ in the humid and per-humid region is due to its inheritance from strongly calcareous parent material and could be the reason for relatively large SIC stock in a dry climate.

Results of annual SOC, SIC and TC stock changes during the observation period from 2011-12 to 2013-14, evaluated from the surface soil layer (15 cm) are presented in Table 3.1. After three years of cropping, we observed a decline in SOC by 2%. Even though the change in the SOC stock from 25.13 Mg h^{-1} during 2011-12 to 23.5Mg ha^{-1} during 2013-14 were not significant but decreased slightly during the study period (Table 3.1). This result indicated that the organic matter inputs into the soil may not be sufficient to maintain the SOC and SIC stock in this study area. Several studies have indicated a positive relationship between the amounts of C incorporated into the soil and SOC content. However,fertilization and irrigation are largely dependent on climatic conditionsof the regions and how the crop residues are managed (Ma et al., 2008; Lal, 2002). The interplay between climate, soil, cropping and management systems determines the carbon productivity and both the input and output of C in soil and thus determine the direction of change in soil C. Our analysis was largely based on the relative change of total soil C or organic C after consecutive three years of paddy cultivation. The arid and humid climate with a high ambient temperature of the study area of Padayatti could lead to increased mineralization of C stored in the soil and could be the reason for declining trend in SOC with increased SIC. Our study revealed that soil type, climate, vegetation indices and terrain attributes are important predictors of SOC. This corroborates reports from previous studies (Jobbágy and Jackson, 2000). Several studies have highlighted the importance of climate in predicting SOC contents at the regional, national and continental scales (Luo et al. 2010). At the supra-national to continental scale, reported that SOC is positively correlated with precipitation amount and negatively correlated with average temperature. Similar observations were also made by Scharlemann et al. (2014) who highlighted a stronger correlation between SOC and precipitation than with temperature. Precipitation plays a key role in biomass productivity which determines litter input to the soil (Zeiger and Fohrer 2009) while temperature influences the decomposition of litter in the soil as well as C mineralization rate.

Soil total nitrogen is used as an important index of soil fertility evaluation and reflects the soil nitrogen status. The major nitrogen sources to paddy soils is mainly from fertilizer inputs, decomposition and mineralization of organic matters, nitrogen fixation, atmospheric deposition and flood water (Zhang et al., 2004). Whereas nitrogen loss from paddy soils are attributed to plant uptake, immobilization, leaching, ammonia volatilization and denitrification. During the present study TN values ranged from 1.74 to 3.57 g Kg^{-1} with a mean value of 2.66 ± 0.083 g kg^{-1} which was comparable with the results of Tong et al., (2009). Significant increase ($p< 0.05$) in TN content in the surface soil layers was observed in the crop growing seasons of CS-I and CS-II when compared to FS. The nitrogen fertilizer treatments during the CS would have increased the N concentrations during CS-I and CS-II respectively. In the present study the TN was observed positively correlated with SMC and rainfall (significant at $p<0.05$).The existence of oxidation layer in the interface of water–soil under submerged conditions, mineralization and subsequent nitrification could occur in this layer (Lamers et al. 2012).

In the present study available nitrogen varied from 0.02 to 0.11 % with a mean value of 0.04 ± 0.03 % which was low compared to other reports from similar ecosystems (Ravikumar and Somashekar 2013). Low nitrogen status in the soils could be due to low amount of organic carbon in the soils since most of the soil nitrogen is found in organic form (Singh and Mishra 2012) Consequently, nitrogen availability in all ecosystems is largely dependent on inputs of biologically available nitrogen from external sources or internal cycling of nitrogenous compounds into biologically available forms. However, it has to be considered that the portion of directly plant available N within the amount of total N in soils is little as most N is contained in slow-cycling soil organic matter. Excess soil moisture content is one of the important factors affecting nitrification in water logged soils and is having a major contribution to vary the process. Since excess water is found in water logged areas, soil suppresses the process of nitrification because of deficient oxygen.

Table 3. 5 Comparison of Total carbon stock (Pg ha^{-1}) in rice paddies of Padayatti, Palakkad with Indo-Gangetic plain, India and other regions

Regions	SOC stock	SIC stock	Total stock
Padayatti	0.08 x 10-7	0.099 x 10-7	0.18 x 10-7
IGP-India	0.63	0.13	0.76
Indian Soils	9.77	4.06	13.83
Tropics	207	76	283
World	704	234	938

C to N ratio of a soil has been considered as a measure of SOM quality and soil N mineralization/immobilization potentials. According to Thomsen et al,(2008) a threshold value exists in C:N ratio below which the lability of SOM is considered to remain constant. Springob and Kirchmann (2002) had suggested that non-labile SOM is related to the soil C to N ratio. Thus, the pool of labile SOM would decrease when soil C to N ratios increase, resulting in less CO_2-C being evolved per unit of soil C indicating C:N ratio as a measure of decomposability of SOM. It is estimated that increase in the soil C to N ratio above 10 (data from Springob and Kirchmann, 2002) reduces the CO_2-C evolution by 50%. Thus soil C/N ratio is an indicator of the quality of soil organic matter with respect to decomposition and nitrification and can reflect coupling relationship of C and N cycles. The dependence of C and N mineralization on soil C:N ratio resulting in the release of CO_2, CH_4 and N_2O has been well described for paddy soils (Šimek et al. 2014).

During the present study the average C:N ratio from rice paddies of Padayatti is estimated as 5.62 ±0.22 indicating a less C per unit N, which may influence the C turnover leading to high decomposition rate of SOM and adversely affecting its sequestration process in soil. In addition to C:N ratio high CO_2 flux from the present study area was also observed indicating a high decomposition rate of SOM. Therefore increasing the soil C concretion in the soils of Padayatti will increase the C:N ratio to above threshold value of 10 to 14 and could reduce the mineralization rate of SOM thereby enhancing soil C storage.

Principle component analysis clearly reflected the variation in environmental parameters with respect to crop seasons. The parameters TN, SMC and pH were negatively correlated with rest of the parameters.

Carbon Balance about NEP and CH_4 Exchange in rice-ecosystem

Enhancing carbon sequestration in soils is an important means to reduce the net CO_2 emissions to the atmosphere (Lal, 2002). In agricultural soils, the SOC pool is much lower than the capacity, and most soils have lost 30–75% of their SOC pool, which comes to 30–40 t C ha^{-1} (Lal et al., 2009). In this study, the NECB is used to evaluate the total rate of carbon accumulation in ecosystems (Smith et al., 2008) on a seasonal crop time scale. In this study, the amount of carbon stored in and emitted or removed from the agroecosystem depends on the balance between the amount of C fixed into soils from residue C and manure addition and C loss from respiration, CH_4 emissions, and removal of C by harvest.

Carbon entered into agroecosystems mainly via manure amendment, stubble and root biomass, rhizodeposition and crop residue accounts for 3.83 Mg C ha^{-1} and 4.335 Mg C ha^{-1}, respectively during CS-I and CS-II respectively, of the total C increase. The positive NECB during the present study was mainly due to a large amount of manure addition and crop residue returned to the soil after crop seasons. In Padayatti agro wetland system the crop season CS-II starts immediately after the harvesting of CS-I. This leads to much more availability of fresh crop residues getting incorporated into the soils devoid of much decomposition. Whereas in CS-I the residues left over by CS-II in the previous crop season has to pass through a period of summer fallow where most of the decomposition of remaining crop residue take place leading to a declining input of crop residue biomass in CS-I. This process is reflected in the present study where carbon input as crop residue is higher in CS-II compared to CS-I leading to an increased sequestration rate in CS-II. The NEE values also reflect in the same level with higher NEE in CS-II compared to CS-I.

Carbon leaving the padayatti are mainly in the form of CH_4 emissions, Harvesting of crop and lost as DOC which accounts for 2.87 and 3.198 Mg C ha^{-1}. During the study balancing the total input and output components in NECB model was found that high land rice paddy wetland of Padayatti, Palakkad behaved as a net sink of carbon with a sequestration rate of 0.957 Mg C ha^{-1} in CS-I and 1.1369 Mg C ha-1 in CS-II on a seasonal basis. The carbon sequestration rate of rice paddies of Padayatti agroecosystem is comparable to the results of various authors in which Bhattacharyya et al. reported C sequestration of 0.91 and 0.59 Mg C ha−1., 2014from a tropical paddy wetland. However a loss of 0.35 Mg C ha^{-1} was reported from a tropical lowland rice paddy is also reported by Bhattacharyya et al., 2013.

Even though the rice paddy of Padayatti is acting as a net sink of carbon, low retention of SOC was observed due to the high rate of SOC decomposition. In addition to this, an increased SIC concentration in the form of $CaCO_3$ was also observed when compared to SOC in Padayatti rice paddy systems. This self-terminating process will lead to the formation of sodic soils with exchangeable sodium percentage (ESP). The process of $CaCO_3$ formation in soils is now considered as a basic and natural process of soil degradation. Therefore restoration process of organic and inorganic carbon balance in rice paddy wetland should be initiated and requires its follow-up.

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Chapter - 4

NET ECOSYSTEM EXCHANGE (NEE) AND FLUX VARIATIONS OF CO_2

4.1 INTRODUCTION

Carbon dioxide (CO_2) is the most important greenhouse gas contributing to nearly 63% of the total radiative forcing of the earth (1.909 Wm^{-2}). Being used as a reference gas CO_2 has been assigned with a global warming potential of 1 regardless of timeframe (IPCC 2014). Since the pre-industrial period, from 1750 to 2013 atmospheric concentration of CO_2 had increased exponentially by 40% from 278 ppm to 390.5 ppm and is currently increasing at a rate of 1.5 ppm y^{-1} (WMO,2014). Over the years the primary source of the increase in CO_2 is the dependence on fossil fuels (Milne et al. 2007), and land-use changes for agricultural operations (Ostle et al. 2009). During the last decade, 5.4 ± 0.3 pg of carbon was added up to the earth's atmospheric C budget as a result of combustion of fossil fuels, and by cement industry, however, nearly 1.7 ± 0.8 pg is added up by global land use change. The latter includes deforestation, biomass and conversion of natural to agricultural ecosystems (Jianwen 2004).

Even though agricultural ecosystems have considerable potential for sequestration of CO_2 from the atmosphere (Bernal and Mitsch, 2013), they can quickly act a source of atmospheric C contributing significantly to the global flux of 68–75 pg CO_2–C $year^{-1}$ (Smith et al. 2008). In the agricultural system, most of the CO_2 fixed or SOC entering the soil surface is rapidly consumed, and some of it is respired by heterotrophic organisms primarily occurring in the rooting zone (top 10–20 cm). This rapid mineralization quickly returns CO_2 to the atmosphere influenced by various environmental factors. Among the agroecosystems, paddy wetlands play a significant role in the global budget of GHGs (Hou et al. 2000) as gaseous carbon emissions in the form of CO_2 are crucial in the dynamics of agroecosystems (Bhattacharyya et al. 2013) and in the contribution to regional carbon budget. Carbon storage in paddy wetlands depends upon the balance of C inputs from photosynthesis and C losses, mostly in the form of CO_2 with some other non-CO_2 losses. The processes of autotrophic and heterotrophic respiration control ecosystem carbon fluxes. CO_2 fluxes can be differentiated into three types: (***1***). Soil respiration includes root, anaerobic and aerobic microbial respiration, (***2***). Ecosystem respiration: additionally includes aboveground plant respiration, and (***3***). Net ecosystem exchange (NEE) is the difference between photosynthesis and ecosystem respiration. The net ecosystem exchange (NEE) of CO_2 between the biosphere and the atmosphere is the balance between the fluxes associated with photosynthetic assimilation by the foliage (gross primary production, GPP) and respiratory effluxes (RE) from autotrophs and heterotrophs (microbial and soil fauna). The balance between production and decomposition determines whether a system is a sink or a source of atmospheric CO_2 (Bhattacharyya et al. 2014). In this context on the processes and components of net ecosystem C balance (NECB) in a rice-rice cropping system, it is essential to determine whether the system is behaving as net C sink (net C accumulation in the system) or C source (net C depletion or loss from the system). Paddy ecosystems are important in contributing to regional C budget where crops are dominant. In agricultural systems, C may be added through activities like, application of organic manures, rhizodeposition, aquatic biomass, CO_2–C fixation in terms of net ecosystem production (NEP), decayed roots and stubbles of the previous crop and C become lost to the atmosphere through crop harvest and gaseous C emission in the form of CH_4 and CO_2 (Bhattacharyya et al., 2013).Thus the investigation of the processes and the mechanisms involved in the CO_2 exchange between terrestrial ecosystems and the atmosphere are essential in the context of global warming and changing climatic scenario. In this context, the investigation was carried out in an agro wetland ecosystem of Padayatti in a regional scale on dynamics of CO_2 evolution from paddy soils, its

NEE and NECB along with various environmental parameters influencing CO_2 emissions from the soil.

4.2 LITERATURE REVIEW

4.2.1 International Scenario

Estimation and understanding the ecosystem process of CO_2 from ecosystem are crucial as it shows a high degree of variability among ecosystems. Higuchi (1982) studied the Gaseous CO_2 transport through the aerenchyma and intercellular spaces about the uptake of CO_2 by rice roots. Higuchi et al. (1984) studied the gaseous CO_2 transport about root uptake of CO_2 in rice plant. Moore (1989) studied the influence of water table levels on carbon dioxide emissions from Peat land Soils china. Relative contributions of greenhouse gas emissions to global warming were studied by Lashof and Ahuja (1990). Rodhe et al. (1991) studied the sources and sinks of greenhouse gases in Sweden. Ohtaki and Oikawa (1991) studied fluxes of carbon dioxide and water vapor above paddy fields. Freeman et al. (1992) studied fluxes of CO_2, CH_4 and N_2O from a Welsh peatland following simulation of water table draw-down and reported the potential feedback on climatic change. Nykanen et al. (1995) studied emissions of CH_4, N_2O and CO_2 from a virgin fen and a fen drained for grassland of Finland. Hamilton et al. (1995) studied oxygen depletion and carbon dioxide and methane production in waters of the Pantanal wetland of Brazil. Rowell (1995) studied colorimetric method for CO_2 measurements in soils. Agricultural soils as a sink to mitigate CO_2 emissions was studied by Paustian et al. (1997). As a rainfall event can result in changes in both soil water content and temperature, the response of soil respiration to precipitation has been a subject of numerous studies (Shi et al., 2011). Liu et al., (2012) found that both the soil volumetric water content and CO_2 efflux dramatically increased immediately after the addition of water, and then gradually decreased. However, many studies have been based on rainfall simulations, and thus there is a disparity between their conclusions and the real world (Lee et al., 2015). The influence of soil moisture and flood levels were studied by Bhattacharyya et al., 2013, observed that during flooded conditions paddy fields act as a net sink of CO_2. However drained conditions showed distinct diurnal variation with a maximum efflux observed in the afternoon (Seiichi Nishimura, Seiichiro Yonemura Kazunori Minamikawa 2015). When the paddy was flooded, daytime soil CO_2 fluxes reversed with a peak negative efflux just after midday. In draining/flooding alternating periods, a sudden pulse-like event of rapidly increasing CO_2 efflux occurred in response to re-flooding after draining. (Liu et al., 2013., Miyata, Leuning, Denmead, Kim, & Harazono, 2000).Though the positive relationship between soil temperature and soil respiration showed its significance in plots with experimental water addition treatments (Lee et al., 2015), investigations with soil moisture changes in natural field conditions have been few and the results were subject to variation (Liu et al., 2013; Schimel et al., 1995).

Net ecosystem CO_2 exchange in a boreal peatland, northern Manitoba studied by Bellisario et al. (1998). Net ecosystem productivity and its uncertainty in a diverse boreal peatland were analysed by Bubier et al., (1999). Miyata et al., (2000) studied Carbon dioxide and methane fluxes from an intermittently flooded paddy field. La Scala et al. (2000) analysed carbon dioxide emission related to chemical properties of tropical bare soil. Diel and seasonal variation in the CO_2 flux of irrigated rice was analysed by Campbell et al. (2001). Net ecosystem CO_2 exchange of mixed forest in Belgium over 5 years was studied by Carrara et al. (2003) and reported that this temperate forest acted as a CO_2 source contrasts with previous results. Pumpanen et al. (2004) Compared different chamber techniques for measuring soil CO_2 efflux. Seasonal variation of carbon dioxide exchange in rice paddy field in Japan was analysed by Saito et al. (2005). Annual carbon dioxide exchange in irrigated and rainfed maize-based agroecosystems on an annual basis was studied by Verma et al. (2005). Diurnal and seasonal variability of soil CO_2 efflux in a cropland ecosystem on the Tibetan Plateau was studied by Shi et al. (2006) and reported that root respiration in the growing season can be estimated approximately by using the discrepancy between CO_2 efflux relations in the growing season and non-growing season of cropland ecosystem.

The stoichiometry of CH_4 and CO_2 flux in a California rice paddy was studied by McMillan et al. (2007), and results report emphasize the importance of year-round measurements to obtain a reliable estimate of CH_4/CO_2 exchange stoichiometry. Dalal et al. (2008) studied mitigation of atmospheric CO_2 concentrations by increased carbon sequestration in the soil. Mancinelli et al. (2010) compared the role of conventional and organic cropping systems in soil carbon dioxide emission and carbon content from the Mediterranean environment. Spatial distribution of greenhouse gas concentrations in arid and semi-arid region of East Asia was studied by Guo et al. (2013). Carbon Dioxide flux from rice paddy soils of Central China was analysed by Liu et al. (2013) and observed that intermittent flooding and draining cycles play a vital role in controlling CO_2 emissions from paddy soils. The influence of ozone pollution on CO_2, CH_4, and N_2O emissions from a Chinese subtropical rice-wheat rotation system under free-air O_3 exposure was analysed by Kou et al. (2015). They observed that elevated O_3 significantly increased the GWP in the rice–soil system and the GWP per unit of rice yield, however, it did not change the GWP in the wheat–soil system or in the root-free soil during the wheat–rice growing period, nor did it change the GWP per unit of wheat yield.

Role of irrigation management on soil CO_2 emissions in agriculture was studied by Zornoza et al. (2016). Variations of carbon dioxide exchange in paddy field ecosystem under water-saving irrigation in Southeast China was studied by Yang et al. (2016), and the results showed that the paddy field ecosystem under water-saving irrigation was a sink for atmospheric CO_2.

4.2.2 Indian Scenario

The CO_2 dynamics from Indian context are studied by various authors are detailed below. Addition of nitrogen fertiliser increases net ecosystem carbon dioxide uptake, and the loss of soil organic carbon in grassland growing in mesocosms study was conducted by Moinet et al. (2016). Yang et al. (2017) studied effects of inorganic and organic fertilizers on soil CO_2 efflux and labile organic carbon pools in an intensively Managed Moso Bamboo (*Phyllostachys Pubescens*) Plantation in Subtropical China. Effect of water management on soil respiration and NEE of paddy fields in Southeast China was observed by Yang et al. (2017) and reported that management slightly enhanced the rice dry matter amount but accelerated the consumption and decomposition of soil organic carbon and significantly increased soil respiration, which led to the decrease of net CO_2 absorption. Greenhouse gas inventory estimates for India was studied by Sharma et al. (2006). Greenhouse gas emission in relation to labile soil C, N pools and functional microbial diversity as influenced by 39 years long-term fertilizer management in tropical rice was studied by Bhattacharyya et al. (2013). Net ecosystem CO_2 exchange and carbon cycling in tropical lowland flooded rice ecosystem was studied by (Bhattacharyya et al. 2013b). Kumar et al. bvi\ (2016) analysed the regression relationship of GHGs emission with key soil parameters was employed to predict seasonal emissions of GHGs from paddy and the results suggest that scheduling irrigation can be an effective strategy in order to save water, maintain rice yield and mitigate CO_2 emission from direct seeded paddy fields in eastern India.

4.3 RESULTS

4.3.1 Net Ecosystem Exchange of CO_2

The NEE estimates over the whole annual crop rotation cycle during the period 2013-2014 varied between a minimum of -2.101 t C ha^{-1} to a maximum of 0.612 t C ha^{-1} (Fig. 4.1). During the period a significant ($p<0.01$) seasonal variation in NEE was observed between wet CS and dry summer FS. Over the seasons NEE was 0.275 t C ha^{-1} during FS and ranged from -0.102 t C ha^{-1} during CS-I and -0.1503 t C ha^{-1} during CS-II. Among CS significant variations in NEE was observed through the vegetative stages of the rice plant. In the wet CS NEE slowly decreased towards tillering stage of the paddy plant with a mean value of -1.07 during July in CS-I and -1.83 t C ha^{-1} during November CS-II. NEE further observed decreasing towards panicle initiation with a mean value of -1.38 and 1.9 t C ha^{-1} during August and December in CS-I and CS-II respectively. Peak values in NEE were observed at the reproductive stages during September in CS-I and January in CS-II with a mean value of -1.59 and -2.1 t C ha^{-1} respectively. NEE was observed to be increasing towards dry FS devoid of plant biomass with a mean value of 0.417 t C ha^{-1} indicating that primary productivity had a significant influence on NEE.

Similar to NEE, NPP also varied significantly ($p<0.01$) with seasons. NPP was found lowest during the FS with a mean value of -0.00067 Kg C ha^{-1}. Whereas it was higher in the crop growing seasons with a mean value of 0.166 and 0.126 t C ha^{-1} in CS-I and CS-II respectively. Whereas the heterotrophic respiration (Rh) didn't vary significantly between seasons during the period 2013-2014.

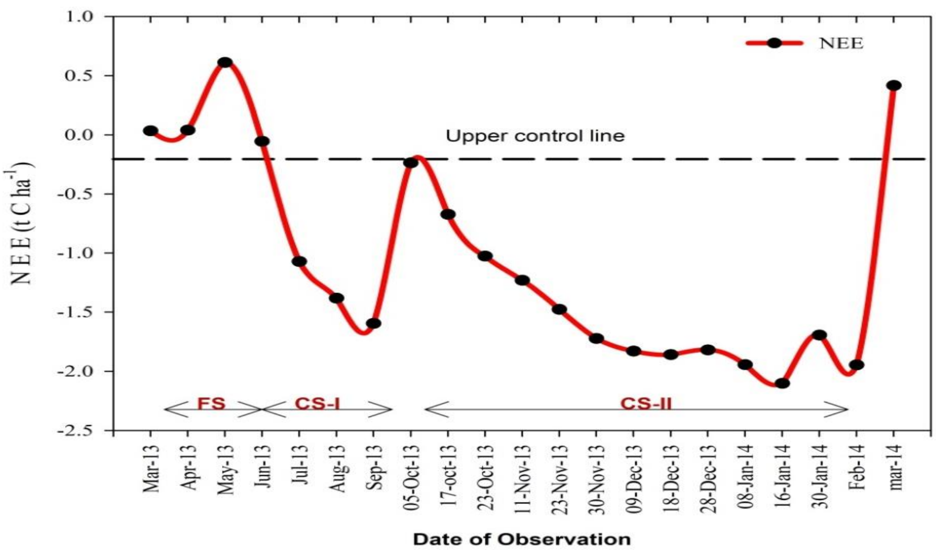

Figure 4.1 Net ecosystem exchange of CO_2 from rice paddies of Padayatti, Palakkad during 2013-2014

Table 4.11 Seasonal mean Rh, NPP and NEE from the rice paddies of padayatti Palakkad during the period 2013-2014

Seasons	Rh Kg C ha^{-1}	NPP Kg C ha^{-1}	NEE Kg C ha^{-1}
FS	275.9331	-0.00067	275.9338
CS-I	236.6961	1262.331	-1025.63
CS-II	158.7448	1662.652	-1503.91
Total	195.9143	1269.704	-1073.79

4.3.2 Seasonal Emission of Soil CO_2 from Rice Paddies

The carbon dioxide emission during the crop growing and summer fallow seasons from rice paddies of Padayatti wetland Palakkad is shown in Fig. 4.2. During the observation period from March 2013 to March 2014, the total CO_2 concentration varied within the range of 0.185 g m^{-2} h^{-1} to 3.26 g m^{-2} h^{-1}. Even though the total CO_2 flux from the soil is influenced by vegetational growth of rice plant, it lacks significant variation among seasons. When compared to the FS CO_2 emissions increased soon after transplantation in both the CS. During the period total CO_2 flux varied from 0.3 to1.8 g m^{-2} h^{-2} in CS-I with a mean value of 1.046 g m^{-2} h^{-1}, where as in CS-II it varied from 0.2 to 3.26 g m^{-2} h^{-1} with a mean value of 1.43 to 3.26 g m^{-2} h^{-1}. In the fallow season CO_2 flux ranged between 1.01 to 1.27 g m^{-2} h^{-1} with an average value of 0.985 g m^{-2} h^{-1}. Even though there was no significant variations, seasonal emissions of CO_2 during the year 2013-2014 were in the order of magnitude FS < CS-I < CS-II with lowest value in FS and highest value in CS-II. During the period pulse event of total CO_2 were observed during July 2013 (1.82 ± 0.089 g m^{-2} h^{-1}) and in September2013 (1.5 ± 0.32 g m^{-2} h^{-1}) in CS-I and during December 2013 (3.26 ± 1.22 g m^{-2} h^{-1}) in CS-II depending on the stages of plant growth, flooding and drainage pattern of the rice fields.

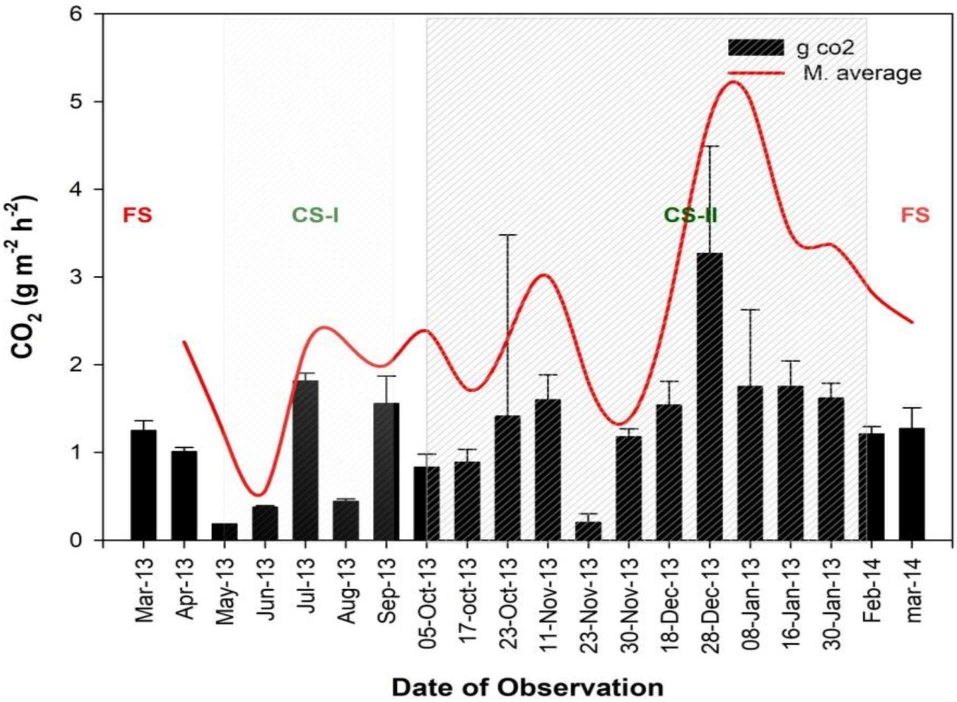

Figure 4.2 Seasonal variation in carbon dioxide emission from rice paddies of Padatatti Palakkad during the year 2013-2014.

4.3.3 CO_2 Emission in Relation to Vegetative Stages

Soil total CO_2 flux increased gradually during the observation period depending on the soil moisture, field flooding pattern and NPP. During the crop growing seasons CO_2 fluxes increased soon after transplantation with an average rate of 0.83 ± 0.14 g m^{-2} h^{-1} (Fig. 4.3). CO_2 flux had its maximum emission during panicle initiation and heading stage of rice paddy, 65 to 93 DAT with an average rate of 3.26 ±.22 g m^{-2} h^{-1}. Fluxes of CO_2 was observed declining towards the harvesting period with an average rate of 1.2 ± 0.23 g m^{-2} h^{-1} subjected to midseason drainage. Even though significant relationship was not observed among fluxes of CO_2 and DPW, a general increase in CO_2 fluxes was observed during the field drainage interval with minimum retention of water levels. However a positive correlation significant at $p < 0.05$ was observed with CO_2 and NPP (Fig. 4.4).

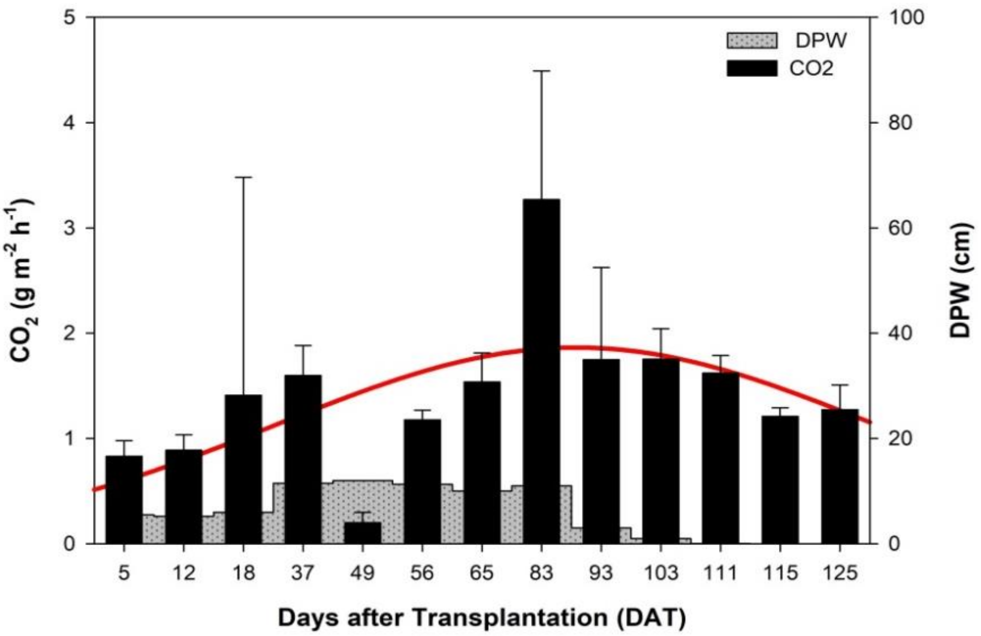

Figure 4.3 Carbon dioxide emission from rice paddies of Palakkad during different stages after transplantation during 2013-2014 periods

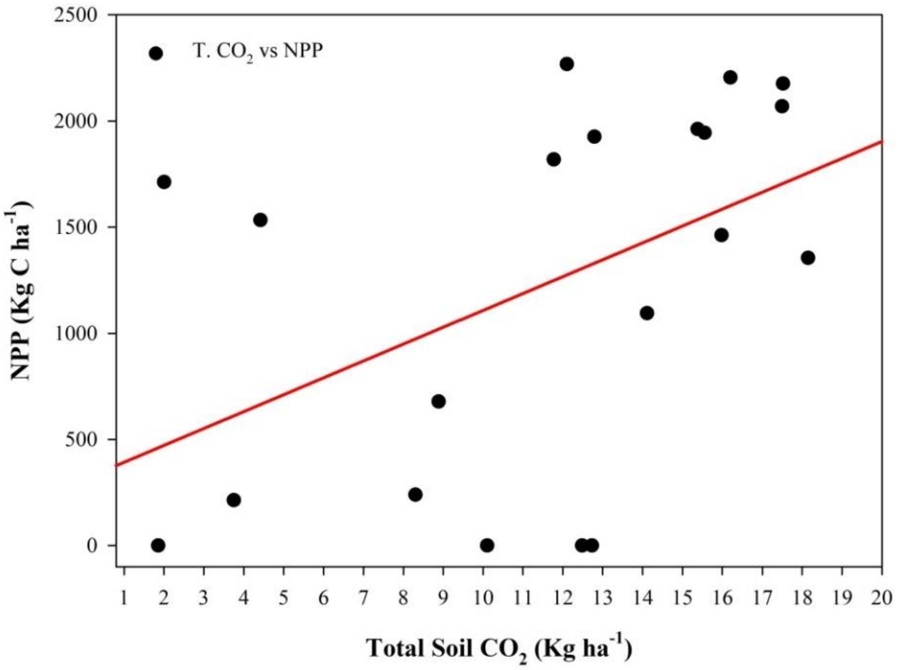

Figure 4.4 Relationship showing total soil CO_2 flux and NPP from rice paddies of Padayatti, Palakkad during 2013-2014

During the study period soil CO_2 fluxes increased soon after re-flooding and exceeded pre-flooding values by 70%. Replacement of soil air by water should thus cause an enriched CO_2 pulse. The CO_2 fluxes remained minimum levels during the flooding in the following days. As standing water declined and eventually disappeared, the CO_2 fluxes gradually increased and finally reached to maximum levels. This indicates that drainage and flooding cycles play a vital role in controlling CO_2 emissions in paddy soils. During the study soil total CO_2 flux is also found correlated with soil pH with a correlation coefficient of 0.610, significant at $p<0.05$.

4.3.4 Spatial emission pattern of CO_2 from the rice paddy

Static chamber based measurements of soil total CO_2 emission lacks significant spatial variability among seven observed stations during the period March 2013 to March 2014. During the period fluxes of CO_2 was varied from a highest value of 2.8 ± 1.9 g m^{-2} h^{-1} in station 4 to a lowest value of 1.3 ± 0.9 g m^{-3} h^{-1} in station 7 (Fig. 4.5).

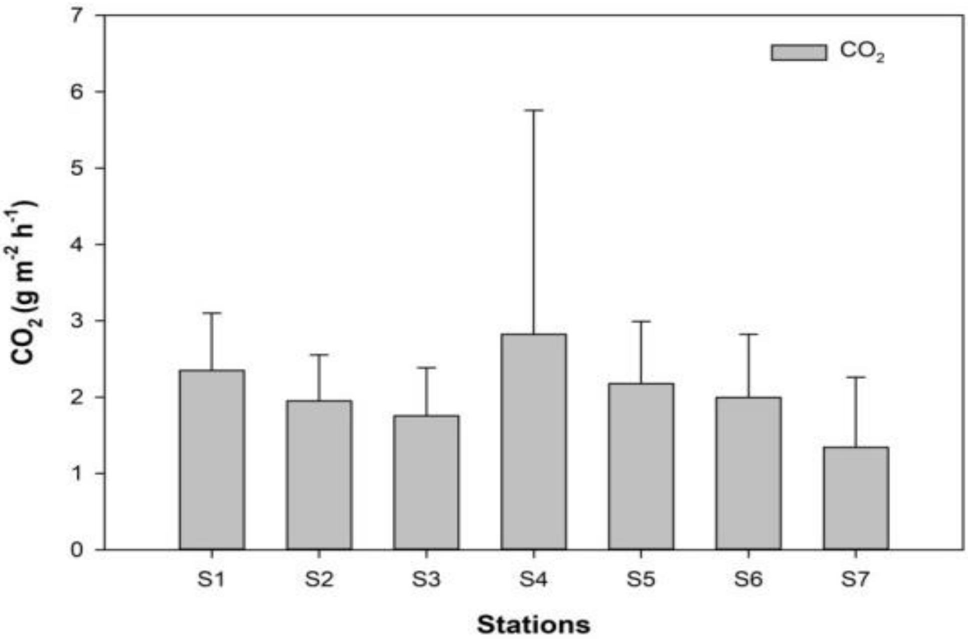

Figure 4.5 Mean variation of CO_2 among stations from rice paddies of Padayatti, Palakkad during 2013-2014

4.3.5 Cumulative, Annual Emission of CO_2

Cumulative CO_2 emission throughout the year including crop seasons and fallow period was 10.86 Kg m^{-2}. Seasonally the CS-II contributed 38.7% (4.2 Kg m^{-2}) of the total cumulative emission, although it was slightly higher than the dry FS 32.7% (3.5 Kg m^{-2}). The contribution of CS-I towards the annual cumulative emission was 28.47% (3.09 Kg m^{-2}) during the continuously submerged period. Overall the seasonal cumulative emission of CO_2 followed the order CS-II (38.7%) > FS (32.7%) > CS-I (28.47%).

4.3.6 Diurnal Variations in CO_2 Emissions

The time series flux variations of CO_2 observed over a period of 24 hours from submerged rice paddy after 56 days of transplantation is shown in Fig.4.6, explained using a nonlinear regression model. During the period CO_2 showed a distinct diurnal emission pattern with highest emission during the night hours and lowest towards the daytime. The net CO_2 flux during the night time 06 pm to 06 am ranged from 0.77 ± 0.014 to 0.89 ± 0.03 g m^{-2} h^{-1}, whereas during the day hours from 06 am towards 05 pm fluxes of CO_2 decreased drastically ranging from 0.379 ± 0.03 (in mid-noon, 02 pm) to 0.70 ± 0.075 g m^{-2} h^{-1}.

The diurnal emission, of CO_2 showed significant negative correlation with soil temperature ($p < 0.001$, $r = -0.7$). During the period diurnal soil temperature ranged from 21.3 to 28.4 °C and temperature was found lowest during the night hours and higher toward the day. CO_2 emission was observed decreased with increasing soil temperature (Fig. 4.7). Similar to temperature fluxes, CO_2 was also showed strong negative correlation with total incoming solar radiation ($p < 0.05$ $r = 0.07$). Total solar radiation varied significantly, which was positive towards day hours ranging from 0.25 to 775W m^{-2} during 06 am to 06 pm. Fluxes of CO_2 was observed decreasing towards increase in solar radiation. Overall diurnal emission pattern of CO_2 decreases with increase in soil temperature and solar radiation (Fig. 4.8).

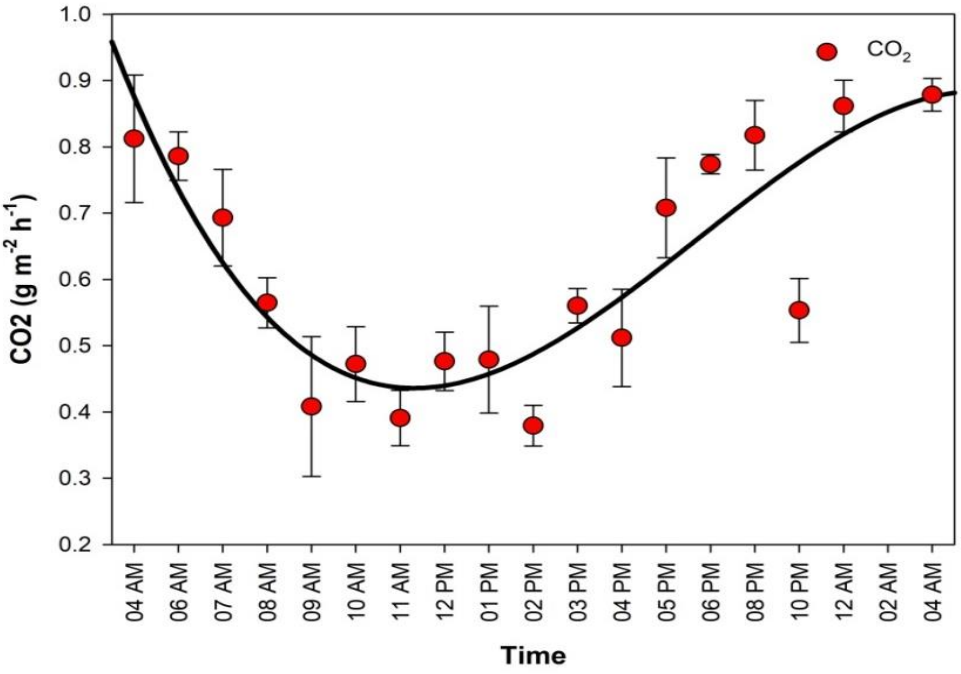

Figure 4.6 Diurnal emission of CO_2 from rice paddies of Padayatti, Palakkad during 2013-2014 period

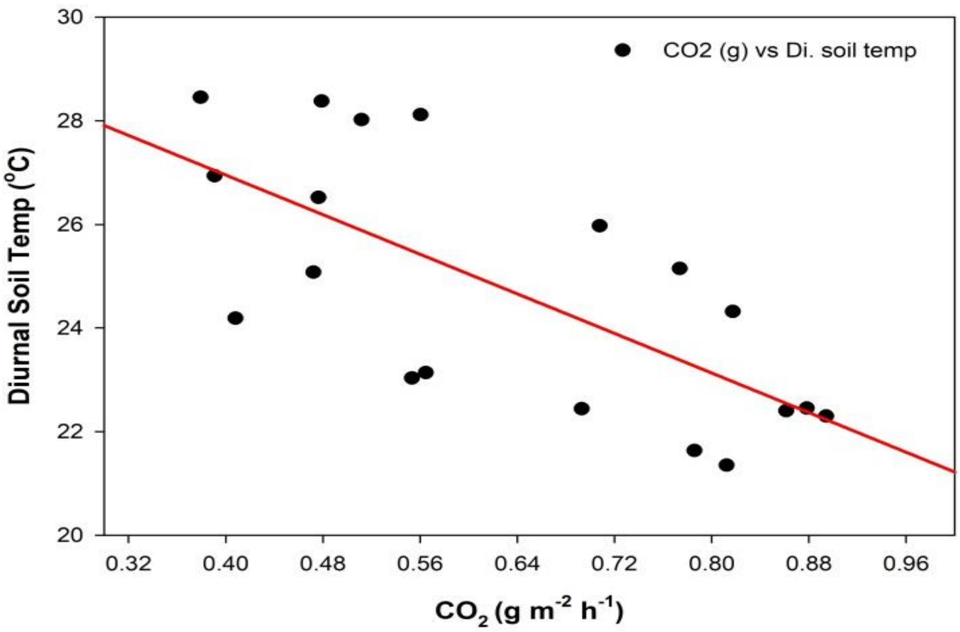

Figure 4.7 Relationship between diurnal emission of CO_2 and soil temperature from rice paddies of Padayatti, Palakkad during 2013-2014

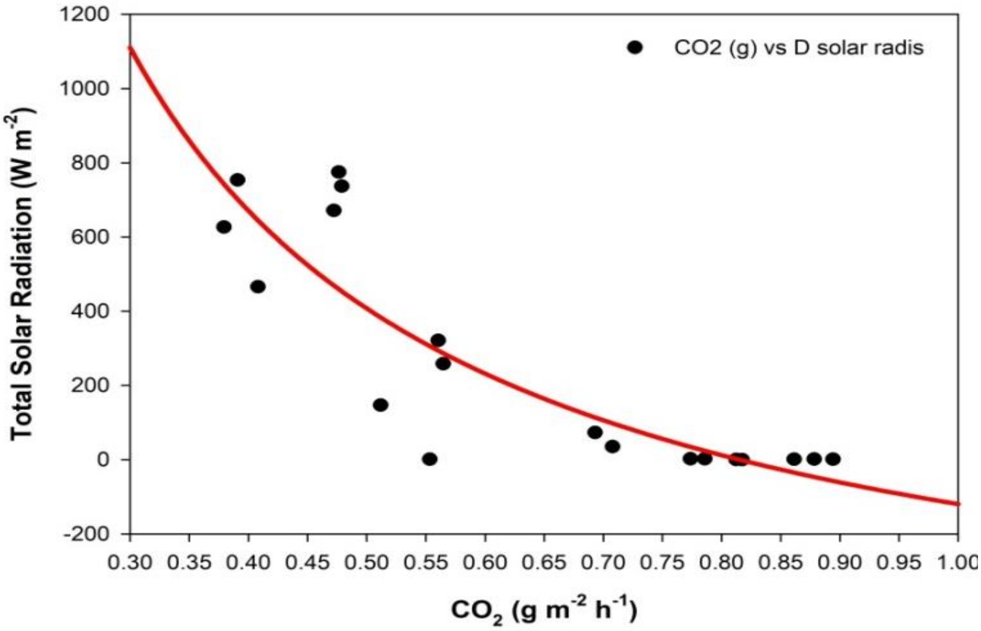

Figure 4.8 Relationship between diurnal CO_2 emission and total incoming solar radiation from paddy wetlands of Padayatti Palakkad

4.3.7 Effect of Environmental Variables in CO_2 Emission

The air temperature and soil temperature exhibited seasonal pattern similar to total soil CO_2 fluxes. Negative correlation significant at $p<0.05$ was observed between soil CO_2 flux, air and soil temperatures. The air temperature varied from 22.06 °C in December 2013 to 28.07 °C in May 2013 whereas soil temperature ranged from 22 °C to 32.3 °C during December and April 2013 respectively. Nonlinear regression analysis was used to model the influence of temperature on soil CO_2 flux rates under both flooded and drained conditions. Negative linear correlation between air temperature and soil total CO_2 fluxes were observed (R^2 = 0.35, P<0.05) during the observation period (Fig.4.9).

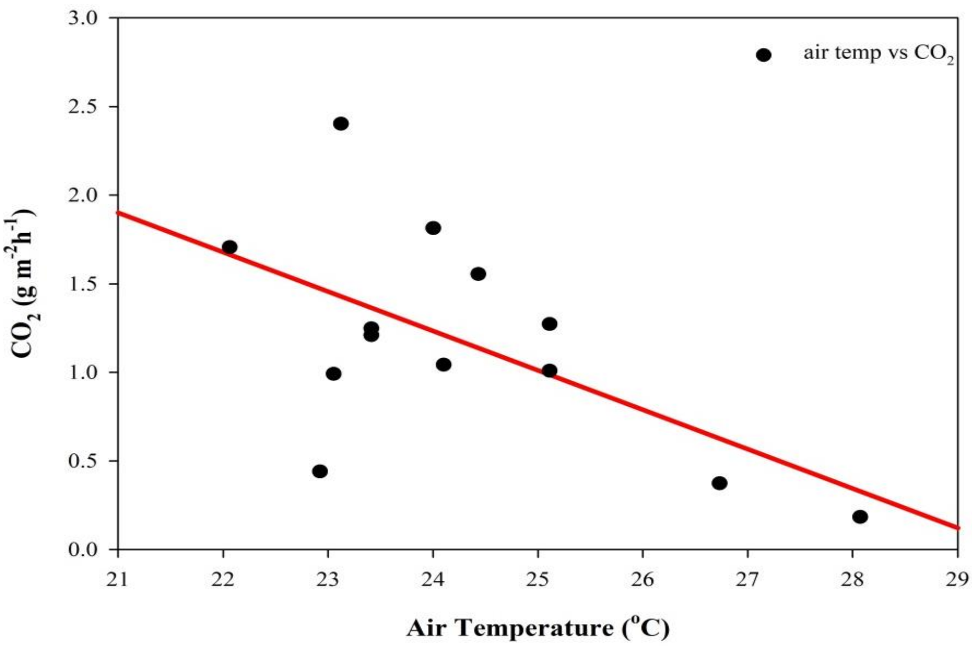

Figure 4.9 Relationship between soil total CO_2 flux and air temperature from Padayatti rice paddy wetland Palakkad during 2013-2014

4.3.7.1 CO_2 efflux from soil in relation to Carbon fractions

During the period from 2013-2014, a significant negative correlation between measured CO_2 efflux and soil variables such as soil inorganic carbon ($p<0.01$, r = -736), total carbon ($p<0.01$, r = -717), C:N ratio($p<0.01$, r = -636) was observed. Throughout period TIC ranged from 2.4 to 8.4 g Kg^{-1} with an mean value of 4.25 g Kg^{-1}. Whereas TOC was in the range of 3.5 to 7.6g Kg^{-1} with a mean vlaue of 5.6 g Kg^{-1}. During the period C:N ratio was in the range 2.6 to 6.9 with an average value of 4.21 in surface (0 -15 cm) soil layers. The influeance of environmeant variable in CO_2 emissions is evident in the PCA (Fig. 4.10). The Dim1 and Dim2 represented respectively 50.2% and 22.6% of the overall variance. The PC1 revealed the opposition between CO_2 emissions and the TC, TIC, and C:N ratio indicating they are inversely correlated.

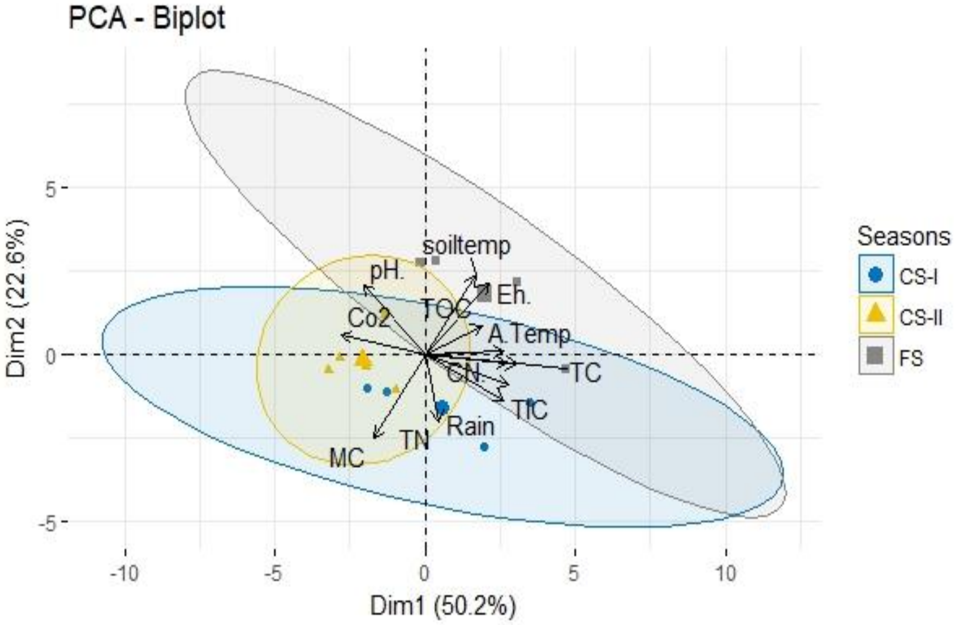

Figure 4.10 PCA showing relationship between CO_2 and various environmental parameters

4.4 DISCUSSION

In the present study NEE, NPP, and Rh indicated strong seasonal trends largely driven by changes in microbial respiration, soil moisture, temperature, plant activity and specific stages of plant development (Saito et al., 2005). The results obtained during the present study were consistent with the results of Rong et al, (2017) that increased rates of photosynthesis will lead to increased biomass and NEE (Bhattacharyya et al. 2013b). During the crop growing seasons, flooded rice field behaved as a net sink of CO_2 from vegetative period to period just prior to harvesting. NEE exchange values were negative in the flooded rice field indicating a net sink of CO_2. During this period the rate of rice plant C fixation outpaces continual loss of C from the cropland by respiration resulting in the net uptake of CO_2. High rates of photosynthesis combined with low rates of respiration in largely anaerobic soils resulted in substantial net carbon uptake in this wetland ecosystem. However NEE tended to decrease towards the reproductive stages due to the cessation of plant C uptake (Xiao et al. 2005).

Over the dry fallow seasons, NEE become gradually more positive, shifting towards a net CO_2 source. Our findings also corroborate with Campbell et al. (2001), Alberto et al. (2015) and Bhattacharyya et al. (2013). NPP also followed a similar pattern with peak NPP during the ripening stage of the plant with maximum biomass and declining towards harvesting due to near-cessation of plant C uptake. Similar to previous studies (Zou et al., 2004; Mosier et al., 2006; Nishimura et al., 2008), Rh had a slightly different seasonal pattern without any significant difference among wet and dry seasons. Basically, a decrease in NEE could be achieved through either an increase in NPP or a decrease in soil CO_2 emissions or both. In this study, total CO_2 emission from soil respiration was generally unchanged.

During the present study from March 2013 to March 2014, the largest net flux of CO_2 into plant-soil system was -1073 Kg CO_2 ha^{-1} (Table 4.1) that exceeded the losses of biomass C via harvesting with a mean value of 332 Kg C ha^{-1} and heterotopic respiration over the period of 323.9 Kg CO_2 h^{-1} leaving -1580 Kg C ha^{-1} remaining in the field. According to Stallard, (1998) rice paddies were capable of sequestering 0.4 to 1.0x 10^{15} g carbon globally. The global area of rice cultivation is 147.5 x 10^{10} m and Stallard's (1998) estimate would, therefore, suggest an NEP of 271-678 g C m^{-1} Y^{-1}.

There was a clear seasonal variation in soil CO_2 fluxes, depending on the growth stage of rice plant, flooding and drainage pattern and temperature. Annually higher CO_2 emissions were observed during the growing seasons than those measured during the fallow periods which were similar to the observation of Song et al. (2003). During the present study seasonal changes in NPP was observed similar to soil CO_2 emission. The NPP provides not only abundant substrate for autotrophic respiration, but also accelerated carbon cycling which in turn increases CO_2 emissions. NPP showed a positive correlation significant at $p<0.05$ level in the present study with a correlation coefficient $r = 0.477$.

Flooding and drainage of paddy soils also had a significant influence on CO_2 efflux from paddy soils (Meijide et al. 2017). Our present study also demonstrates the variations in soil CO_2 efflux depending on the soil moisture regime and flood water levels. During the flooding of paddy soils subsequent to rice cultivation cuts off the oxygen supply from the atmosphere and the microbial activities switch from aerobic (i.e. oxic condition) to facultative (i.e. hypoxic condition) and to anaerobic (i.e. anoxic condition) conditions (Kögel-Knabner et al. 2010). Anoxic conditions prevailing due to submergence leads to reduction in biological activity. During submergence water replaces the soil pores inhibiting the CO_2 diffusion rate from the soil dramatically (Miyata et al. 2000; Campbell et al. 2001; Saito et al. 2005).The CO_2 efflux observed in this study during the intermittent drainage in summer was generally much higher than those reported in previous studies in upland cropland soils. During this period there was an abundant supply of labile fermentation products that were mineralized rapidly once oxic conditions were established. This, together with the higher soil temperatures, accounted for the large increase in CO_2 during the drained period (Seiichi Nishimura, Seiichiro Yonemura Kazunori Minamikawa 2015). Minamikawa and Sakai (2006, 2007) found a marked increase in CO_2 efflux from the paddy soil surface during intermittent drainage similar to this study and reported that the average CO_2 efflux was 740mg CO_2 m^{-2} h^{-1}. Miyata et al. (2000) suggested that the presence of floodwater acts as an almost complete diffusion barrier to CO_2 efflux based on 9 days of observations. In the present study, the slow yet sustained rate of CO_2 efflux over the flooded period resulted in a significant loss of carbon.

Furthermore, correlation analysis revealed that air temperature and soil temperature explained most of the diurnal fluctuations in soil CO_2 flux. Our study also demonstrated that, in rice fields exposed to intermittent flooding and draining cycles, environmental factors regulating diurnal fluctuations in CO_2 flux are quite different from those governing seasonal variations. In the present study maximum diurnal CO_2 emissions were observed during the night hours from 06pm to 06am when compared to the day hours form 06 am to 06pm. In day hours drastic decline in CO_2 efflux occurred to CO_2 assimilation due to photosynthesis (Campbell et al. 2001). This occurred primarily because of the layer of standing water, which is the habitat of bacteria, phytoplankton, macrophytes and small fauna. The photosynthesis process of these aquatic organisms affects ecosystem respiration.

A small diurnal variation in net CO_2 flux indicated that photosynthetic CO_2 uptake and respiratory CO_2 release by the aquatic weeds and algae were the main components of the net CO_2 flux fromthe water surface, which was in good agreement with previous reports by Koizumi et al. (2001). In the daytime, dissolved CO_2 in the paddy water would have been assimilated by the aquatic weeds and algae through photosynthesis, which resulted in the significant decrease in the dissolved CO_2 concentration and increase in the pH of the paddy water. At night time, in contrast, the respiratory CO_2 release by the aquatic weeds and algae would have increased the dissolved CO_2 concentration and decreased the pH of the paddy water (Seiichi Nishimura, Seiichiro Yonemura Kazunori Minamikawa 2015). Under flooding conditions, fluxes of CO_2 were, as expected, lower because the diffusivity and biological activity of the topsoil that was substantially reduced by floodwater. Initially, there was a slow release of CO_2 into the atmosphere as a positive efflux throughout the night. At sunrise the fluxes decreased, even negatively peaked at around 16:00 where negative values indicate net carbon sequestration. This may have been because some aquatic plants, such as algae, inside the floodwater began to photosynthesize again. In contrast, CO_2 flux under draining conditions was positive and settled throughout the night, despite falling temperatures. After sunrise, CO_2 fluxes remained positive and increased with temperature, reaching a peak at 2 pm (14:00 h) before falling again as temperatures declined.

The C:N ratio of a soil has been considered as a measure of SOM quality and soil N mineralization/immobilization potentials (Thomsen et al. 2008).

(Springob and Kirchmann 2003) had reported an decline in soil CO_2 evolution with increasing C:N ratio showing an inverse relationship between soil CO_2 efflux and soil C:N ratio. Less N per unit C is thus present in soil with higher soil C content, which may influence the C turnover. Varying proportions between C and N in the different pools with different turnover times may be the reason why the C to N ratio better describes SOM decomposability than the actual C concentration. Thus C to N ratio has likewise been found to relate better to N mineralization than the soil N concentrations (Springob and Kirchmann 2003). It is estimated from a wide variety of soil types that an increase in C to N ratio from 10 to 14 (Thomsen et al. 2008) or 16 (Springob and Kirchmann 2003) is observed to reduce soil CO_2 emission by 50%. Thus indicating soil C to N ratio as a feasible indicator of decomposability of soil organic fractions. During the present study soil C to N ratio ranged between 3.1 to 8.1 indicating a low significant value below the threshold range of 10 to16. A negative correlation indicting an increase in soil total CO_2 efflux with decreasing C to N ratio was also observed during the study period. The low rate of C to N resulted in the increased flux of CO_2 from the paddy soils upsetting the carbon sequestration potential of the soil.

The results revealed that seasonal changes in soil CO_2 flux were influenced by a combination of environmental factors including the air, soil temperatures water management and soil C:N ratio. Timely and appropriate management of flooding pattern and fertilizer management can able to regulate the efflux from soil to a greater extent.

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Chapter - 5

METHANE FLUX- DIURNAL AND SEASONAL VARIATIONS FROM RICE PADDY SOILS

5.1 INTRODUCTION

Methane (CH_4) is the second most potent greenhouse gas in the atmosphere after CO_2 and has 34 times the GWP of CO_2 over a period of 100-years (IPCC, 2013). Global atmospheric CH_4 concentration has increased from pre-industrial level of 0.715 ppm in 1750 to 1.824 ppm in 2013 (WMO, 2014). In the atmosphere, CH_4 has a residence time of 12.4 years, and instantaneous forcing of 1.37×10^5 Wm^{-2} makes it an important gas among GHG contributing 20% to the anthropogenic greenhouse effect (IPCC, 2013). The massive increase in the number of ruminants, emissions from fossil fuel extraction and use, expansion of rice paddy agriculture and the emissions from landfills and waste are the primary sources of anthropogenic CH_4. Biogenic anthropogenic sources include paddy cultivation, livestock, landfills and waste treatments, biomass burning and fossil fuel combustion, while natural sources are wetlands, oceans, forest fires, termites and geological settings. Presently, anthropogenic emissions of CH_4 dominate over natural emissions, accounting for about 50–65% of the total emissions (Kayranli et al. 2010).

Globally wetlands and rice paddies are the largest natural source of CH_4 to the atmosphere, accounting for approximately 139–343 Tg CH_4 y^{-1}. These ecosystems contribute 32–47% to the total global CH_4 emissions (Denman et al., 2007). Among wetlands paddy wetlands are considered to be one of the significant sources of greenhouse gases - CH_4, contributing up to 20% or ~100 Tg CH_4 to the global budget on an annual basis. According to IPCC (1996a), paddy fields contribute to one-fifth of the annual increase in radiative forcing and 30% of global agricultural CH_4 emissions, adding up nearly 12,000 mega tones of CO_2 equivalent per year (Holm et al., 2016). In paddy fields CH_4 is formed as an endpoint of methanogenesis, anaerobic bacterial degradation of complex organic matter, mediated by acetoclastic, hydrogenotrophic and methylotrophic methanogens (Conrad et al., 2007; Liu and Whitman, 2008). Under the anaerobic condition of flooded rice ecosystem, CH_4 is produced as a result of bacterial degradation of organic matter (Penning and Conrad, 2007) known as methanogenesis and the bacteria/archaea involved are known as methanogens. Methanogens are strictly anaerobic obligate, belonging to the domain Archaea of Phylum Euryarchaeota (Conrad, 2007; Fazli et al., 2013).

The methane emission process is a composition of several micro-bacterial kinetics. In particular, rice field soils, characterized by O_2 depletion, high moisture, and relatively high organic substrate levels, offer an ideal environment for the activity of methanogenic bacteria, (Mathews et al., 2000). Two distinct micro- biological processes control methane emission from rice fields, methane production, a anaerobic process responsible for methane production and methane oxidation, a but aerobic process responsible for methane oxidation Neue and Boonjwat, 1993). A considerable part of produced methane is oxidized microbiologically by in aerobic environment (Oremland and Culbertson, 1992). A part of produced methane which is not oxidized enters into the atmosphere by three possible mechanisms such as diffusion, ebullition and plant-mediated transport. Among these pathways, diffusional plant transport was found to be dominant in paddy soils (Nouchi et al., 1990). CH_4 released through the parenchyma conduit was much higher possibly bypassing the microbial CH_4 oxidation (methanotrophy) at the soil oxic layers. CH_4 oxidation is the only biological sink where 80% of the produced CH_4 being consumed by methanotrophic bacteria for biological needs, for energy or building up microbial biomass (Hanson and Hanson, 1996; Nouchi et al., 990).

CH_4 exchange between paddy ecosystem and the atmosphere is one of the key processes that affect the atmospheric concentration of CH_4. As rice is grown in different environmeants, ranging from tropical to temperate regions, with varying climatic, edapic and biological conditions and different agricultural management practices that naturally affects the rate of CH_4 exchange (Bhattacharyya et al., 2013). Therefore, studies regarding the CH_4 exchange between paddy field ecosystem and the atmosphere are important to analyse the magnitude of emission and factors controlling CH_4 emissions. In these context diurnal, monthly and seasonal estimations of CH_4 along with factors influencing its emission behaviour was studied in an agro wetland ecosystem of Padayatti Palakkad.

5.2 LITERATURE REVIEW

5.2.1 International Scenario

CH_4 exchange between paddy ecosystem and the atmosphere is one of the key processes that affect atmospheric CH_4 concentration are be regulated by various factors including temperature (Conrad, 2002; Glissman et al., 2004; Inglett and Inglett, 2013), pH (Wang et al., 1993; Ye et al., 2012), substrate availability (O'Connor et al., 2010), and availability of electron acceptors (D'Angelo and Reddy, 1999). In Asia, many studies have been conducted to monitor diurnal and seasonal variations of CH_4 flux from paddy fields and to analyze the factors controlling the CH_4 flux (Aubinet et al., 2000). These previous studies were performed mainly in Asian countries such as China (Zhu et al., 2005; Ren et al., 2007), India (Bhattacharyya et al., 2013a,b), Japan (Miyata et al., 2000, 2005; Saito et al., 2005), Thailand (Pakoktom et al., 2009), South Korea (Moon et al., 2003), Bangladesh (Hossen et al., 2011) and Philippines (Alberto et al., 2009). Many studies point at nitrogen (N) as an important variable influencing CH_4 cycle in wetland ecosystems (Bodelier, 2011). Effects of N addition can act directly on the methanogenic community but may have indirect effects, by stimulating the bacteria capable of denitrification. Denitrifiers and methanogens compete for organic carbon (C), and furthermore, denitrification produces toxic intermediates (NO, NO_2, and N_2O) which can inhibit methanogenic archaea in wetland sediments, thereby reducing CH_4 production (Roy and Conrad, 1999). Alternations of wetting and drying appear in paddy fields with water-saving irrigation. These alterations can significantly reduce the water demand and maintain the rice yield (Mao, 2002). The influence of water management on CH_4 emission from paddy fields has been well documented (Johnson-Beebout et al., 2009; Hadi et al., 2010; Liu et al., 2010; Hou et al., 2012).

Quantification of CH_4 between the ecosystem and the atmosphere is one of the key issues for assessing the global budget of greenhouse gases and the global warming potential. Rice is the major food crop in Asia, and about 80% of its growing in different environments conditions ranging from tropical to temperate regions with varying climatic, edaphic and biological conditions and under different agricultural management practices which naturally affect the rates of CH_4 emissions. There are uncertainties in the estimation of methane from Indian agriculture because of its diverse soil, climate, land-use types and socio-economic conditions. Moreover, various crop-management practices, water management also play a major role in the emission behavior. In India, the studies regarding methane emission were limiting especially from south India. Therefore the observations of the present study in the process and magnitude of the CH_4 emissions from paddy fields under different will provide information for regional greenhouse gas inventories and mitigation measures.

A perusal of available literature reveals that the various factors both environmental and agricultural operations are crucial in the methane emission from soil. On paddy system and wetlands, carbon steam reaction is controlled by oxygen group attached to the carbon and the methane produced is formed by reaction of steam with adsorbed hydrogen. Baker-Blocker et al. (1977) studied the methane flux from wetlands areas of Michigan, and ebullient gases were collected and analyzed to deduce in situ methane fluxes. Lee et al. (1981) studied the gas transport through a rice paddy. Seiler and Holzapfel-Pschorn (1984) studied methane emission from rice paddies of Andalusia, Spain and observed substantial seasonal variations in methane flux, with low values during the tillering stage and shortly before harvest, while maximum values were observed at the end of the flowering stage. Influence of water table levels on CH_4 and CO_2 emissions from peatland soils was studied by Moore (1989). King (1990) studied the relationship between methane emissions and light from a wetland. The mechanism of methane transport from the rhizosphere to the atmosphere through rice plants was studied by Nouchi et al. (1990). Relative contributions of greenhouse gas emissions to global warming were studied by Lashof and Ahuja (1990).

Schütz et al. (1990) studied the influence of soil temperature on methane emission from Italian rice paddy fields and observed that seasonal variations in methane were not closely related to soil temperatures whereas diurnal changes were significantly correlated with the diurnal changes of the temperature to particular soil depth. Moore and Knowles (1990) studied the methane emissions from fen, bog and swamp peatlands in Quebec, Canada. Distribution and rate of methane oxidation in sediments of the Florida Everglades was studied by King et al. (1990). Moore and Roulet (1991) compared the dynamic and static chambers method in methane emission measurements from subarctic fens. Khalil et al. (1991) studied methane emissions from rice fields in China and observed that methane emissions from rice fields of China were 4-10 times higher than emission rates from rice fields in the United States and Europe. Rodhe et al. (1991) studied sources and sinks of greenhouse gases in Sweden. Roulet et al. (1992) studied the methane flux and climatic change from northern peatlands and reported that methane flux plays an important role in global methane budget. Freeman et al. (1992) studied fluxes of CO_2, CH_4, and N_2O from a welsh peatland about water draw-down and calculated the potential feedback in climatic change.

Roulet et al. (1993) compared the methane flux from drained northern peatlands with a rice field with a persistent water table. Neue (1993) studied methane emission from wetland rice fields rice fields and anlysed the role in global warming. Dueñas et al. (1994) studied consumption rate of methane by soils. Nouchi et al. (1994) developed a model based on the seasonal variation in methane flux from rice paddies associated with soil water, rice biomass and temperature. Lindau et al. (1994) studied the role calcium sulfate in methane evolution from flooded rice paddy field. Shannon and White (1994) studied methane emissions from two Michigan Peatlands. Role of rice paddies in methane emission was studied by Minami (1994).

Nykanen et al. (1995) compared the emissions of CH_4, N_2O, and CO_2 from a virgin fen and a fen drained for grassland of Finland. Sciences and Babos (1995) studied methane emission from a wetland rice field and analysed the role of salinity in methane emission. Oxygen depletion and carbon dioxide and methane production in waters of the Pantanal wetland of Brazil were studied by Hamilton et al. (1995). Banker et al. (1995) studied methane as sources or sinks in paddy rice soils and its emissions relationship to methane production. Gilbert and Frenzel (1995) studied methanotrophic bacteria in the rhizosphere of rice microcosms and their effect on pore water methane concentration and methane emission. They observed that rates of CH_4 emission depend on both CH_4 productions in anoxic parts of the soil and on CH_4 oxidation at oxic-anoxic interfaces. Mikkela et al. (1995) studied diurnal-variation in methane emission in relation to the water-table, soil-temperature, climate and vegetation cover in a Swedish Acid Mire. Kelley et al. (1995) studied methane dynamics across a tidally flooded river bank margin. Plant-mediated methane transport and methane production as controls on methane flux from arctic wet meadow tundra were studied by Schimel (1995).

Methane oxidation in the rhizosphere of rice plants was studied by Denier Van Der Gon and Neue (1996). (IPCC, 1996) Reported methane emissions from flooded rice fields. Methane emissions from natural wetlands were studied by Wang et al. (1996). Sequential reduction processes and initiation of CH_4 production upon flooding of oxic upland soils was studied by Peters and Conrad (1996). Control of the diurnal pattern of methane emission from emergent aquatic macrophytes by gas transport mechanisms was studied Whiting and Chanton (1996). Role of methyl fluoride in methane oxidation and methane production was studied by Frenzel and Bosse (1996). Thomas et al. (1996) analyzed the role of wetland plants in the diurnal control of CH_4 and CO_2 fluxes in peat. Methane oxidation in the rhizosphere of *Sagittaria lancifolia* using methyl fluoride was studied by Schipper and Reddy (1996). Minoda et al. (1996) studied the role of photosynthathates as dominant sources of CH_4 and CO_2 in soil water and also reported the CH_4 emission pathway to the atmosphere from paddy fields.

Papen et al. (1997) studied the impact of gas transport through rice cultivars on methane emission from rice paddy fields from China. Chanton et al. (1997) studied stable isotopes, diurnal variations, and CO_2 exchange. Neue et al. (1997) studied factors and processes controlling methane emissions from rice fields of Japan. Methane-oxidizing activities and methanotrophic populations associated with wetland rice plants were studied by Watanabe et al. (1997). Chidthaisong and Watanabe (1997) studied the methane formation and emission from flooded rice soil incorporated with 13C-labeled rice straw. Top p and Pattey (1997) studied the role of soils as sources and sinks for atmospheric methane. Hosono and Nouchi (1997) studied the effect of gas pressure in the root and stem base zone on methane transport through rice paddies of Tatsuo. Roy et al. (1997) analysed early initiation of methane production in anoxic rice soil despite the presence of oxidants. Chen et al. (1997) the observed the nitrous oxide and methane emissions patterns from soil-plant systems. (Kanno et al. (1997) studied methane emission from rice paddy fields in all of the Japanese prefecture and drawn a relationship between emission rates and soil characteristics, water treatment, and organic matter application.

Methane and nitrous oxide emissions from rice paddy fields as affected by nitrogen fertilizers and water management were studied by Cai et al. (1997). Buendia et al. (1997) studied the nature of methane emission from rice ecosystems as the basis of mitigation strategies. The dependence of methane transport in rice plants on the root zone temperature was analysed by Hosono and Nouchi (1997). Role of rice in mediating methane emission was analysed by Wang et al. (1997). Segers (1998) studied methane production and methane consumption. Elevated carbon dioxide stimulates methane emission in tropical paddy rice was analysed by Ziska et al. (1998). Khalil et al. (1998) studied Factors affecting methane emissions from the rice fields. Bosse and Frenzel (1998) studied methane emissions as production, accumulation and oxidation from rice microcosms. Huang et al. (1998b) drew a semi-empirical model of methane emission from flooded rice paddy soils. Khalil et al. (1998) studied effects of production and oxidation processes on methane emissions from rice fields. Ratering and Conrad (1998) compared the effects of short-term drainage and aeration on the production of methane in submerged rice soil. Effect of environmental conditions on methane production and emission from paddy soil was studied by Yang and Chang (1998). Huang et al. (1998) studied the model estimates of methane emission from irrigated rice cultivation of China.

Wang et al. (1999) studied factors controlling diel patterns of methane emission via rice paddy. Joabsson et al. (1999) studied the role of vascular plant in methane emissions from northern peat-forming wetlands. Methane production and oxidation potentials about water table fluctuations in two boreal mires were studied by Kettunen et al. (1999). Temperature effects on soil methane production were studied by Van Hulzen et al. (1999). Bossio et al. (1999) studied methane pool and flux dynamics in a rice field following straw incorporation. Diurnal variation of methane emission from paddy fields at different growth stages of rice cultivation in Taiwan was analysed by Yang and Chang (1999). Frenzel et al. (1999) studied rice roots and methanogenesis in a paddy soil were ferric iron act as an alternative electron acceptor. Chareonsilp et al. (2000) studied methane emission in a rice field of Thailand. Le Mer and Roger (2001) analysed the production, oxidation, emission and consumption of methane by soils. Aulakh et al. (2002) studied methane transport capacity of twenty-two rice cultivars from five major Asian rice-growing countries. Jia et al.

(2002) studied effects of rice cultivars on methane fluxes in a paddy soil located at Jurong Agriculture School, Jiangsu province and observed that the contribution of rice plants to CH_4 production seems to be more important than to rhizospheric CH_4 oxidation and plant-mediated transport in impact of rice plants on CH_4 emission.

Maljanen et al. (2003) studied methane fluxes on agricultural and forested boreal organic soils and reported that CH_4 oxidation in agricultural organic soil is more sensitive to soil drying than CH_4 oxidation in forested organic soil. Zhao et al. (2011) studied the mitigation strategies for methane emission from rice paddies. Diel variation of methane emission from a subtropical paddy field of South China in the second crop season was studied by Liu (2012) and observed that soil moisture plays an important role in CH_4 emission. Wania et al. (2013) presented a global wetland extent and methane modelling from wetlands Ebullition of methane from rice paddies was studied by (Green (2013). Centeno et al. (2017) assessed the diel variation of CH_4 flux from rice paddies through temperature patterns and reported that adequate management of the water table level reduces CH_4 fluxes and has the potential to decrease the GWP

5.2.2 Indian Scenario

Sinha (1995) studied global methane emission from rice paddies of India. Shalini-Singh et al. (1997) studied methane emission from two Indian soils planted with different rice cultivars such as Inceptisol and vertisols. Mishra et al. (1997) studied the effect of continuous and alternate water regimes on methane efflux from rice paddies and their influence on greenhouse conditions. Satpathy et al. (1997) studied diurnal variation in methane efflux at different growth stages of tropical rice. Methane entrapment in different rice soils of India was studied by Majumdar et al. (1998). Methane emission from rice fields at Cuttack, India was analysed by Adhya et al. (2000). Modelling of methane emission from rice based production system in India with denitrification processes was analysed by Jagadeesh Babu et al. (2005). Rath et al. (2000) studied methane emission from flooded rice fields of IRRI dehi.

Coast et al. (2002) studied methane emissions from a coastal lagoon, Vembanad Lake, and observed that seasonal variation was significant between pre- and post-monsoons and soil temperature, time of the day, salinity sediment organic carbon, all control the rate of methane emissions from the Vembanad Lake). Krüger et al. (2002) studied seasonal variation in pathways of CH_4 production and in CH_4 oxidation in rice fields by using stable carbon isotopes and specific inhibitors. Bhatia et al. (2004) studied inventory of methane and nitrous oxide emissions from agricultural soils of India and their global warming potential. Tyagi et al. (2004) investigated temporal variation in methane emission from different rice cultivars under the influence of weeds and observed that peak emission of CH4 at the flowering stage in all the rice cultivars was associated with maximum extension of root mat, releasing exudates, which serve as carbon source for the methanogenic bacteria for CH_4 formation. Jain et al. (2004) studied emission of methane from rice paddy fields . Jagadeesh Babu et al. (2005) drew a model of methane emissions from rice-based production systems in India with special emphasis on denitrification and decomposition processes. Anand et al. (2005) investigated methane emissions from rice cultivation in the Indian context and estimated methane emissions from rice fields in India till the year 2020.

Methane emission from a flooded field of Eastern India as influenced by planting date and age of rice (*Oryza sativa* L.) seedlings was studied by Nayak et al. (2006). The behaviour of methane emission from a paddy field with high carbon content was studied by De (2007). Methane emission from two different rice ecosystems (Ahu and Sali) at lower Brahmaputra valley zone of north east India was studied by Gogoi et al. (2008). Estimation of Methane Emission from a North-Indian Subtropical Wetland was analysed by Mallick (2009) and the finding suggests that tropical wetlands act both as source and sink of CH_4 emission depending upon the specific ecological and environmental conditions.

Gupta et al. (2009) developed a methane emission factors for Indian paddy fields and estimated national methane budget. Trend in GHG Emissions from Northeast and West Coast Regions of India was studied by Jamir and De (2013) and the findings show warming trends in the mean air temperature over a majority of the stations indicating a possible role by increased GHGs. Pattern of methane emission and water productivity under different methods of rice crop establishment was analysed by Suryavanshi et al. (2013). Trends, drivers and mitigation strategies for greenhouse gas emission from Indian agriculture was reported by Pathak (2015)

5.3 RESULTS

5.3.1 Seasonal Emission of CH_4 from Rice Paddies

Temporal emission pattern of CH_4 observed during six crops growing (CS-I and CS-II) and three summer fallow (FS) seasons from June 2011-12 to June 2013-14 was shown in Fig. 5.1. During this period CH_4 showed significant ($p<0.01$) variations in magnitude and emission pattern both seasonally and annually. Seasonal fluxes of CH_4 followed a bimodal emission pattern, lowest during FS followed by CS-I and highest in CS-II respectively. Seasonally CH_4 emissions were lowest during FS ranged from 0.014 to 4.14 mg m^{-2} h^{-} with a mean of value 0.81 ± 0.13 mg m^{-2} h^{-1}, which increased since water indentation and rice field preparation. Among crop growing seasons, lowest emission was observed in CS-I that ranged from 0.75 to 126.5 mg m^{-2} h^{-1} with an average emission rate of 24.24 ± 3.3 mg m^{-2} h^{-1}. Whereas CS-II showed the highest emission that ranged from 0.23 to 384.92 mg m^{-2} h^{-1} with an average rate of 60.94 ± 9.5 mg m^{-2} h^{-1}. Overall the magnitude of seasonal emission of CH_4 during the years was highest in CS-II followed by CS-I. However, lowest emission of CH_4 was observed in FS.

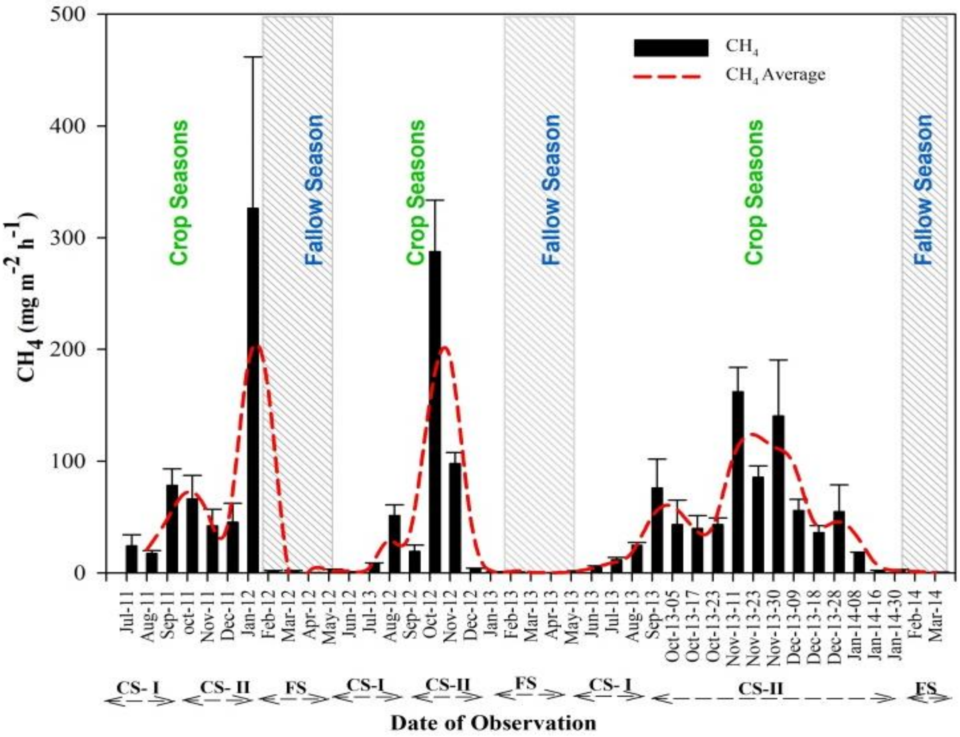

Figure 5.1 Temporal variation of methane emissions from the rice paddy of Padayatti Palakkad during the period 2011-12 to 2013-14

In the present study annual variations were also observed with CH_4 emissions. CH_4 emissions were higher in the year 2013-2014 with a mean value of 64.22 ± 8.17 mg m^{-2} h^{-1} followed by 2011- 2012 with a mean value 47.09 ± 7.33 mg m^{-2} h^{-1} and lowest value in 2013-2014 with a mean value of 40.90 ± 4.07 mg m^{-2} h^{-1}. Annual highest CH_4 emission was observed during 2013-2014 followed by 2011-2012 whereas lowest emission of CH_4 was observed during 2012-2013 (Fig. 5.2).

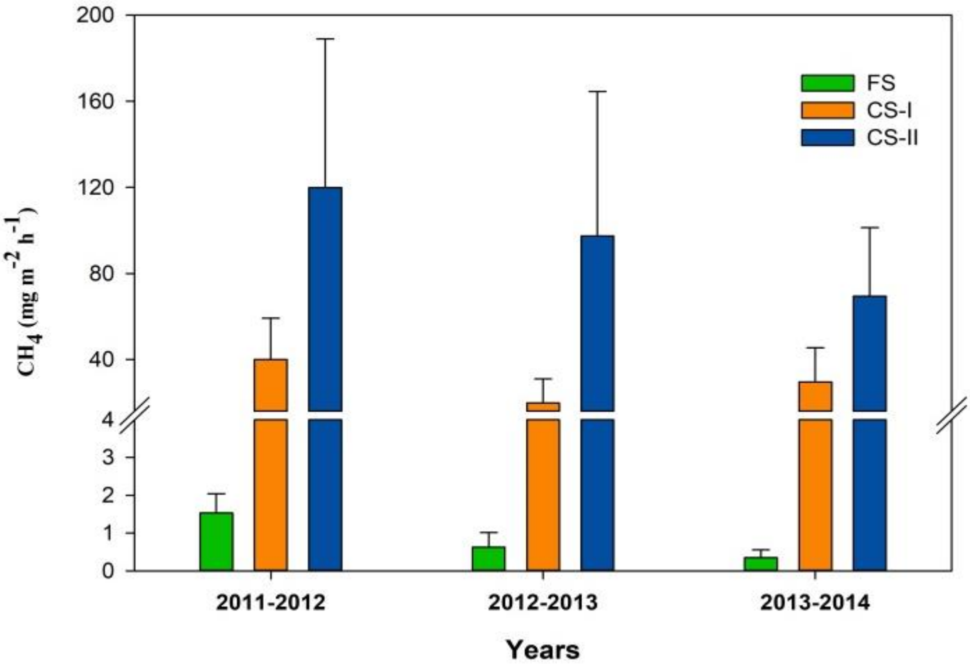

Figure 5.2 Seasonal emission of methane from rice paddy soils from Padayatti Palakkad during the period 2011-12 to 2013-14

5.3.2 Methane Emission in Relation to Vegetative Stages

In the present study methane emission co-varied with vegetative stages of the crop, increasing with the early crop (EL) to panicle initiation (PI) while it was lowest during harvesting stage (HS) (Fig. 5.3). The mean flux of CH_4 during pre-planting of rice was low at about 1.18 ± 0.18 mg m^{-2} h^{-1}. During the period after water indentation and transplanting, 5 to 12 DAT emission rates increased from 39.5 ± 11.5 to 43.05 ± 6.18 mg m^{-2} h^{-1}. CH_4 had its maximum flux during 37 to 56 DAT with an average rate of 162 ± 21 to 140 ± 50 mg m^{-2} h^{-1}. The emission rates gradually decreased to minimum ranging from 17.17 ± 1.4 to 0.14 ± 0.012 mg m^{-2} h^{-1} after 93 to 125 DAT towards harvesting. However, in contrast to the declining stage of CH_4 flux, an increase in CH_4 emission was observed during 83 DAT with a mean value of 54.61 ± 24.12 mg m^{-2} h^{-1}.

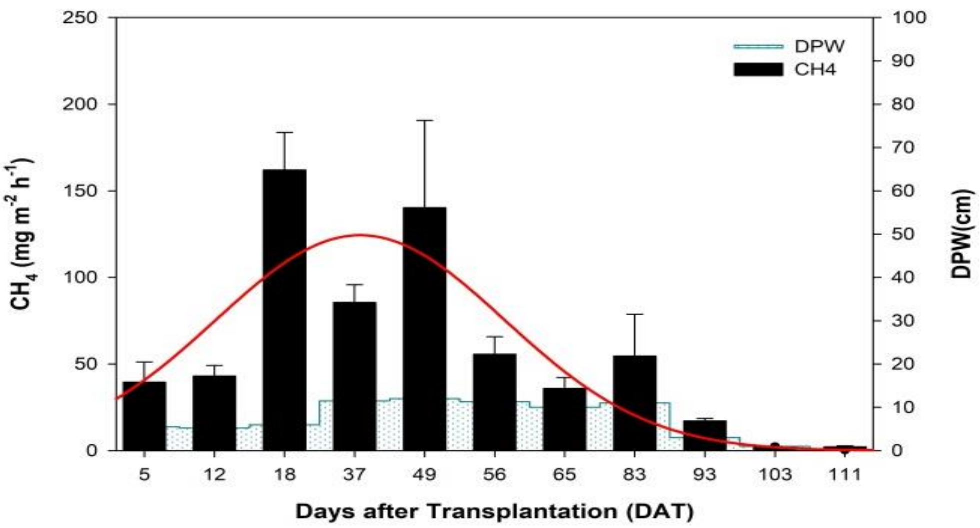

Figure 5.3 Emission of methane during different stages of crop growth

5.3.3 Spatial emission pattern of methane from the rice paddy

In the present study, the spatial distribution of CH_4 emissions did not differ between stations. The mean flux of CH_4 ranged from the lowest value of 40.82 mg m^{-2} h^{-1} to a highest value of 60.60 mg m^{-2} h^{-1} in St.1 and St. 5 respectively during the observation period from 2011-12 to 2013-14 (Fig. 5.4).

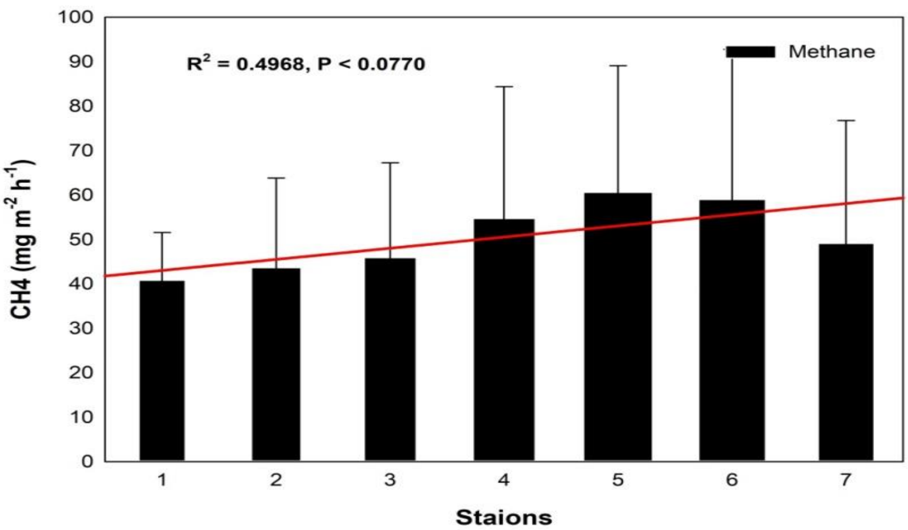

Figure 5.4 Spatial distribution of Methane flux from rice paddy soils during the period 2011-12 to 2013-14

5.3.4 Cumulative Emission of methane from the rice paddy

Annually cumulative emission was lowest during the period 2012-2013 (274.7 gm^{-2}) followed by 2013-2014 (279.8 gm^{-2}) and the highest (332.25 gm^{-2}) in 2011-2012 (Fig. 5.5). Compared to fallow season cumulative emission was significantly ($p<0.05$) higher in the wet crop growing season (CS-I and CS-II). From the study, it is observed that among seasons CS-II contributed nearly 92.01 % of the total annual CH_4 emission followed by CS-I (29 %) and FS (1.1%). Seasonally in CS-II maximum cumulative emission was 257.85 g m^2 observed during 2011-2012) and the minimum was 190.62 g m^2 in 2013-14. Whereas in CS-I maximum emission was observed in 2013-2014 (87.08 g m^2) and minimum in 2012-2013 (60.32 g m^2). During FS maximum emission was observed in 2011-2012 (4.56 g m^2) whereas minimum in 2012-13 (1.83 g m^2) (Table 5.1).

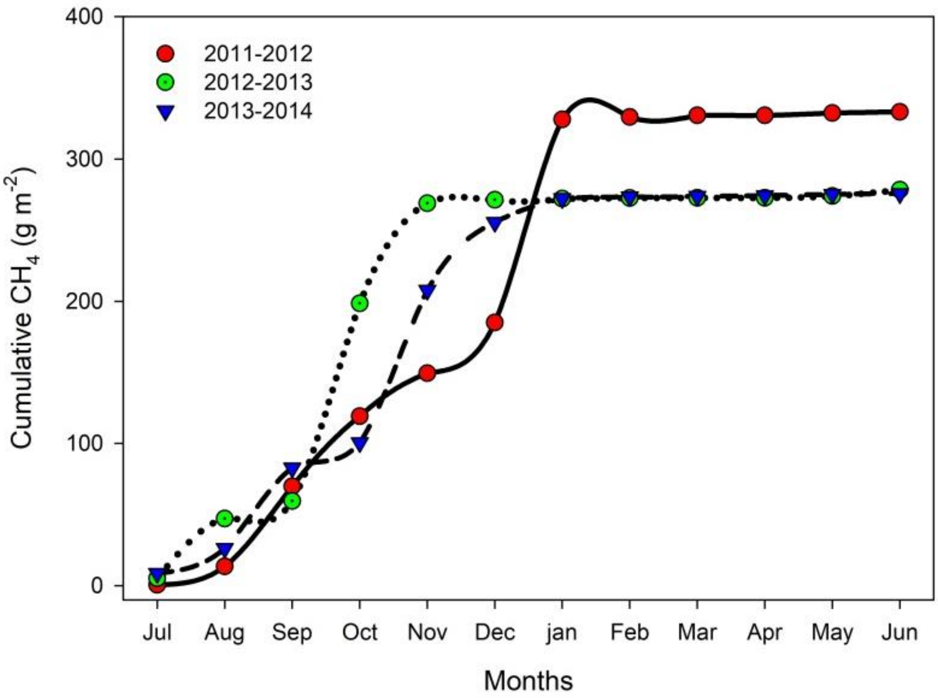

Figure 5.5 Annual cumulative emission of methane from rice paddy soils during the period 2011-12 to 2013-14

Table 5.1 Seasonal variation in cumulative emission of methane from rice paddies of Padayatti Palakkad during 2011 to 2014

Years / Units	2011-2012		2012-2013		2013-2014		Total	
	g m^{-2}	%	g m^{-2}	%	gm^{-2}	%	gm^{-2}	%
CS-I	69.85	21.02	60.32	21.95	87.08	31.11	260.23	29.34
CS-II	257.85	77.6	212.58	77.37	190.62	68.11	816.04	92.01
FS	4.56	1.37	1.83	0.66	2.13	0.76	10.57	1.192

5.3.5 Diurnal variations of methane

The time series flux variation of CH_4 observed over a period of 24 hours from submerged rice paddy after 56 days of transplantation is presented in Fig. 5.6. The CH_4 flux over time is explained using a nonlinear regression model, fitted to a Gaussian equation. In the present study rice paddy follow strong diurnal emission pattern in CH_4 emission ranging from 17.17 ± 7.65 to 39.4 ± 3.11 mg m^{-2} h^{-1} (R^2 = 0.738). The fluxes of CH_4 were positive during the day hours and increased at an accelerating rate from 17.17 ± 7.6 to 30.97 ± 4.5 mg m^{-2} h^{-1} during the morning hours from 06 am to 01 pm. The emission flux was at its peak during the afternoon at 02 pm (39.4 ± 3.11 mg m^{-2} h^{-1}) which rapidly decreases to low values 18.46 ± 0.21 mg m^{-2} h^{-1} after 07 pm and stabilised during the night.

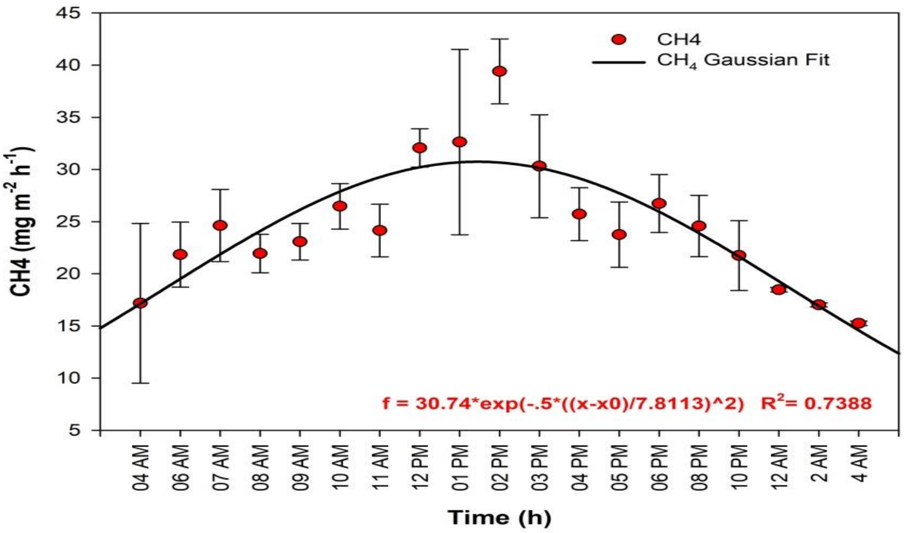

Figure 5.6 Diurnal emission of methane from paddy soil

Nevertheless, diurnal pattern of methane showed positive significant positive correlation with soil temperature ($p < 0.01$, r = 0 .6823) (Fig. 5.7). During the observation period, diurnal soil temperature varied from 21.35°C to 28.45 °C. After peaking during the early afternoon, soil temperature declined to low values during the night. Similar to soil temperature total inward solar radiation also showed strong positive correlation with diurnal methane emission pattern ($p < 0.01$, $r^2 = 0.2777$). Total incoming solar radiations varied from 0.25 to 775 W m^{-2}, with maximum intensity during 10 am to 1 pm and that was minimum during 7 pm to 5 am (Fig. 5.8). Overall, the diurnal methane emission increases with increase in air temperature and total solar radiation.

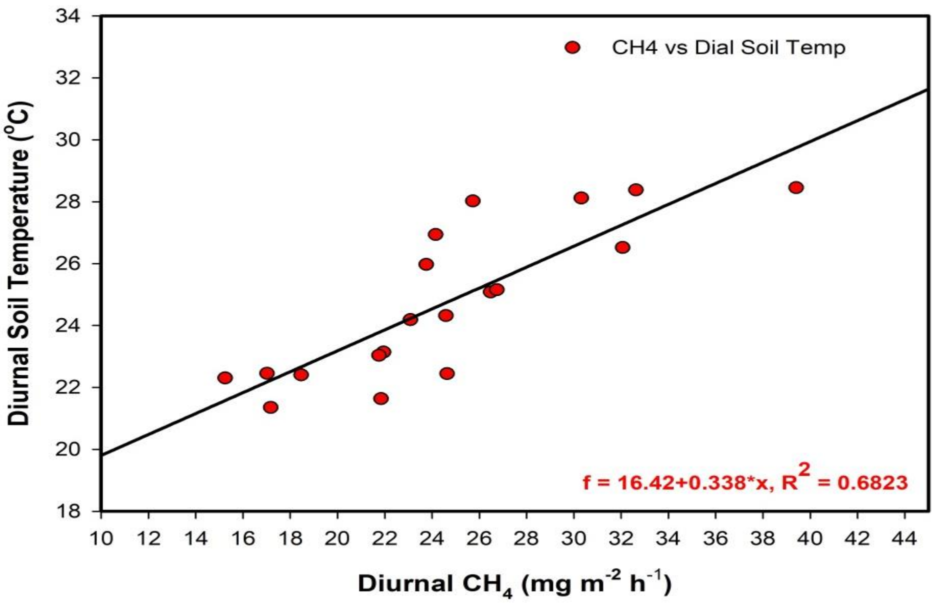

Figure 5.7 Relationship between diurnal methane and soil temperature from rice paddy wetlands of Padayatti Palakkad

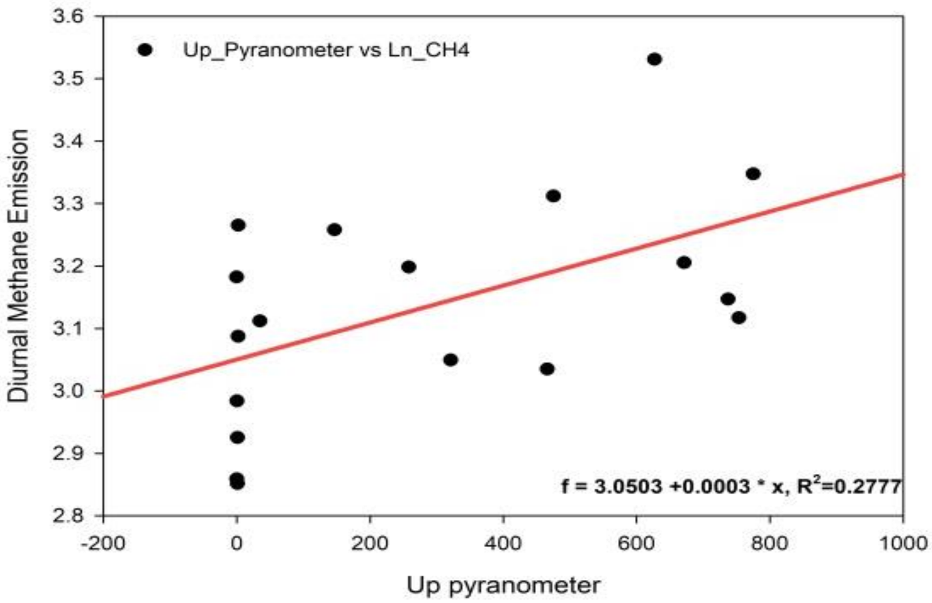

Figure 5.8 Relationship showing diurnal methane emission and incoming solar radiation from Padayatti wetland Palakkad

5.3.6 Plant Mediated diffusional transport of Methane

The plant-mediated transport of CH_4 from soil to the atmosphere during the different vegetative stages of rice paddy are shown in Fig. 5.9. In the present study, plant and soil alone transport nearly 86% and 13.1 % of the total emission from the soil respectively. Both followed a similar emission pattern co-varied significantly ($p<0.05$) with the crop growth in their magnitude of emission. In the plant-mediated transport of CH_4 it was relatively low during EC, 5 DAT with a mean value of 11.92 ± 3.57 mg m^{-2} $h^{-1}$and increased as the crop matured. The rate peaked (315.05 ± 18.63 mg m^{-2} h^{-1}) on panicle initiation (PI) and then decreased (-8.99 ± 0.75 mg m^{-2} h^{-1}) towards ripening of the rice crop, indicating a net uptake of CH_4 during the draining period. However compared to plant-mediated transport ebullition of CH_4 through the soil alone was low ranging from 2.1 to 37 mg m^{-2} h^{-1}, without any significant emission pattern.

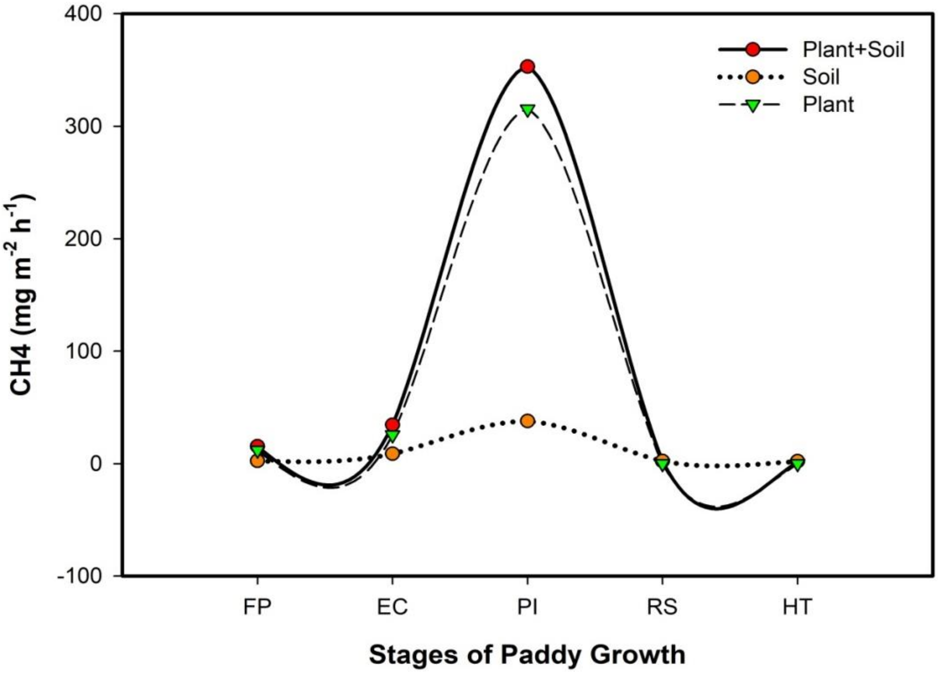

Figure 5.9 Flux variations of methane during different stages of plant growth from Padayatti rice paddy wetland

During the diurnal study, experiments were carried out to identify the zone of maximum resistance to plant-mediated transport of CH_4. A significant difference ($p<0.01$) in the rate of transfer of methane from the soil was observed from the intact plant and stubble. Compared to the intact rice plant CH_4 emissions from stubble showed a distinct diurnal emission pattern. However, an exponential increase in the CH_4 flux was observed from the stubble. The mean diurnal emission rate was similar to the intact plants before removing the shoot, ranging from 75 ± 5.68 to 154 ± 6.8 mg m^{-2} h^{-1}. After removing the shoot from the shoot-root transition zone, the diurnal emission pattern increased exponentially from 12 pm to 08 am ranging from 28.7 ± 3.5 to 634.04 ± 3.2 mg m^{-2} h^{-1} which started to decrease by 9 am with an emission rate of 332.24 ± 3.2 mg m^{-2} h^{-1} (Fig. 5.10).

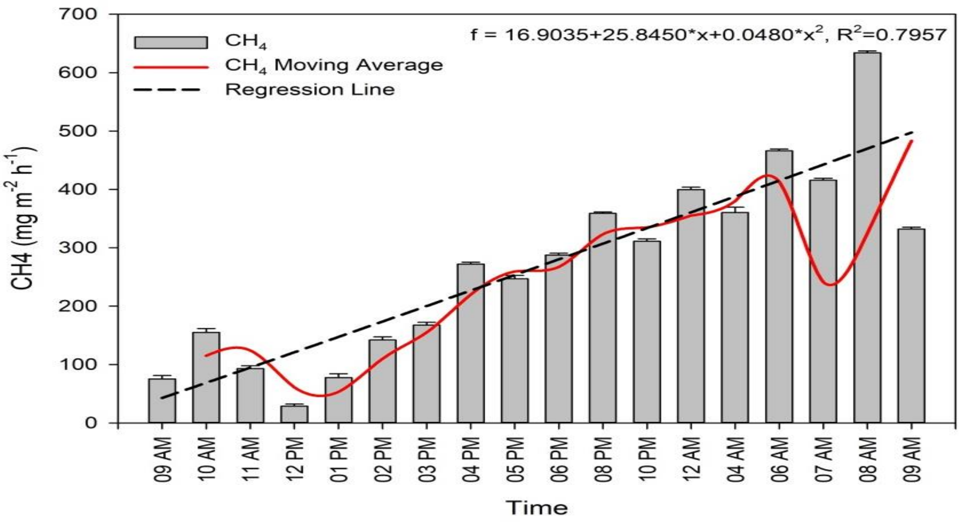

Figure 5.10 Diurnal variation showing plant-mediated transport from Padayatti rice paddy wetland Palakkad

5.3.7 Effect of Environmental Variables on Methane Emission

Physical and chemical characteristics such as TC, SOC, TIC, TN, C:N ratio, pH, Eh, moisture content and temperature were measured along with CH_4 emission.The distinct effect of environmental factors influencing CH_4 is shown in Table 5.2. From the study, it is evident that drying and rewetting the soil occurring during the summer fallow and preceding flooded crop seasons had significant effects ($p<0.05$) on CH_4 emission. In contrast to the weak correlation between CH_4 fluxes and air, soil temperatures, a significant negative relationship ($p<0.05$) were observed between CH_4 emission and Eh.

Table 5.2 Correlation analysis showing relationship between CH_4 and other environmental parameters

	CH_4	MC	Soil Temp	AirMax	AirMin	Rain fall	pH	Eh	TC	TIC	TOC	TN	C:N
CH_4	1	0.595*	-0.394*	-0.711**	-0.324*	-0.146	-0.605**	-0.635**	-0.232	-0.091	-0.335*	0.482*	-0.531*

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

5.3.8 Global Warming Potential of Methane

Global warming potential (GWP_{100}) of CH_4 in terms of CO_2 equivalent varied significantly ($p < 0.01$) with seasons in the order FS (0.616 ± 0.18 Mg CO_2 equivalent ha^{-1}) <CS-I (6.16 ± 2.07 Mg CO_2 equivalent ha^{-1}) <CS-II (15.97 ± 4.9 Mg CO_2 equivalent ha^{-1}). Seasonally GWP $_{(100)}$ flux of CH_4 was higher during the wet crops growing seasons compare to dry fallow seasons, and the variation was significant at 1% level ($p > 0.01$). Annually the GWP flux of CH_4 over 100-year time frame at the study site varied with the highest value in 2011-2012 (9.4 ± 4 Mg CO_2 equivalent ha^{-1}) followed by 2012-2013 (7.8± 4.16 Mg CO_2 equivalent ha^{-1}) and lowest observed value was in 2013-2014 (5.05± 2.3 Mg CO_2 equivalent ha^{-1})

5.4 DISCUSSION

CH_4 emissions from rice paddy wetlands of Padayatti, Palakkad showed significant intra and inter seasonal variations and are driven mostly by environmental and soil management practices (Bhattacharyya et al., 2012). Seasonally significant ($p<0.01$) positive and negative changes in the CH_4 emission pattern was observed with respect to submerged crop growing and dry summer fallow seasons. Observations similar to the present study was reported by several authors (Adhya et al., 2000; Gaihre et al., 2014; Morillas, Portillo-Estrada, & Gallardo, 2013). Fluxes of CH_4 were higher in the flooded crop growing seasons compared to dry summer fallow seasons. Fallow seasons in Padayatti Palakkad is characterized by oppressive hot summer resulting in low production of CH_4 due to prevailing aerobic non-flooded soil conditions. Aeration of the soil reduces the potential of CH_4 production by altering the soil redox conditions.($r= -0.635^{**}$) (Le Mer and Roger, 2001) as well as by enhancing methanotrophic oxidation of CH_4 (Le Mer and Roger, 2001). CH_4 emissions gradually increased with water indentation and field preparation during CS-I and CS-II and significant emission rates were maintained under continuous flooded conditions. ($r=0.595^{*}$). As methane is usually evolved from paddy soils as a result of anaerobic mineralization of organic matter decomposition under submerged soil conditions (Gupta et al., 2009).

In addition to hydrological fluctuations, CH_4 fluxes from soil are regulated by soil amendments exhibiting positive (Krüger and Frenzel, 2003), negative or neutral effects (Qin et al., 2010). Among CS, a significant enhancement in the fluxes (62.67 %) of CH_4 was observed in CS-II compared to CS-I. The incorporation of residual rice straw and stubbles of preceding crop season in CS-II could be the reason for the increase in CH_4 flux (Wang et al., 2016). Retaining rice stubble/straw after harvesting is a common agricultural practice especially in India and in Asian countries, mainly due to enhancing nutrient recycling and forbidden straw burning (Ma et al., 2008). Straw retention provides abundant substrate and exerts priming effect on soil organic matter which in turn act as an additional substrate for CH_4 production, thus accelerating CH_4 emission by a large margin (Ma et al., 2008). However, incorporation of partially oxidized crop residues of the fallow season in CS-I could be the reason that might have led to a decrease in CH_4 during CS-I (Tang et al., 2016).

Plant diffusional transport is one of the most important pathways of transport of methane evolved in the soil to the atmosphere (Malyan et al., 2016). In the present study significant variations in CH_4 fluxes were observed respectively to growth stages of rice plants comparable to the results of Askaer, Elberling, Friborg, Jørgensen, & Hansen, (2011); Singh, Raghubanshi, Singh, & Kashyap (1996). CH_4 emissions started to increase on the 5th days of submergence of the rice field. The highest emission was observed during reproductive stages. The prevailing low soil redox potential, neutral pH and increased release of plant born C sources could be the reason for increased CH_4 emission during reproductive stages (Denier Van Der Gon and Neue, 1996; Lu et al., 2000; Wassmann et al., 1998) in the Padayatti paddy wetlands. In the present study, values for pH in the soil ranged from 6.0 to 7.5, which favour the growth of methanogenic bacteria. In addition to pH, the soil oxidation-reduction potential

(Eh) plays a significant role in the CH_4 production, as the obligatory anaerobic methanogenic bacteria requires Eh of about −200 mv or less to grow (Jain et al. 2004). In addition to the latter part of ripening stage, it was observed that CH_4 started to decrease until harvest. This could be as a result of root aging and senescence which decreased C sources, root porosity, and root transport capacities of the rice plant (Ahmad et al., 2009; Wang et al., 2017). A hydrological fluctuation is a significant factor controlling the anaerobiosis of paddy soils. In the present study, soil water content is found positively correlated ($p<0.05$) with CH_4 emission while intermittent drainage is observed to appreciably reduce its emissions.

In the present study, values for pH in the soil ranged from 6.0 to 7.5, which favor the growth of methanogenic bacteria. In addition to pH, the soil oxidation-reduction potential (Eh) plays a significant role in the CH_4 production, as the obligatory anaerobic methanogenic bacteria requires Eh of about −200 mv or less for its growth (Jain et al. 2004).

The specific emission pattern of variation in CH_4 emission rate observed during a 24 hr period from Padayatti rice paddy wetlands varied in relation to soil temperature and incoming total solar radiation. The emission followed a diurnal pattern which was lower in the early morning that increases towards early afternoon to late afternoon which was similar to the results of (Mikkela et al., 1995). In the present study, a positive correlation was observed between diurnal soil temperature pattern, incoming total solar radiation, and diurnal CH_4 emission flux. An emission increase with increasing soil temperature and was highest during the afternoon when both soil and air temperatures were at their maximum and were lowest during the early morning. The results indicated that soil temperature is a factor driving methane emission, while other factors interact with soil temperature, limiting emissions. Previous reports from Bi et al. (2007) and Weller et al. (2015) have indicated a significant relationship between diurnal CH_4 emissions and temperature in rice fields. Warming of soil by daytime insolation enhances the methanogens at optimal temperatures increasing the emission flux during day hours (Zhang et al., 2011). Plant-mediated diffusional transport of CH_4 was also found that increases with increasing temperature (Krüger et al., 2001; Yao et al., 2000). Molecular diffusion and ebullition of CH_4 from soil also increases with increase in soil temperatures (Joabsson et al., 1999).

In paddy fields, 15–52% of the CH_4 produced is oxidized to CO_2 by methanotrophic bacteria in the aerobic microsites present in the soil (Komiya et al. 2015). The CH_4 leftover in the soil is usually released to the atmosphere through rice plant by physical processes (molecular diffusion) and by gas bubble ebullition. Among these pathways, diffusional plant transport was found to be dominant in paddy soils (Nouchi et al. 1990). From our study, it was observed that CH_4 released through the parenchyma conduit was much higher (92%) than from unplanted soil control, possibly bypassing the microbial CH_4 oxidation (methanotrophy) at the soil oxic layers. CH_4 oxidation is the only biological sink where 80% of the produced CH_4 was being consumed by methanotrophic bacteria for biological needs, for energy or building up microbial biomass. Nouchi et al. (1990) described the mechanism of CH_4 transport in rice plants, where the dissolved CH_4 in the soil interstitial waters diffuses into the root cortex driven by the concentration gradient between the roots and lysigenous intercellular spaces. In the paddy root cortex, dissolved CH_4 is gasified and transported to the shoot via the lysigenous Intercellular spaces and aerenchyma. Eventually, CH_4 is released through micropores in the leaf sheath.

The accumulative methane emission was around 70% lower with intermittent irrigation than with continuous flooding treatment. Annual methane emission from paddy field was calculated with the emission factors at each location and cultivation area, and the results are illustrated in Table 5.1. Annual methane emission decreased with the decreasing of cultivation area of rice. Total methane emission was 37,073 ton in 1990, and it decreased to 25,678 ton in

2000. Methane emission from paddy fields was only 20.45 to 21.90% of those calculated with IPCC guideline. This might be due to the irrigation management at the latter stage of rice growth.

Chapter - 6

NITROUS OXIDE FLUXES AND DYNAMICS FROM PADDY SOILS

6.1 GENERAL INTRODUCTION

Nitrous oxide (N_2O) is the third most important GHG with the time-integrated radiative forcing of 298 times larger than that from CO_2 emissions for a 100-year time horizon (Ciais et al., 2013; Myhre et al., 2013). N_2O is a radiatively active gas, it absorbs and reflects back some of the thermal radiations, along with similar GHG mainly CO_2, CH_4 thereby increasing the earth's temperature (Tian et al., 2012). Also, N_2O accounts for approximately 5% of the total greenhouse effect and is involved in stratospheric ozone depletion with a potential of 0.017 (Crutzen, 1970; Ravishankara et al., 2009). Multiple lines of evidence indicate that human activities play a significant role in the perturbation of the global N cycle (Galloway et al., 2008; Gruber et al., 2008; Fowler et al., 2015). Since preindustrial times the atmospheric concentrations of N_2O had increased by 21% from 271 to 329 ppb (MacFarling et al., 2006; Prather et al., 2012, 2015; Thompson et al., 2014).

6.1.1 Nitrification and Denitrification

N_2O is mostly evolved through the microbial-mediated processes of nitrification and denitrification in terrestrial and aquatic systems, including rivers, estuaries, coastal seas and the open ocean (Smith and Arah, 1990; Wrage et al., 2001; Schmidt et al., 2004). Nitrification is an aerobic process, either as oxidation by autotrophic bacteria or as enzymatic oxidation by heterotrophic bacteria or fungi (Myrold et al., 1999). During this process, NO and N_2O are formed with nitrification rate as one factor controlling the number of gases emitted (Firestone and Davidson, 1989). After nitrification, NO_3^- will either undergo assimilatory nitrate reduction resulting in the reformation of NH_4^+, be leached from the system, or will be denitrified to NO_2^-, NO, N_2O and N_2. Denitrification is an anaerobic process, and soil water content is crucial for gas formation, and every step in the pathway involves a corresponding enzyme. Denitrification occurs when nitrate is present in anaerobic microsites developed wherever microbial demand for O_2 exceeds diffusion mediated supply (Meijide et al., 2017). Denitrification in soils also consumes N_2O through the reduction of N_2O to N_2 Hence; this bacterial process may serve as a source or a sink of N_2O.

6.1.2 Factors influencing N_2O Emission

Both the processes of nitrification and denitrification are regulated by microbial activities under various soil micro-environments. The micro-environment includes soil temperature, moisture and aeration, clay content, pH, and C and N availability. However N_2O emissions from terrestrial ecosystems can be regulated by both natural disturbances and human management such as synthetic N fertilizer, manure N application, irrigation, tillage, and the choice of crop varieties (Cai et al., 1997; Ding et al., 2010). The biophysical processes (such as canopy structure, albedo, and evapotranspiration), biogeochemical processes (such as decomposition and denitrification), and N input for cropland are significantly different from those for natural vegetation.

6.1.3 Spatial Distribution of N_2O

Terrestrial N_2O emissions showed substantial spatial variations across the global land surface since 1860. The highest emission was from the tropical area during all four periods (i.e., the 1860s, 1900s, 1950s, 2001 and 2015), primarily due to higher soil N transformation rates and soil N contents in tropical ecosystems. (Saikawa et al., 2014) The latitudinal distribution patterns were slightly different from the 1860s to 2001- 2015, showing an increasing peak of N_2O emissions in the temperate climatic zone of the Northern Hemisphere. Temperate regions were another hotspot for N_2O emissions due to the high N fertilizer use and N deposition rates in China, India, Europe, and the contiguous United States. In the recent three decades, China, India, and Western

Europe were the only three regions with higher N_2O emissions from croplands than that from natural ecosystems (Tian et al., 2018).

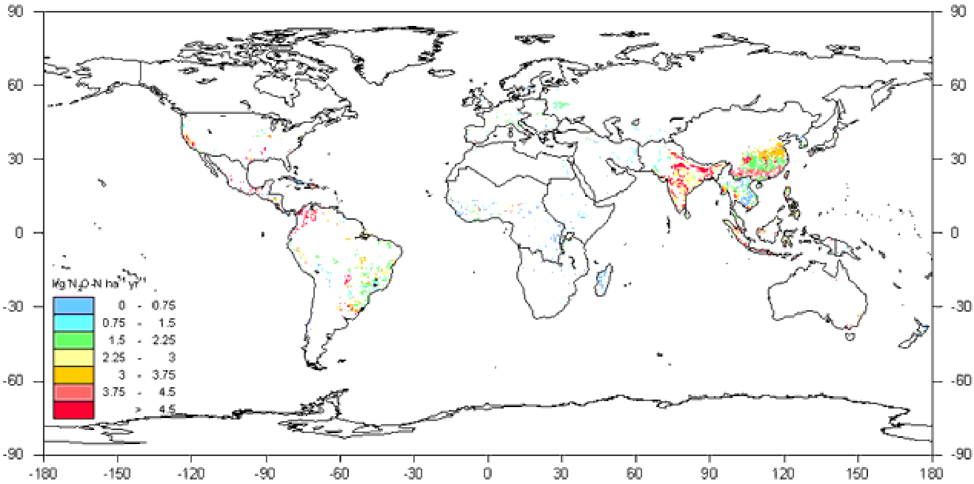

Figure 6.1 Emission of N_2O from wetland rice. Emissions represent the emissions per year, accounting for country-specific cropping intensities (source FAO United Nations 2005)

Among the sources of N_2O, there are several known sources of N_2O emissions, categorized them as the following: agricultural soil, industrial (including all combustion sources), natural soil, ocean, and biomass burning. The anthropogenic N_2O emissions are estimated to have increased from 0.7 Tg N y^{-1} in 1860 to 6.9 Tg N y^{-1} in 2006, ~ 60% of which was ascribed to agricultural activities (Ciais et al., 2013, Davidson and Kanter, 2014). Currently, the primary sources of anthropogenic N_2O emissions are agriculture, industry, biomass burning and indirect emissions from reactive nitrogen leaching, runoff, and atmospheric deposition. Of these, emissions from agricultural soils dominate widespread use of nitrogenous fertilizers and increasing manure inputs that combine to drive emission growth. With an increasing human population and the consequent need for more food production, both agricultural land area and N_2O emissions are likely to continue to rise in coming decades.

Worldwide agriculture contributes nearly 10 -20% of the anthropogenic GHG emissions (Smith et al., 2008). In 2005 agriculture alone contribute 60% of the total anthropogenic N_2O emissions (Oo et al., 2018). Rice paddies are considered one of the primary sources of N_2O emissions, as agricultural activities that add nitrogen to soils, such as increased organic and synthetic fertilizer which increase the amount of nitrogen (N) available for nitrification and denitrification, and ultimately the amount of N_2O emitted. These processes have received considerable attention due to their contribution to global warming (Harris et al., 1985; Bouwman, 1990). In India, paddy rice cultivation occupies about 44 million ha, the most abundant rice producing area in Asia, and accounts for 20% of the total rice production worldwide capable of emitting a considerable amount of N_2O into the atmosphere. Regional estimate of N_2O emission from rice paddy fields will give a better understanding of the process and factors influencing the flux variations of N_2O. Only a few studies have been attempted to calculate detailed regional N_2O emissions. In this context, the study was conducted to reveal the process and factors affecting N_2O emission form Padayatti agro wetland ecosystem Palakkad.

6.2 LITERATURE REVIEW

6.2.1 International Scenario

N_2O is an important greenhouse gas, and its emission pattern, its and various factors influencing its evolution were studied by many authors internationally, nationally and regionally. Duxbury et al. (1982) studied the emissions of nitrous oxide from soils, and he reported that various soil, climate, and management factors such as soil moisture regime, temperature, pH, N content of the soil, soil organic carbon and presence of crops control the N_2O emission from soils. Yoshida & Rinaudo (1982) analysed heterotrophic N_2 fixation in paddy soils of Hokkaido, Japan. Lashof & Ahuja (1990) developed the index of global warming potential and can be used in clarifying the relative contributions to global warming of different countries. Davidson et al., (1991) studied the seasonal variations in the nitric oxide from soils of a dry tropical forest of México. Rodhe et al. (1991) analysed the greenhouse gases emission from the paddy soils of Sweden as a case study. Fluxes of CO_2, CH_4, and N_2O from a welsh peatland related to water table was studied by Freeman et al. (1992) and reported potential feedback to climatic change. Stephen C et al. (1994) studied the nitrogen mineralization, immobilization, and nitrification where nitrous oxide emissions from peatlands in northern Quebec were studied by The et al. (1994).

Nykanen et al. (1995) compared the emissions of CH_4, N_2O, and CO_2 from a virgin fen and a fen drained for grassland of Finland. Hua Guangxi et al. (1997) compared nitrous oxide emissions from three rice paddy fields in China. Wilson et al. (1997) from south-eastern Australia and Yu et al. (1997) from China have studied the nitrous oxide transport through rice plants whereas Chen et al. (1997) studied the transport of nitrous oxide through soil-plant systems. Bremner (1997) analyzed the sources of nitrous oxide in soils. Denitrification coupled to nitrification in the rhizosphere of rice paddy was studied by Arth et al. (1998). Yan et al. (2000) studied and observed different pathways of N_2O emissions from rice paddy of Wuxi, Jiangsu, China.

Nitrogen oxide fluxes and nitrogen cycling during post-agricultural succession and forest fertilization in the humid tropics was studied by Erickson et al. (2001). Choudhary et al. (2002) studied the spatial and seasonal variability of nitrous oxide emissions due to soil: tillage effects from New Zealand. Xiong et al. (2002) were measured the nitrous oxide emissions from two rice-based cropping systems in China and reported that both green manure N and synthetic fertilizer N contribute to N_2O emission during double rice season. Xing et al. (2002) studied the seasonal denitrification in a saturated underground soil where rice and wheat are cultivated and reported that the regions with high N input, denitrification in the saturated underground soil where mitigated NO_2 and contributed N_2O to the atmosphere. N_2O and NO productions through nitrification was studied by Cheng et al. (2004) from agricultural soils of China. Huang et al. (2004) monitored the nitrous oxide emissions as a result of amendments of plant residues with different C:N ratios. Nitrous oxide emissions from a fertilized paddy field in a tropical region was studied by Mosier et al. (2004) and also tested the sources and sinks mechanisms that take place in the paddy soil.

Klemedtsson et al. (2005) analysed the role of soil C:N ratio to predict nitrous oxide emissions and reported that low C:N ratios (below 15–20) and other parameters such as climate, pH and groundwater tables regulating the N_2O emissions. Simultaneous minimization of nitrous oxide and methane emission from rice paddy soils due to potential redox changes in a greenhouse experiment without plants was studied by Johnson-Beebout et al. (2009). Emissions of nitrous oxide from arable organic and conventional cropping systems with two soil types were analyzed by Chirinda et al. (2010). Effect of biochar amendment on yield and nitrous oxide emissions from a rice paddy from Tai Lake plain, China was studied by (Zhang et al., 2010). Influence of water table level and soil properties on emissions of greenhouse gases from cultivated peat soil was studied by Berglund and Berglund (2011) and reported that lowering the water table without exposing new layers with the easily decomposable material would have a limited effect on greenhouse emission.

Nitrous oxide mitigation by farm nitrogen management intemperate grassland-based agriculture was studied by Li et al. (2013). N_2O-N emissions from organic and conventional paddy fields of Central Java, Indonesia was studied by Rahmawati et al. (2015). Sun et al. (2016) analysed the field measurement of nitrous oxide fluxes from rice paddies under different climate conditions and reported that N_2O emission depended more on fertilization and Surface standing water depth. Liu et al. (2016) analysed the wet irrigation and nitrification inhibitor effect on nitrous oxide and methane emissions from a rice cropping system. Deng et al. (2017) compared the nitrous oxide emission from organic fertilizer and controlled release fertilizer in tea fields and reported that controlled release fertilizer has significantly lower N_2O compared to organic fertilizer.

6.2.2 Indian Scenario

In India, a study regarding N_2O was limited. Major research activities, especially in N2O emissions in India, started by late 1990's. Majumdar et al. (2000) observed reduced nitrous oxide emission from an irrigated rice field of North India with nitrification inhibitors. Emission of nitrous oxide from rice-wheat systems of Indo-Gangetic plains of India was analysed by Pathak et al. (2002). Inventory of methane and nitrous oxide emissions from agricultural soils of India and their global warming potential was studied by Bhatia et al. (2004). Baruah et al. (2010) recorded the plant physiological and soil characteristics associated with methane and nitrous oxide emission from a rice paddy. Garg et al. (2012) compared the temporal, regional and sector trends in N_2O emissions of India. Effect of combined application of organic manure and inorganic fertilizer on nitrous oxide emissions in a tropical flooded rice paddy was analysed by Das and Adhya (2014).Pal et al. (2015) studied carbon sequestration in Indian Soils: the Present Status and the Potential. The greenhouse gas emission from direct seeded paddy fields under different soil water potentials in Eastern India was studied by Kumar et al. (2016) However the latest report on the methane and nitrous oxide emissions from conventional and modified rice cultivation systems in South India was studied by (Oo et al., 2018).

6.3 RESULTS

6.3.1 Seasonal Emission of N_2O from rice paddies

The N_2O emissions from rice paddy soils of Padayatti ranged from 0.0039 ± 0.0007 to 1.43 ± 0.12 mg m^{-2} h^{-1} with a mean value of 0.519 ± 0.34 mg m^{-2} h^{-1} during the observation period from March 2013 to March 2014. During the period seasonal fluxes of N_2O differed statistically ($p< 0.05$) between crop growing (CS) and summer fallow seasons (FS) (Fig. 6.2). In FS, fluxes of N_2O observed was low ranging from 0.003 ± 0.00076 to 0.12 ± 0.0058 mg m^{-2} h^{-1} with a mean value of 0.046 ± 0.35 mg m^{-2} h^{-1}. During this period from March to May, the highest emission of N_2O was observed in March 2014 with a mean value of

0.12 ± 0.005 mg m^{-2} h^{-1}, whereas lowest emission was observed in May 2014 with a mean value of 0.003 ± 0.00076 mg m^{-2} h^{-1}.

In CS-I, from June to September, the fluxes of N_2O ranged from 0.26 ± 0.03 to 0.96 ± 0.09 mg m^{-2} h^{-1} with a mean value of 0.562 ± 0.32 mg m^{-2} h^{-1}. During this period fluxes of N_2O started to increase gradually and exponentially soon after water indentation and transplanting. The N_2O emission was observed lowest in July 2013 with a mean value of 0.264 ± 0.011 mg m^{-2} h^{-1}. However, the highest mean value of 0.967 ± 0.099 mg m^{-2} h^{-1} was observed during September 2013.

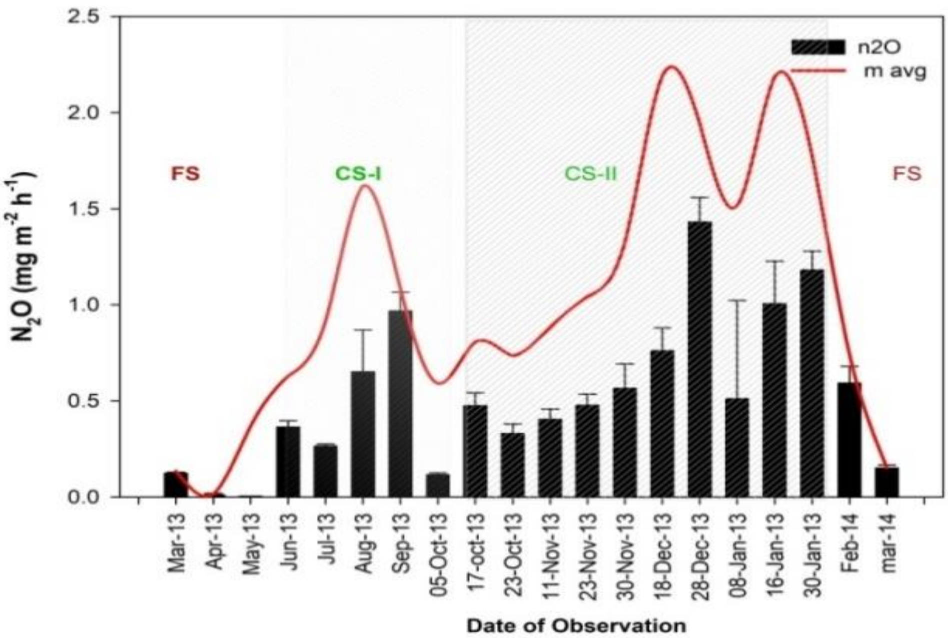

Figure 6.2 Seasonal fluxes of N_2O from rice paddies of Padayatti Palakkad during 2013-2014

During the period of the intensive weekly sampling of CS-II, which started on October 2013 and ended in February 2014 the fluxes of N_2O ranged from 0.11 ± 0.009 mg m^{-2} h^{-1} to 1.43 ± 0.13 mg m^{-2} h^{-1} with a mean value of 0.654 ± 0.15 mg m^{-2} h^{-1}. In CS-II N_2O emission was observed lowest in October 23rd with a mean value of 0.33 ± 0.04 mg m^{-2} h^{-1}. Whereas highest value was observed in December 28th with a mean value of 1.43 ± 0.12 mg m^{-2} h^{-1}. In CS-II also fluxes of N_2O increased gradually soon after transplantation and flooding reaching its peak value in December 28th and decreased towards harvesting.

Among seasons the highest fluxes of N_2O from the rice paddies of Padayatti Palakkad was observed in the crop growing seasons of CS-II, which was followed by CS-I. However, among seasons, lowest emission of N_2O was observed in FS during the summer months of March to May.

6.3.2 Nitrous Oxide in relation to vegetative stages of Rice paddy

N_2O emission from the rice paddies of Padayatti in relation to the vegetative stages of rice paddy is shown in Fig. 6.3. During the period soil emissions of N_2O were monitored at regular interval from the 0th day of field preparation to 125th day after paddy harvesting. The N_2O emissions are co-varied with plant growth and DPW with a significant increase in N_2O emission since 5 to 12 days after re-flooding. During the initiation of the study N_2O emissions were observed near to zero with a mean value of 0.0118 ± 0.008 mg m^{-2} h^{-1} before flooding (DPW= 0 cm) where the soil moisture content was observed minimum. However, on the 5th day after water indentation, the emission started to increase reaching a mean value of 0.115 ± 0.09 mg m^{-2} h^{-1} with a DPW of 5.2 cm. After transplantation of paddy seedlings on the 28th day of observation, emission rates remained high and increased gradually reaching its highest peak on the 93rd day with a mean value of 1.43 ± 0.02 mg m^{-2} h^{-1}. N_2O emission was highest during the heading stage of the rice plant with a mean emission rate of 1.43 ± 0.128 mg m^{-2} h^{-1} with a DPW of 3 cm. Compared to the flooded periods from 05 to 103 days, N_2O emission was found higher in the drained period from 103 to 125 days before harvesting even though there was some fluctuation with time. During the draining period, N_2O emissions ranged from 0.51 ± 0.05 to 1.18 ± 0.09 mg m^{-2} h^{-1}. N_2O emission gradually decreased towards harvesting period with a mean value of 0.59 ± 0.08 mg m^{-2}. In addition to DPW, fertilizer inputs also had a crucial influence on soil N_2O emissions. During the present study, fertilizers were added during the 18th day (one week after transplantation) 38th day, 57th and 85th day after transplantation. Concomitant peaks of N_2O was observed after regular interval of fertilizer inputs.

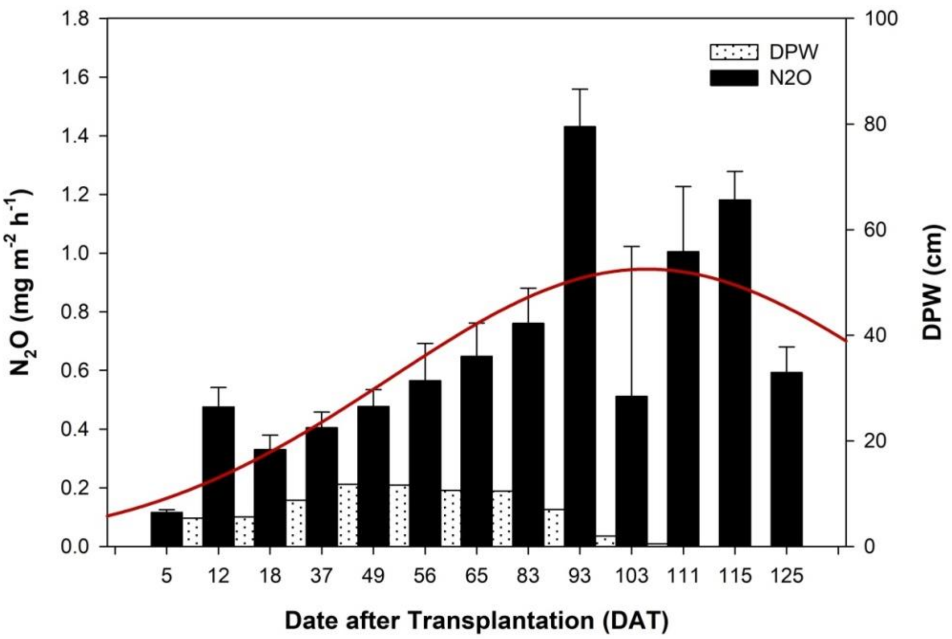

Figure 6.3 N_2O emissions from rice paddies of Padayatti wetland Palakkad in different crop growing seasons during 2013-2014

6.3.3 Spatial variations of N_2O

Spatially N_2O emission ranged between 0.384 ± 0.401 to 1.32 ± 0.56 mg m^{-2} h^{-1} (Fig. 6.4). Even though N_2O emissions vary significantly between seasons, spatial distribution pattern did not differ among stations. As most of the observed stations are located in similar geographical locations with minor changes in the soil management and agricultural operations could be the reason for lack of variations. Highest emission was observed in St.1 with a mean value of 1.32 ± 0.5 whereas lowest emission was observed in St.7 with a mean value of 0.38 ± 0.4. The overall magnitude of N_2O among stations was in the order St.1 > St.4 > St.6 > St.2 > St.1 >St.5 >St.3.

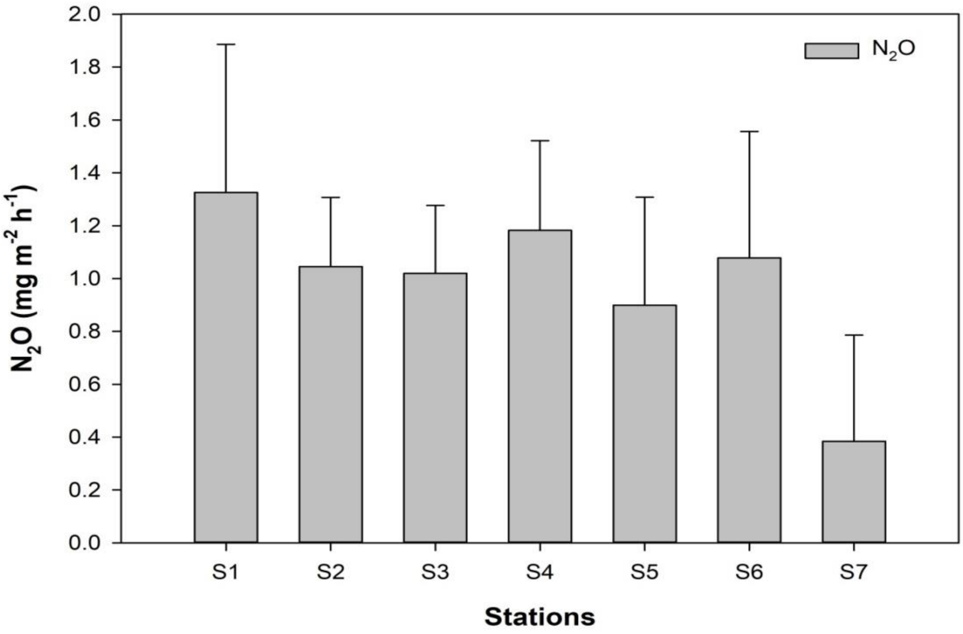

Figure 6.4. Variation in N_2O among stations from Padayatti rice paddies Palakkad during 2013-2014

6.3.4 Cumulative, Annual Emission and GWP of N_2O

Annual cumulative emission of N_2O from Padayatti rice paddy was 3.96 gm^{-2}. Seasonal maximum cumulative emission was observed in CS-II with a mean value of 2.11 ± 0.05 gm^{-2} and minimum in FS with a mean value of 0.13 ± 0.34 gm^{-2}. CS-II alone contributes nearly 54.63% of the total cumulative emission followed by CS-I and least contribute by the FS, 2.6%. Global warming potential (GWP_{100}) of N_2O regarding CO_2 equivalents varied significantly ($p<0.05$) with seasons with highest GWP in CS-II with a mean value of 192.42 ± 3.6 Mg ha^{-1} followed by CS-I with a mean GWP of 167.49 ± 4.7 Mg ha^{-1}. Annually the paddy wetlands of Padayatti emit GWP of 11.18 Mg CO_2 equivalent.

6.3.5 Diurnal Variation of N_2O

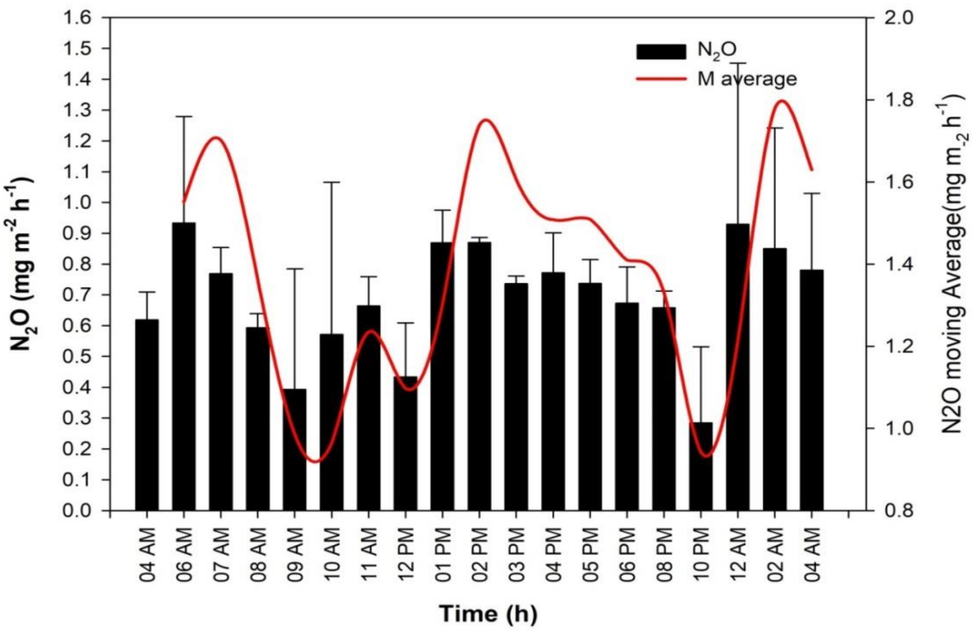

Figure 6.5. Diurnal variation of N_2O observed on 56th DAT from rice paddy wetland of Padayatti Palakkad during 2013-2014

Flux variations of N_2O over a period of 24 h. were observed from 56 days old rice paddy from Padayatti Palakkad was shown in Fig. 6.5. During the observation period, the diurnal emission of N_2O from rice paddies varied with time but didn't follow any regular pattern. The pattern of diurnal variation in N_2O fluxes from rice paddies was different from those of CH_4 and CO_2 fluxes. During the period the N_2O emissions were sporadic, and pulse like the emission was highest at 06 am, and 12 am with a mean value of 0.93 ± 1.22 and 0.929 ± 1.21 mg m^{-2} h^{-1} respectively. Whereas lowest emission was observed during 10 pm and 09 am with an average value of 0.28 ± 0.094 and 0.39 ± 0.098 mg m^{-2} h^{-1}. Diurnal emission pattern of N_2O followed an irregular bimodal emission pattern with highest observed emission pattern during the early morning (04 to 06 am) hours with a mean value ranging from 0.618 ± 0.09 to 0.9 ± 0.03, mid-noon (01 to 02 pm) ranged from 0.86 ± 0.01 and during the late night hours (12 am to 02 pm) ranging from 0.929 ± 0.05. However, lowest values of N_2O were observed during morning hours of 09 to 12 pm and during the 10 pm in the night with a mean value of 0.39 ± 0.03 and 0.28 ± 0.024 mg m^{-2} h^{-1} respectively. In the present study, no significant relationship was observed between N_2O and physical parameters such as temperature and solar flux.

6.3.6 N_2O emission in relation to Soil Eh and Soil Moisture Content

The seasonal patterns N_2O emission had a strong negative relationship with soil Eh (Fig. 6.6). During the period N_2O increases with a decrease in soil redox conditions. Soil redox values were in the range + 76 to +131.67 before the field was flooded following the summer fallow in late May. Soil redox gradually decreased after flooding, reaching an Eh value less than -393 in the middle of January. The low redox was maintained until the field was drained at maturity in the middle of January, with a redox range of + 178 mV. The response of N_2O emission to changes in redox was explained a nonlinear regression equation by plotting soil Eh (mV) against N_2O emission. It was observed that more than 71.79% of the measure N_2O emission occurred in conditions where soil Eh was below -200 to -450 mV whereas rest of the 28.2% occurred in Eh values above 0 to 175 mV. The arithmetic mean of the N_2O fluxes was 0.871 and 0.399 mg m^{-2} h^{-1} in the reduced zone and the moderately oxidized zone respectively. During the present study a positive correlation is observed between soil moisture content (Fig. 6.7) and N_2O emission with a correlation coefficient r = 0 .747 with a $p<0.01$. The maximum N_2O is observed in the regions where SMC is in the range 40 to 50%.

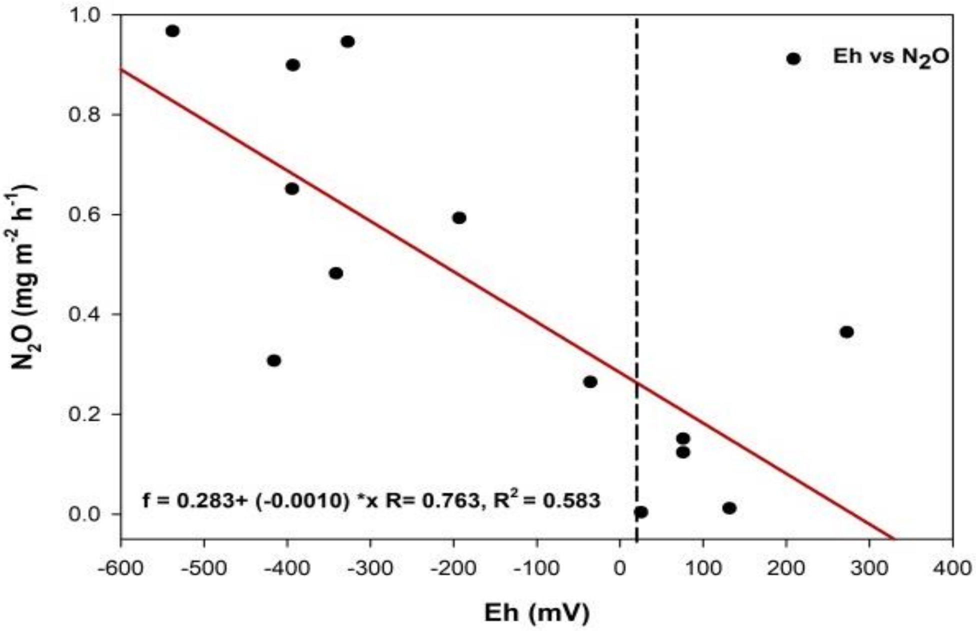

Figure 6.6. N_2O emissions under different soil redox conditions from rice paddies of Padayatti wetland Palakkad

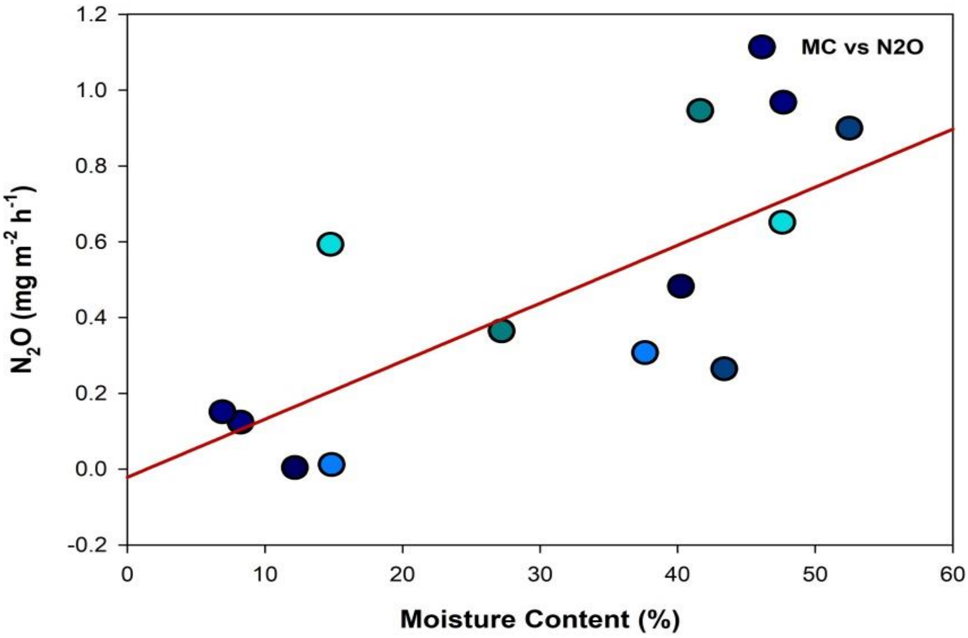

Figure 6.7 Relationship between soil moisture content (SMC %) and N_2O emissions from rice paddy soils of Padayatti Palakkad during 2013-2014

In the present study, N_2O emission was negatively correlated with soil C:N ratio (Fig. 6.8) yielding a correlation coefficient of r = -0.562 significant at 0.05% level ($p<0.05$). In the present study C:N ranged from the lowest value of 3.1 in December 2013 and 8.1 in April 2013. The exponential negative relationship between C:N ratio and N_2O was interpreted by using the nonlinear regression equation f = 1.1007 + (-0.1337) * X, with R^2 = 0.562. When considering the efflux of N_2O, 99 % of the emission occurs from soil having surface soil (0- 15 cm) C:N ratio within the range of 03 To 6.5 with a mean value of 0.668 mg m^{-2} h^{-1} N_2O. N_2O emission was found a correlation between soil moisture content, and the air temperature was also observed during the study period significant at 0.05% level with an r-value of 0.747 and -607 respectively (Table 6.1).

6.3.7 N_2O emission in relation to Soil C:N ratio

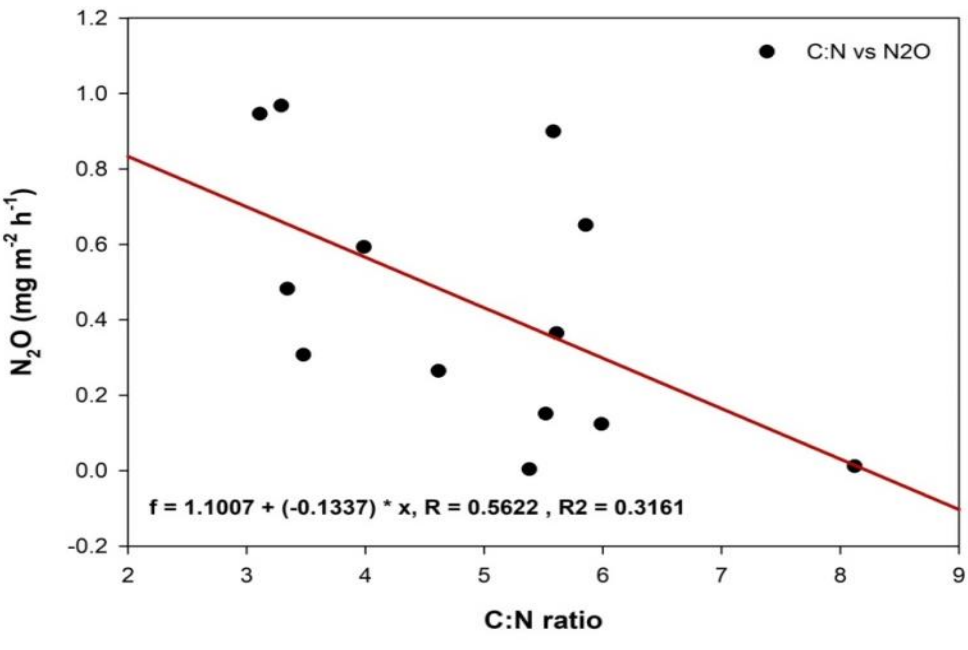

Figure 6.8 Relationship between C:N ratio and N_2O emission from rice paddy wetlands of Padayatti Palakkad during 2013-2014

Table 6.1 Correlations between N_2O with other environment variables from Padayatti Paddy wetlands during 2013-2014

	N_2O	MC	Soil Temp	AirMax	AirMin	Rain fall	pH	Eh	TC	TIC	TOC	TN	C:N
N_2O	1	.747**	-.607*	-0.367	-595*	-0.342	-0.135	-0.764**	-0.43	-0.309	-0.394	0.036	-0.562*

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

6.4 DISCUSSION

Rice paddies are one of the major contributors of N_2O to the atmosphere and were produced from the soil as an intermediate product of microbial nitrification and denitrification process (Yang et al., 2009). During nitrification of NH_4^+ or NH_3 to NO_3^- is oxidized. Where N_2O was formed through chemical decomposition of intermediates such as NH_2OH. Denitrification is the facultative bacterial mediated reduction of NO_3- to N_2O and N_2. During the present study, ph was observed correlated with N_2O which was consistent with the observations of (Arth et al. 1998; Bremner 1997). The production of N_2O or denitrification will be higher if the soil pH is low because at low pH N_2O reductase is inhibited (Jiang et al., 2015). Generally, in rice paddy soils, N_2O fluxes are regulated by water management, nitrogen substrates, vegetative stages of the rice plants and the soil organic carbon (Chen et al. 2013; Zhang et al. 2016). In the present study, soil N_2O emission was dependent on ambient and soil temperatures, pH, Eh, and C:N ratio. During the study, a strong negative correlation was observed between N_2O and soil temperature. However, the effect of temperature on nitrous oxide fluxes is not always clear; high N_2O fluxes from temperate soils during the winter and early spring have been attributed to specific freeze/thaw phenomena (Campbell and Curtin, 2007).Whereas other studies have reported high N_2O fluxes during the warmer months (Wang and Cai, 2008). In a vegetated riparian buffer zone in Belgium, no temperature related seasonal trends were found in the temporal variation of the N_2O fluxes (Gaihre et al., 2014). During the present study N_2O emission varied from 0.11± 0.009 to 1.18 ± 0.09 mg m^{-2} h^{-2}, with a mean value of 0.645 ± 0.15 mg m^{-2} h^{-1}. The results are consistent with the observations of Majumdar, Kumar, Pathak, Jain, & Kumar (2000); Das and Adhya (2014); Pathak et al. (2002) from Indian rice paddies. However, N_2O emissions reported by Cai, Ding, & Luo (2012); Wang and Cai (2008); Chen et al. (2013) from rice paddies of different countries were well comparable to our results.

As depicted in Fig. 6.3 there were three N_2O emission peaks occurred during September 2013 in CS-I and during December and January 2014 in CS-II respectively. Several factors have culminated in the N_2O pulse events during this period. The emission peaks were primarily due to the aeration created by seasonal drainage during September 2013, and December 2014 that creates suitable soil conditions for N_2O production by nitrification or denitrification, may enhance the N_2O diffusion rate (Yan et al. 2000). This has been reported by various authors (Bengtsson et al. 2003; Aulakh et al. 2000). Secondly, the nitrogenous fertilizer applied during June 2013, October 2013 and in the panicle initiation stage of December 2013 provides additional substrate for N_2O production (Wang and Cai, 2008). Thirdly, the elevated soil temperature of Padayatti may enhance the microbial activity and the rate of the N_2O reaction (Hua Guangxi, X., Cai, ZC., Tsuruta, H., 1997). Except for this period fertilizer inputs on 19^{th}, 38^{th}, 57^{th} and 85^{th} days after transplantation and early draining also induced short pulse events of N_2O emissions (Li et al., 2003)

In the present study, N_2O fluxes were comparatively lower in the flooded crop growing seasons compared to non-flooded drained periods. The emission of N_2O was sporadic, and pulse like events, observed during the draining period during the end of CS-I (August and September 2013) and in CS-II (January to March 2014). The flux peaks were usually observed at the beginning of the disappearance of the flood water layer. Smith et al. (2003) also observed that anaerobic and aerobic cycling that would considerably increase soil N_2O emission relative to constant aerobic and anaerobic conditions. During the study,

N_2O emission was found dependent on the flooding/ irrigation and the drainage pattern of the rice fields with a significant correlation with SMC ($p<0.01$, $r = 0.747$). During the present study when comparing the magnitude of emission between flooded and drained periods N_2O is often low during flooded periods probably because N_2O can be denitrified to N_2 under long-term anaerobic conditions (Mosier et al., 2004). The phenomenon that the peaked N_2O fluxes observed at the beginning of the disappearance of the floodwater layer could be the release of trapped N_2O in the soil solution and optimum conditions for the production of N_2O and its release at that time.

During the present study, N_2O emission rates were dependent on SMC ($p< 0.01$) with the lowest emission in FS where SMC is also minimum. However N_2O fluxes increase with an increase in SMC during the flooded crop seasons. Regression analysis obtained a best-fit equation explaining covariation of SMC and N_2O (Fig 6.7). In which highest seasonal emission efflux of N_2O was concentrated in areas with SMC in the range 40 to 50%. In the present study, moderately moist soil conditions with SMC of 40 to 50 % could have made it favorable for N_2O production. More recent findings also suggested that denitrification can occur under aerobic soil conditions (Kelliher et al., 2016). Gleeson et al. (2010) also reported the production of N_2O in aerobic conditions by nitrate and nitrite reduction. As a result of autotrophic nitrification is reduced and N_2O production via denitrification is enhanced. Keating et al. (2016) also observed higher denitrification rates in aerobic than in anaerobic conditions due to organic residues.

During the study Eh fluxes had a significant influence on N_2O emissions with a correlation significant at $p <0.01$ and values of 'r' being -0.764 (Fig. 6.6). Decreasing water level was accompanied by high soil Eh and increased N_2O emissions. Under submergence, the soil Eh values were highly negative, and N_2O emissions were low. Flooded rice paddies have an aerobic surface layer and an anaerobic subsurface layer where N_2O is produced, via nitrification of ammonium to nitrate and denitrification of accumulated nitrate respectively

(Xing et al., 2002). It is well known that flooded soil has an aerobic surface layer and a subsurface anaerobic layer. The presence of the two distinct soil layers nearby favors the simultaneous occurrence of nitrification and denitrification reactions. When soil is submerged continuously with a water layer, nitrification proceeds slowly, while denitrification proceeds increasingly towards N_2 and N_2O diffusion is severely hindered by the water layer (Hua Guangxi, X., Cai, ZC., Tsuruta, H., 1997)

The C:N ratio of the topsoil seems to be a good predictor of N_2O emission as shown by the strong negative relationship(Zhu et al., 2008). During the present study, N_2O emissions were negatively correlated with the soil C:N ratio yielding a correlation coefficient of -0.562 significant at $p < 0.05\%$. The healthy relationship observed between C:N ratio and N_2O supports the assumption that nitrogen availability is the major factor limiting the N_2O emission from the rice paddy soils (Campbell and Curtin, 2007). The result observed during the present study is supported by Khalil et al. (2002) reported that N_2O production was increased by decreasing the soil C:N ratio. Kiese and Butterbach-Bahl (2002) also found a strongly negative correlation between mean annual N_2O emission rate and C:N ratio of tropical rain forest soils.

The optimum C:N ratio for soil microbial activities is thought to range from 25 to 30. Stevenson (1990) concluded that the mineralization would occur for organic compounds with C:N ratios lower than 20, neither mineralization nor immobilization that will prevail for C:N ratios between 25 and 30, and microbes will immobilize inorganic N when C:N ratio is higher than 30. The microbial immobilization will decrease the concentration of NH^{4+} and NO^{3-} which are N_2O precursors and thus both N_2O production and emission will be reduced. It is expected that soils with lower C:N ratios would release more N_2O than those with higher C:N ratios, and that the N_2O emission would be markedly reduced when the C:N ratio approaches 20. During the present study C: N ratio was observed below 6.4 and 6.1, < 20 cause positive priming effect resulting in the mobilization of C and N from the system. (Kuzyakov et al. 2000; Thomsen et al. 2008; Li et al. 2010) leading to the higher emission of N_2O from the paddy soils.

N_2O transport is a physical process in which most of the N_2O produced in the soil was also emitted through the rice plant in the same pathway as CH_4. Mosier et al. (1990) pointed out that rice plants increase the flux of N_2O from the soil to the atmosphere through their conduit transport. However, no records of the N_2O emission from the plant are reported. During the present study, diurnal N_2O emission from rice paddies did not follow a regular pattern. N_2O is a more water-soluble gas with a solubility in water about 20 times that of CH_4 (0.675 and 0.033 g l^{-1} H_2O at 20 °C, respectively). This water may act as a carrier of N_2O, and emission through diffusion might be enhanced for N_2O. Also, in combination with the physiological movement of water, such as transpiration, N_2O may be emitted to the atmosphere through the rice plants. The opportunities for emission of N_2O through ebullition should be smaller than for CH_4 due to the high solubility of this gas.

The N_2O emissions from paddy fields were often neglected in many early reports, but a growing number of studies have indicated that paddy fields are a significant source of atmospheric N_2O (Huang et al., 2004). The cumulative emission of N_2O-N from rice paddies of Padayatti was 0.27 kg N ha^{-1} during the entire period from 2013-2014.This level was comparable may of the continuously flooded fields of the tropical region having an average emission rate of 0.3 ± 0.5 kg N The denitrification and nitrification process leading to the evolution of N_2O are regulated by multifaceted factors. The fertilizer inputs along with the water management are the primary factors influencing in Padayatti paddy agroecosystems. During the study, Padayatti had delt with a cumulative emission factor of 0.27 kg N ha^{-1}.

Chapter - 7

ORGANIC AND CONVENTIONAL MINERAL FERTILIZER EFFECTS ON GHG EMISSIONS

7.1 INTRODUCTION

Agriculture contributes nearly 10-12% of the global anthropogenic greenhouse gas (GHG) emissions, significantly altering earth's atmospheric composition of GHG and energy balance (IPCC 2013). Globally, occupying about 5.8% of the total agricultural area, rice paddies contribute nearly 12,000 MT of CO_2-equivalents per year (FAOSTAT 2016; Tubiello et al. 2013).

Paddy cultivation by incorporation of organic manures or in combinations with non-organic fertilizers has been practiced for long to improve soil productivity, health, and sustainability. Last few decades with the global concerns over increasing demand for food and reducing per capita arable lands (FAOSAT 2016) have forced the need for intensification of agriculture production using chemical fertilizers and pesticides. Recent studies on the use of agrochemicals, environment protection and agricultural sustainability in India have focused on reconsidering traditional fertilization practices using organic manures. Locally prepared compost, farmyard manures are often followed by Indian farmers to improve the fertility as well as for better yield (Nayak et al., 2007; Das & Adhya, 2014). Indian agriculture has decadal history of organic farming. Green revolution in 1956 intensified the agricultural production using chemical fertilizers for meeting the ever increasing demand for food.

The emerging shift in soil management from conventional mineral fertilizers to organic manures is expected to influence the SOC (soil organic carbon) and GHG emissions (Kuzyakov, 2010). The evolution of major GHG-CO_2, CH_4 and N_2O emissions from paddy soils are as a result of mineralization of SOC through complex heterogeneous processes of respiration, methanogenesis, and denitrification influenced by soil management activities and environmental factors (Akhilesh Vijay and Bijoy Nandan 2017).

Organic fertilizers are known to improve soil quality, structure as well as stimulate soil microbial biomass enzyme activities, and functional diversity whereas mineral fertilizers are reported to improve the nutrient availability and primary production of the system indirectly (Zhou et al. 2016). A higher concentration of SOC is often predicted in organically treated soils enhancing sequestration of carbon and mitigating climate change. However, several studies have failed to establish this expected increase in SOC ending up in contradictions (Gosling and Shepherd 2005). This may be attributed to initial soil C and N status, the microbial community composition, fertilizer type, and the application rate. Furthermore, organic manures and mineral fertilizers potentially alter the intensity and direction of soil C and N mineralization (Cheng et al. 2016) through positive or negative priming effect depending on the quality and quantity of substrate applied (Qiu et al. 2016). Such substrate additives create a pool of readily available C and N regulating the increase or decrease in SOC (Thomsen et al. 2008) , CO_2, CH_4 and N_2O fluxes from the soils (Bhattacharyya et al. 2013b). Influence of organic and mineral fertilization on soil GHG flux are controversial exhibiting positive (Krüger and Frenzel 2003), negative, and neutral effects (Liu et al. 2016).

A view on the organic and mineral fertilizers in regulating the retention of C and N and factors influencing GHG emissions. from a nutrient exhaustive tropical paddy wetland in southern India is discussed. Our observations in the process and magnitude of the total GHG emissions from paddy fields under different management practices will provide information for regional greenhouse gas inventories and mitigation measures.

7.2 LITERATURE REVIEW

7.2.1 International Scenario

The effect of organic matter application on methane emission from some Japanese paddy fields was studied by Yagi and Minami (1990). Moiser et al. (1991) compared methane and nitrous-oxide fluxes from native, fertilized and cultivated grasslands. Lindau et al. (1991) studied the effect of urea fertilizer and environmental factors on CH_4 emissions from rice field of Louisiana, USA. Spatial and seasonal variation in methane emission from Chinese rice fields with organic amendments was analysed by Soils and Province (1996). Greenhouse gas emissions from farmed organic soils was reported by Kasimir-Klemedtsson et al. (1997). Global estimates of potential mitigation of greenhouse gas emissions from agriculture was studied by Cole et al. (1997). Pansu (1998) tested the soil nitrogen forms after organic amendments under controlled conditions. Gunapala and Scow (1998) studied the dynamics of soil microbial biomass and its activity in conventional and organic farming systems. Wong et al. (1999) tested the utilization of manure compost for organic farming in Hong Kong. Condron et al. (2000) compared the soil and environmental quality under organic and conventional farming systems in New Zealand. Effect of organic manures varying in N content and C:N ratio on mineralization and denitrification processes in upland, nearly saturated and flooded subtropical soil was represented by Aulakh et al. (2000). Rigby and Cáceres (2001) studied the organic farming and the sustainability of agricultural systems from United Kingdom.

The effect of organic soil amendment and chemical fertilizer on available pool and mineralization rate of soil N in a dryland agro- ecosystem was analysed by Ghoshal (2002). Bulluck et al. (2002) studied the influence of organic and conventional farming on soil microbial, physical and chemical properties. Kramer et al. (2002) studied the importance of combining fertilizer and organic inputs to synchronize N supply in alternative cropping systems of California and reported that alternative cropping systems is to minimize excessive loss of N while maximizing N use efficiency and meeting crop N requirements. The effects of N-fertilisation on CH_4 oxidation and production, and consequences for CH_4 emissions from microcosms and rice fields was studied by Krüger and Frenzel (2003). Zou et al. (2005) measured the methane and nitrous oxide emissions from rice paddies in China and reported that water management by flooding with mid-season drainage and frequent water logging without the use of organic amendments is an effective option for mitigating the combined climatic impacts from CH_4 and N_2O in rice paddy.

Long-term effect of fertilizer and manure application on soil-carbon sequestration and soil fertility under the wheat-wheat-maize cropping system in northwest China was analysed by Su et al. (2006). Petersen et al. (2006) studied the nitrous oxide emissions from organic and conventional crop rotations in five European countries and reported that nitrous oxide emissions were higher from conventional than from organic crop rotations. Fluxes of nitrous oxide and methane and nitrogen leaching from organically and conventionally cultivated sandy soil in western Finland was reported by Syväsalo et al. (2006). Soil organic matter and biological soil quality was measured by Fließbach et al. (2007) from organic and conventional farming field. Effects of long-term chemical fertilization and organic amendments on dynamics of soil organic C and total N in paddy soil from barren land in subtropical China was studied by Li et al. (2010).

Emissions of nitrous oxide from arable organic and conventional cropping systems was studied by Chirinda et al. (2010). Effects of organic and mineral fertilizer nitrogen on greenhouse gas emissions and plant-captured carbon under maize cropping in Zimbabwe was analysed by Mapanda et al. (2011). Reduced greenhouse gases emission by using organic fertilizer was studied by (Sampanpanish 2012). de Urzedo et al. (2013) studied the effects of organic and inorganic fertilizers on greenhouse gas emissions in tropical forestry. Brar et al. (2013) analysed the effect of long-term use of inorganic fertilizers and organic manure on C sequestration and soil carbon pools in a rice-wheat cropping system. A global meta-analysis of greenhouse gas fluxes from agricultural soils under organic and non-organic management was studied by Skinner et al. (2014). Ryals et al. (2014) studied the impacts of organic matter amendments on carbon and nitrogen dynamics in grassland soils and reported that a single application of compost to grassland soils can increase soil C and N storage in labile and physically protected pools over relatively short time periods and contribute to climate change mitigation. Environmental effects of organic farming was studied by Lee et al. (2015)

Greenhouse gas emissions from paddy fields with different organic matter application rates and water management practices was studied by Nishiwaki et al. (2015) and the observation concluded that organic farming in paddy fields might have more promising potential to mitigate N_2O-N emission than conventional farming in paddy fields. Wu et al. (2015) studied the effect of biochar on paddy field that cultivating a rice variety *Oryza sativa* L. and that the results inferred that root exudates and transportation of biochar particles into rice plants might decrease the stability of biochar in paddy soil. Nitrogen soil surface balance of organic vs conventional cash crop farming in the Seine watershed was studied by Anglade et al. (2015). Effects of long-term inorganic and organic fertilizations on the soil micro and macro structures of rice paddies was studied by Zhou et al. (2016) and overall study demonstrates that organic fertilization can improve the physical qualities of paddy soils across different scales but inorganic fertilization in isolation does not. Combined effects of nitrogen addition and organic matter manipulation on soil respiration in a Chinese pine forest was studied by Wang et al. (2016) and observed that N addition inhibit the microbial heterotrophic respiration by suppressing soil microbial biomass, but stimulated root respiration and release CO_2 from litter decomposition by increasing either root biomass or microbial biomass. Poeplau et al. (2017) studied qualitative and quantitative response of soil organic carbon to 40 years of crop residue incorporation under contrasting nitrogen fertilisation regimes and the study concluded that residue incorporation is not a significant management practice that affects soil C storage in warm temperate climatic regions. Zhang et al. (2017) studied replacement of mineral fertilizers with anaerobically digested pig slurry on paddy fields in plant growth and grain quality and reported that anaerobically digested pig slurry can replace mineral fertilizers in rice production when applied as a basal dressing together with urea.

7.2.2 Indian Scenario

Ghoshal and Singh (1995) studied the effects of farmyard manure and inorganic fertilizer on the dynamics of soil microbial biomass in a tropical dryland agroecosystem and reported that changes in the soil microbial biomass were observed with the applications of farmyard manure. Organic farming and its relevance to the Indian context was studied by Rasmesh et al. (2005). Bhatia et al. (2005) studied the global warming potential from manure amended soils from a rice-wheat system of Indo-Gangetic plains. Organic farming in sustaining soil health was studied by Pandian et al. (2005). Pattern and factors influencing on greenhouse gas emissions from India was studied by Sharma et al. (2006). Majumder et al. (2008) analysed the organic amendments and its influence on soil organic carbon pools and rice–wheat productivity from moist sub-humid bio-climatic zone of India and reported that balanced fertilization with FYM (farm yard manure) as suitable management for sustaining crop productivity of the rice–wheat system. Organic farming for sustainable agriculture in Northern India was reported by Yadav et al. (2013). Gaseous emissions from agricultural activities and wetlands in national capital territory of Delhi was studied by Gurjar et al. (2015). Effects of various organic amendments on organic carbon pools and water stable aggregates under a scented rice–potato–onion cropping system was studied by Padbhushan et al. (2016).

7.3 RESULTS

7.3.1 Influence of ORG and CMF Treatments on GHG Emissions

Incorporation of ORG and CMF had a significant positive effect exhibiting an increase in the fluxes of CO_2-C, CH_4-C, and N_2O-N compared to unfertilized control. Even though there were significant ($p \leq 0.05$) variations in the emission patterns among CS-I, CS-II, and FS seasons the amounts of GHG emissions did not vary significantly between ORG and CMF treatments.

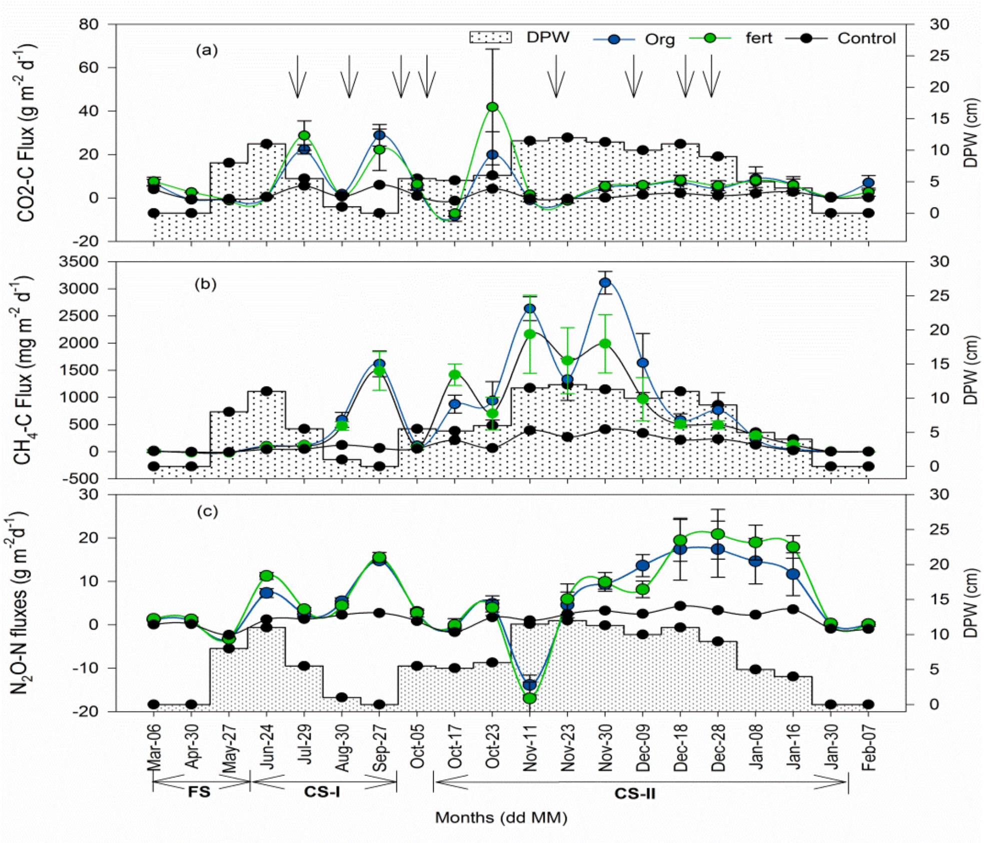

Figure 7.1 Dynamics of (a) CO_2-C, (b) CH_4-C and (c) N_2O-N emissions from rice paddy treated with Organic and Conventional Mineral fertilizers, under the influence of depth of paddy water (DPW) during 2013-2014

In the rice-rice, fallow system both the treatments behaved as a net source of CO_2-C throughout the year (Fig. 7.1a). CO_2-C fluxes were mainly dependent on the soil C: N ratio significant at 1% level, p=0.0041 (Fig. 7.2). The average CO_2-C flux for the entire study period varied between -0.84 to 28.9 g $m^{-2}d^{-1}$ and -1.11 to 22.27 g m^{-2} d^{-1} in ORG and CMF treatments significant at the seasonal level. Seasonally CO_2-C emissions were higher in the wet (CS-I, CS-II) than in dry-fallow season (FS). CO_2-C emission rate during CS-I was 13.42 and 13.15 g m^{-2} d^{-1} with a seasonal cumulative emission of 16628 and 16283 Kg ha^{-1} for ORG and CMF paddy respectively. In CS-II the mean value of CO_2-C emission was 4.2 and 6.8 mg $m^{-2}d^{-1}$ for ORG and CMF treatments with a cumulative emission of 5250 Kg ha^{-1} and 8250 Kg ha^{-1} (Fig 7.3a). During the fallow season (FW) CO_2-C emissions were low, ranging from -0.84 to 7 g m^{-2} d^{-1}, with an average rate of 3.1 g m^{-2} d^{-1} and 2.9 g m^{-2} d^{-1} for ORG and CMF treatments with seasonal cumulative fluxes of 3805.6 and 36216 Kg ha^{-1}. In the present study after the initiation of ORG treatments, a decrease in the annual cumulative emission of CO_2-C by 3.4% was observed compared to CMF. In comparison among treatments, seasonal cumulative CO_2-C emissions decreased by 24.3 % in CS-II compared to CS-I. The three seasons CS-I, CS-II, and FS contributed 64.7%, 20.44% and 14.8% in ORG and 57.8%, 29% and 12.8 % in CMF paddy respectively (Fig. 7.4a). However, there was increased CO_2-C pulse event of 28.90 ± 4.95 g $m^{-2}d^{-1}$ (ORG) and 22.27 ± 9.53 g $m^{-2}d^{-1}$ (CMF.) in both treatments during the ploughing and field preparation period followed by first crop season in September 2013 indicating that the soil inputs have a significant positive effect on CO_2-C emissions.

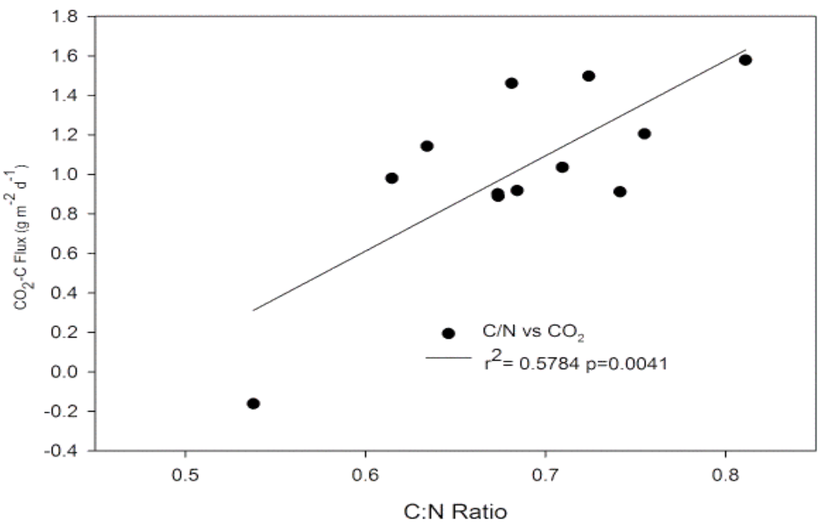

Figure 7.2 Dependence of CO_2-C fluxes on soil C:N ratio in the tropical rice paddy wetland during 2013-2014

Similar to CO_2-C, ORG and CMF treatments had significant ($p < 0.05$) positive influence on the CH_4-C emissions compared to the control (Fig. 7.1b). Seasonal variations of CH_4-C emissions were mainly dependent on the depth of paddy water (DPW) regime (Fig. 7.5) and soil redox conditions. During the observation period, both the treatments followed a similar bimodal seasonal pattern varying in the magnitude of CH_4-C emission. The rate of CH_4–C emissions was low during the fallow season due to the predominant positive of soil redox conditions and methane oxidation, ranging from -19.35 to 14.97 mg m^{-2} d^{-1}, with an average rate of -1.64 and -8.06 for ORG and CMF paddies respectively. Seasonal cumulative CH_4-C fluxes during the fallow season were -7.25 and -9.80 Kg h^{-1} for ORG and CMF paddies respectively. CH_4-C emissions increased steadily soon after transplantation during CS-I, reaching peak emissions in the middle of September following top dressing with an average rate of 1617.5 and 1485.5 mg m^{-2} d^{-1} for ORG and CMF respectively. CH_4-C emissions decreased to about 64.8 mg m^{-2} d^{-1} at the end of CS-I with a seasonal cumulative emission of 745 and 663.29 Kg h^{-1} (Fig. 7.3b). The rate of CH_4-C emissions during the CS-II ranged from 2.7 to 2634 mg m^{-2} d^{-1}, at an average rate of 1021.9 mg m^{-2} d^{-1} and 867.2 mg m^{-2} d^{-1} for ORG and CMF paddies respectively. The seasonal cumulative emission during CS-II was 1250 and 1061g Kg^{-1}. Among seasons cumulative emission, CH_4-C increased by 25% and 23% in the CS-II compared to the CS-I whereas annual cumulative emissions were 7.4 6 % greater in the ORG treatment. During this period all the three seasons contributed 37.48 %, 62.87 % and -0.36 % in ORG and 38.67 %, 61.8 % and -0.57 % in CMF paddy respectively (Fig. 4b).

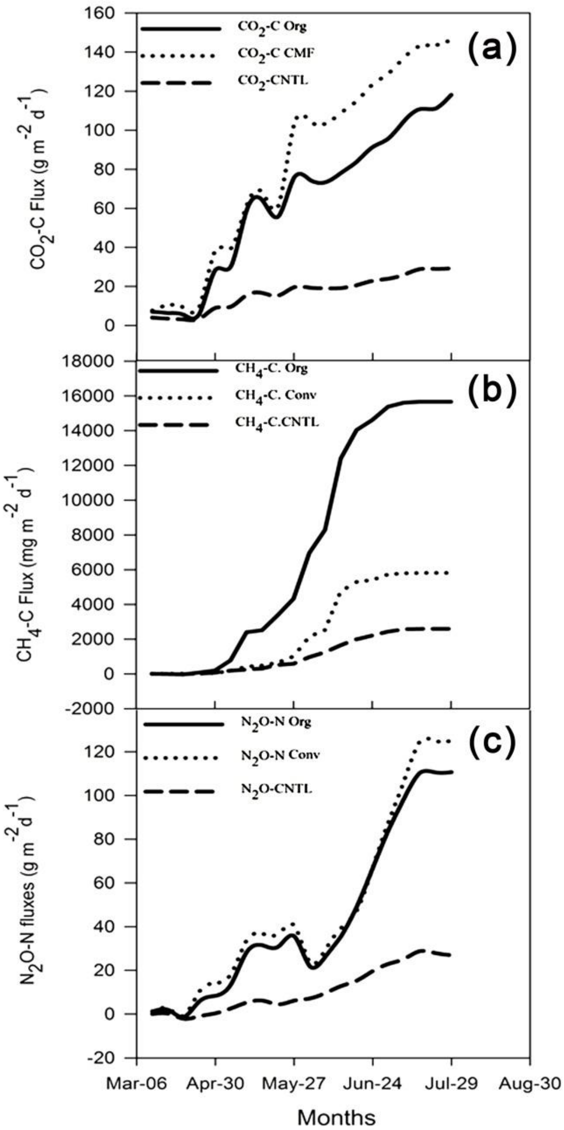

Figure 7.3 Cumulative emissions of CO_2 (a), CH4 (b), and N_2O (C) fluxes measured from organic (ORG), conventional mineral fertilizers (CMF) and control (CNTL) treatments during 2013-2014

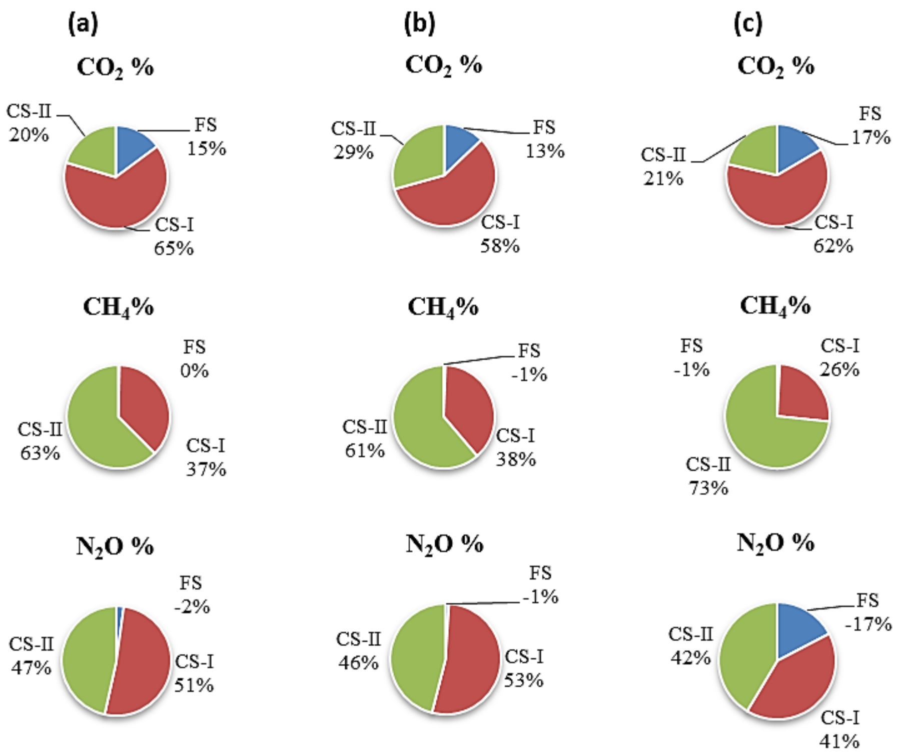

Figure 7.4 Seasonal cumulative percentage emissions of CO_2-C, CH_4-C and N_2O-N among organic (a), conventional mineral fertilizer (b) and control treatments(c) in rice paddies

In the present study, variations in N_2O-N remained positive among seasons and treatments depending on C and N inputs and depth of paddy water (DPW) but was not significantly affected by ORG and CMF inputs (Fig. 7.1c). During the FS N_2O-N emission was near to zero, increased soon after transplanting and water logging obtained its peak during panicle initiation and decreased towards harvesting in both the seasons. For ORG treatments N_2O-N emissions ranged from 2.4 g $m^{-2}d^{-1}$ to 7.33 g $m^{-2}d^{-1}$ and -0.61g N_2O-N $m^{-2}d^{-1}$ to 17.4 g N_2O-N $m^{-2}d^{-1}$ respectively in CS-I and CS-II. Whereas seasonal CMF emissions ranged from 3.5 g N_2O-N $m^{-2}d^{-1}$ to 15.5 g N_2O-N $m^{-2}d^{-1}$ and -7.28 g N_2O-N $m^{-2}d^{-1}$ to 8.94 g N_2O-N $m^{-2}d^{-1}$ respectively. Duel peaks of N_2O emissions occurred in both the treatments and of seasons (Table 7.1). The first peak appeared following topdressing in ORG (7.3 g N_2O-N $m^{-2}d^{-1}$) and CMF (11.33 g

N_2O-N $m^{-2}d^{-1}$) treatments at 34 DAT whereas the second peak occurred at 42 DAT in ORG (14.7 g N_2O-N $m^{-2}d^{-1}$) and CMF (15.2 g N_2O-N $m^{-2}d^{-1}$) treatments respectively in CS-I. In the CS-II peaks appeared 37 DAT (9.3 and 9.8 g N_2O-N $m^{-2}d^{-1}$) and 48 DAT (17.4 and 20.8 g N_2O-N $m^{-2}d^{-1}$) in the ORG and CMF treatments respectively. Seasonal cumulative emissions were -384.63 g N_2O-N ha^{-1} in the FS, 9142.6 g N_2O-N ha^{-1} during the CS-I and 6110.67 g N_2O-N ha^{-1} during the CS-II in the ORG and -200.46 g N_2O-N ha^{-1}, 10604.82 g N_2O-N ha^{-1} and 6739.04 g N_2O-N ha^{-1} respectively in CMF of FS, CS-I, and CS-II (Fig. 7.3c). Total N_2O-N emission from ORG (46%) and CMF (53%) showed only a marginal difference of 7% during the whole observation days (Fig. 7.4c). Temporal variations in the N_2O-N flux had a significant relationship ($p<0.05$) with DPW and consequently occurring redox conditions. N_2O-N fluxes were lower during high DPW and increased with decreasing DPW persisting with moderate soil moisture, significant correlation at 5% levels ($p<0.05$) was observed.

Dynamics of Soil total carbon (TC), total organic carbon (TOC) and soil Inorganic carbon (TIC) fractions from rice paddies treated with organic and conventional mineral fertilizers.

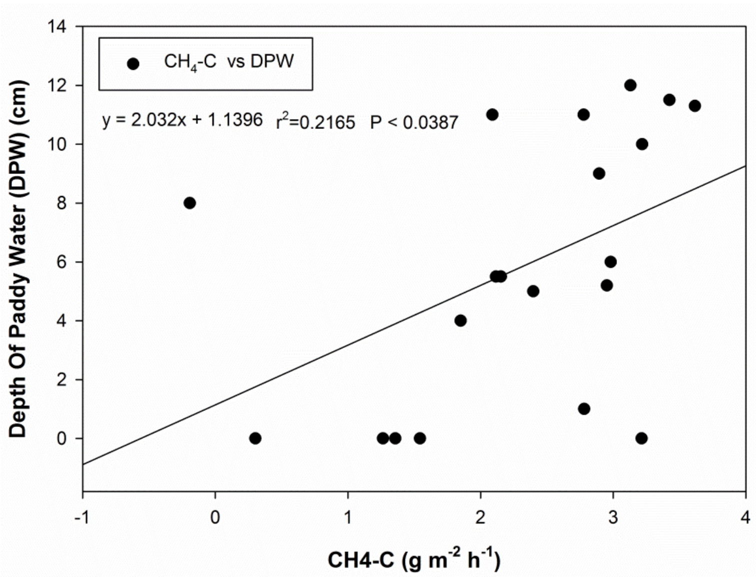

Figure 7.5 Dependence of CH_4-Cfluxes on depth of paddy water (DPW) in the tropical rice paddy wetland of Padayatti during 2013-2014

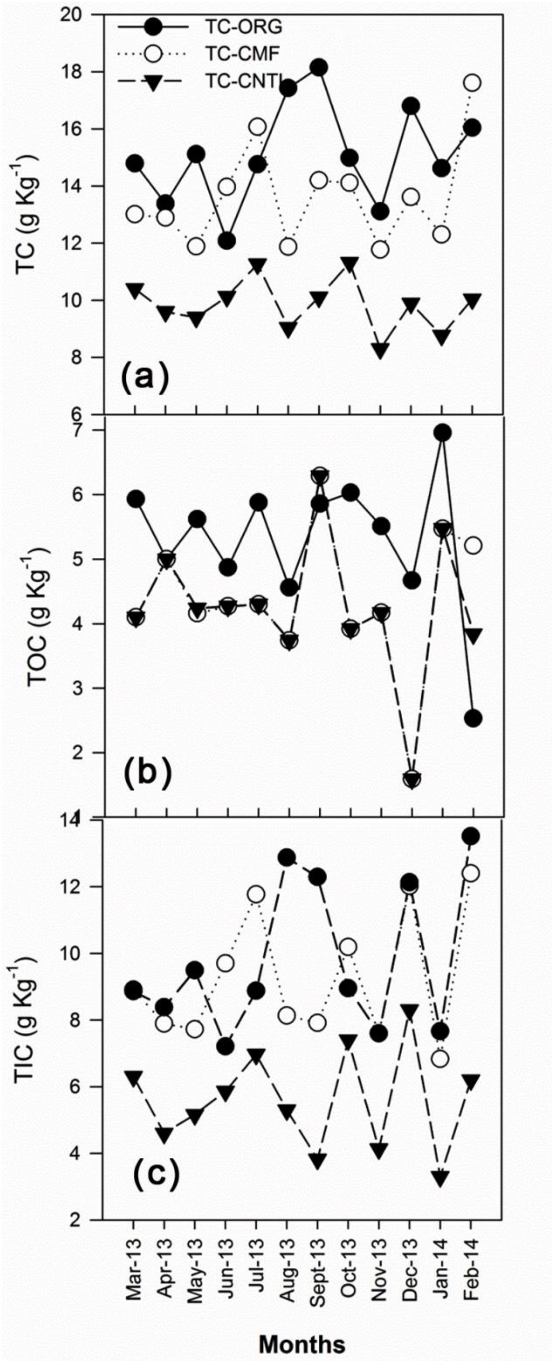

Figure 7.6 Dynamics of Soil total carbon (TC), total organic carbon (TOC) and soil Inorganic carbon (TIC) fractions from rice paddies treated with organic and conventional mineral fertilizers

7.3.2 Dynamics of Soil Active Carbon and Nitrogen

A significant variation in the surface distribution of soil C and N fractions was observed among cropping and non-cropping fallow seasons following the application of the disparate composition of organic and mineral fertilizer (Fig.7.6). Throughout the year on an average TOC content showed a similar trend among both the treatments ranging from 2.56 to 6.03 g Kg^{-1} with an average of 5.16 g Kg^{-1} in ORG and 1.59 to 6.29 with an average of 4.35 g kg^{-1} in CMF surface (0 -15 cm) soil layers (Fig. 7.6b). The total carbon (TC) (Fig. 7.6a) and total organic carbon (TOC) (Fig. 7.6c) in the soil (0-15 cm) were higher in the organic followed by conventional and minimum in the control (organic > conventional > control). Even though TC and TOC were marginally higher in the organic treatments significant difference ($p<0.05$) was not observed. Soil inorganic carbon ranged from 7.21 to 13.51 g kg^{-1} with a mean value of 9.8 g kg^{-1} in ORG and 6.83 to 12.4 with a mean value of 9.2 g kg^{-1} in CMF rice paddies accounting for 54 % and 42.87 % of the total carbon (TC) in the soil under study. The C/N ratio of organic and conventionally cultivated fields (0-15cm) ranged between 6.4 to 3.4 and 6.1 to 2.9 respectively (Fig. 7.7). Even though there was the significant seasonal difference ($p <0.05$) in C/N ratio between fallow and first crop season, lack of significant difference was observed among the treatments. The FS shows comparatively higher C/N ratio than first and second crop season. During the study soil C/N ratio is found to have a significant positive ($p<0.01$) correlation with CO_2-C emission in both ORG and CMF, where no such relations was observed between CH_4-C and N_2O-N emissions.

The distinct effect of fertilizer treatments (ORG, CMF & CNTL) on GHG emissions, soil C and N fractions is evident in the PCA. The Dim1 and Dim2 represented respectively 47.9% and 2.1% of the overall variance, indicating positive correlations among GHG emissions, TC, TIC, TOC and TN. Most measured soil variables were clustered in the left quadrants of PCA biplot with greater loadings on dimension 1 (Fig.7.8), explaining most of the observed variation. The PC1 revealed the opposition between GHG emissions and the C: N ratio indicating they are inversely correlated.

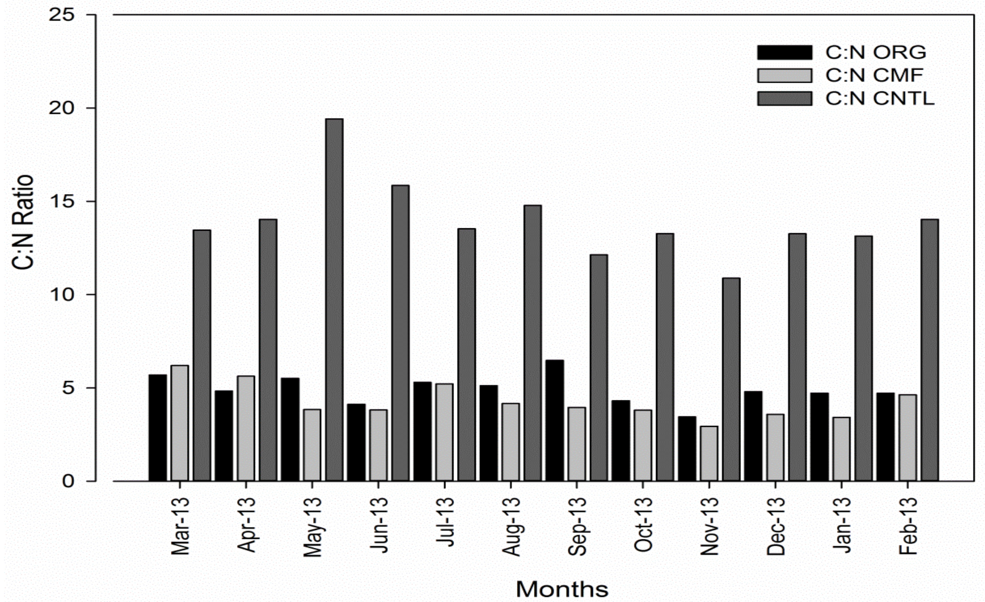

Figure 7.7 Monthly variation in the soil C/N ratio (0 to 5 cm) under organic conventional mineral fertilizers and control from Padayatti wetland during 2013-2014

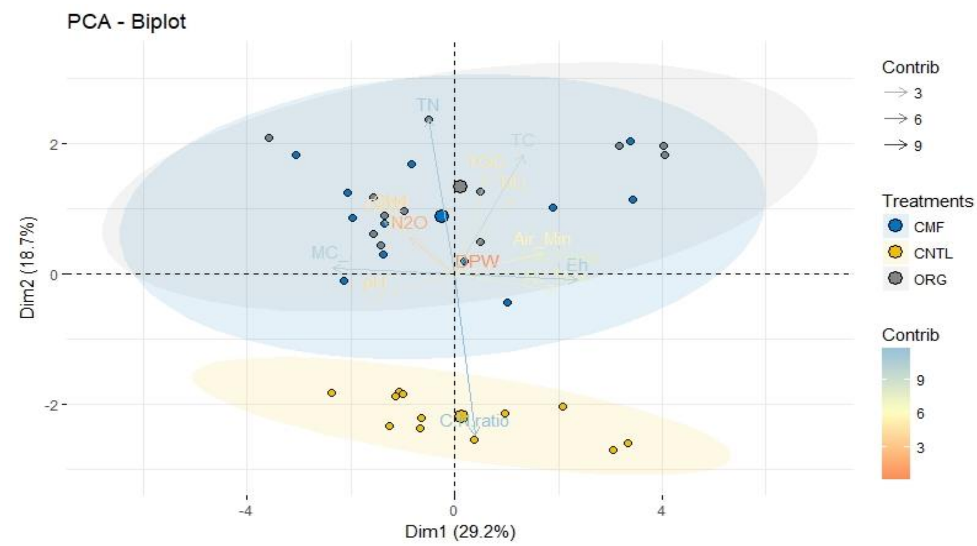

Figure 7.8 Scores and loadings from Principal Component Analyses (PCA)-biplot from ORG, CMF and CNTL from Padayatti wetland Palakkad during 2013-2014

7.3.3 Relationship of GHG emission to Environmental Factors

From the study, it is evident that drying and rewetting (DRW) of the soil occurring during the summer fallow and preceding flooded crop seasons had significant effects ($p<0.05$) on CO_2-C, CH_4-C, and N_2O-N emissions. Continuous flooding leads to increased emissions of CH_4-C and N_2O-N in the cropping than the summer fallow season ($p<0.05$) where DPW was positively correlated ($p<0.05$) with CH_4-C fluxes among both the treatments. During the seasons, DPW ranged from 0 cm to 11.5 cm from the soil surface with an average value of 6.8 cm. Mean annual precipitation was 131.58 mm of which 88% fall in the monsoon from May to August 2013. During the observation period, the mean ambient temperature was 25.77 ± 3.1 ^{o}C, that reaches an oppressive high of 35.4 ± 2.1 ^{o}C in the summer months of April-May. Soil surface temperature (0-5cm) ranged from 22 ± 2.62 ^{o}C to 28 ± 2.46 ^{o}C, with a mean value of 24.6± 2.6 ^{o}C. The seasonal variation of ambient temperature was comparable to that of soil temperature with a positive correlation coefficient $r = 0.825$ ($p<0.01$). In contrast to the weak correlation between GHG fluxes and air, soil temperatures, a significant negative relationship ($p<0.05$) between CH_4-C emission and Eh were found for both the organic and conventional treatments. The Eh was found positive during the dry summer fallow, and it decreased with increase in DPW ($p < 0.05$). The methane emission in both the treatments was dependent on redox potential. Paddy fields are mostly characterized by high reducing and anoxic conditions due to water inundation favoring methanogenesis and denitrification. On the other hand, soil pH and Eh in both organic and conventional treatments were similar without any significant difference where the pH ranged from 4.58 to 6.8 and Eh from 121 to -607 mv respectively.

Table 7.1 Seasonal CO_2-C, CH_4-C and N_2O-N fluxes in rice paddy treated with Organic, conventional Mineral Fertilizers and control

Seasons	Treatments	CO_2-C g kg^{-1}	CH_4-C g kg^{-1}	N_2O-N g kg^{-1}
Fallow Season	Organic	3805.6	-7.2506	-381.955
	Fertilizer	3621.6	-9.80856	-198.445
	Control	1037.7	-2.666	-962.244
First Crop Season	Organic	16628.4	745.8266	9142.613
	Fertilizer	16283.8	663.296	10604.81
	Control	3896.0	83.63	2290.642
Second Crop Season	Organic	5250.9	1250.924	8289.947
	Fertilizer	8250.3	1061.557	9212.07
	Control	1348.3	237.4807	2295.637
Annual Emissions	Organic	25685.0	1989.5	17050.61
	Fertilizer	28155.8	1715.044	19618.44
	Control	6282.0	318.4447	3624.035

Global Warming Potential (GWP)

Cumulative emissions, GWP in terms of gaseous emissions lack significant variation among amendments. GHG's were not consistent with seasons and significantly varied ($p<0.05$) in cumulative emissions, GWP between FS, CS-I and CS-II. Irrespective of amendments, among GHGs CH_4-C contributed 56.04% to 88.67% and 60% to 81.84% respectively in CS-I and CS-II. Soil CH_4-C uptake (negative flux) was noticed in FS. The FS emissions in both amendments was dominated by CO_2-C, 38% and 8% in CS-I and CS-II in organic and 40.1% (CS-I) and 15.2% (CS-II) in non-organic plots respectively (Table 7.2). N_2O-N emissions were mostly positive in both amendments especially in the wet seasons and contributed 2.3% to 3% to the GHG emissions. Annually GHG emissions were dominated by CH_4-C and N_2O-N in CS-I and CS-II where CO_2-C was dominant in FS. The GWP in both amendments during the cropping season was primarily contributed by CH_4-C emissions of 72.1% and 67.4% respectively.

Table 7.2 Seasonal and Cumulative Green House Gas Emissions, GWP and CEE from a tropical rice-rice double cropping system

Seasons			FS	I^{st} CS	II^{nd} CS	Annual
Cumulative Emissions (g ha^{-1})	CO_2-C	Org	3665.279	16628.43	3718.029	24011.7
		Non-Org	3568.304	16283.84	6021.31	25873.5
	CH_4-C	Org	-7.44701	752.7062	4111.808	4857.07
		Non-Org	-10.0041	668.8829	3226.168	3885.05
	N_2O-N	Org	-384.636	9142.642	6110.676	14868.7
		Non-Org	-200.463	10604.83	6739.047	17143.4
GWP (g ha^{-1})	CO_2-eqvl.	Org	6507.3	42160.3	45402	94069.6
		Non-Org	6230.69	39266.1	41632.1	87128.9
CEE (Kg h^{-1})		Org	1774.71	11720.6	12160	25655.3
		Non-Org	1699.28	10934.8	11128.3	23762.4

7.4 DISCUSSION

In the rice paddy system, soil treatments by ORG and CMF lead to a general increase in the soil CO_2-C, CH_4-C and N_2O-N emission compared to the unfertilized control consistent with the result in Ding et al. (2007). Compared to other tropical rice paddies the elevated GHG fluxes was observed during the present study (Bhattacharyya et al. 2012; Bhattacharyya et al. 2013a; Bhattacharyya et al. 2013b; Das and Adhya 2014; Gupta et al. 2016). Increase in GHG may be attributed to greater C inputs, directly via organic fertilizers, and indirectly via increased root biomass and rhizodeposition due to better crop productivity as a result of mineral fertilization (Mancinelli et al. 2010) along with the prevailing environmental conditions.

During the observation period, a significant increase in the soil CO_2-C fluxes could be the influenced by nutrients via ORG and CMF inputs (Fisk and Fahey 2001; Xiao et al. 2005). Similarly, studies from tropical rice paddies amended with fertilizers had already reported 50% increase in CO_2-C emissions compared to unfertilized soils (Bhattacharyya et al. 2012). However, this was in contrast to the findings of Ding et al. (2010), and Lee et al. (2007) reported suppression and neutral effect on CO_2 emissions respectively following fertilizer addition. Higher emission trends of CO_2-C in comparison with the control could be the result of the narrow range in soil C: N ratio among ORG and CMF treatments which had lead to greater mobilization of C from the system. Usually, CO_2-C evolution by C mineralization or its bio-immobilization processes in arable systems is regulated stoichiometrically by C: N ratio of the amended materials, SOM, and the soil microbial biomass (Chen et al. 2013). During the present study, average C: N ratio of the ORG and CMF treated soils was in the range 4.8 to 6.4 indicates a positive response to CO_2-C efflux. The influence of C: N ratio on CO_2-C evolution (Fig. 7.2) obtained during the present study corresponds to the *in-situ* observation of Thomsen et al. 2008, reported an increase in CO_2-C efflux with lower C: N ratio. Generally, net mineralization takes place when C: N ratio of the soil is below the threshold value of 9.7 to 15, determined based on the *in situ* mineralization study using soil samples with varying in C to N ratios (Mohanty et al. 2013; Zimmerman et al. 2011). The principle component analysis, Dim1 (Fig. 7.8) clearly revealed the opposition between CO_2-C and C: N ratio in the present study. Soil C: N ratio within 0-5 cm between plot did not differ significantly could be a reason for similar emissions between ORG and CMF treatments whereas the microbial metabolism could not be N limited in both the treatments leading to the enhanced mobilization of C as CO_2 from the soil.

Soil CO_2-C emissions were observed higher during the paddy growth period (Yang et al. 2017). Highest emission of CO_2-C was observed during the panicle initiation stage due to the availability of the C substrates and higher microbial activity (Iqbal et al. 2009; Ibrahim et al., 2013). Dynamics of CO_2-C in paddy fields varies with the phase change in soil wet and dry conditions. CO_2-C production during the submerged anoxic conditions during the crop season was 26% higher than under non-submerged aerobic conditions during the fallow season. These results, therefore, suggest that the higher rate of soil respiration during the flooded period was not a direct consequence of the greater availability of soil moisture. These temporal patterns, therefore, suggest that the effect of flooding on soil respiration is probably indirect, and likely involves the deposition of nutrients and organic materials added (Nishimura et al. 2015).

Paddy fields are one of the major anthropogenic contributors of atmospheric methane (Liu et al. 2016) influenced by soil fertilization leading to positive, negative and neutral effects (Kruger and Frenzel 2003; Zhou et al. 2016; Fan et al.2016). In the present study fertilization using both ORG and CMF along with environmental variables significantly enhanced CH_4-C fluxes compared to the unfertilized control. Usually, methanogenesis in rice paddies is as a result of anaerobic decomposition of soil organic matter under submerged soil conditions depend on the availability of quality and quantity carbon substrate (Kögel-Knabner et al. 2010). However, in the present study, it was observed that ORG and CMF treatments were not able to make any significant variations in the quality and quantity regarding active carbon substrate fractions could be the reason for similar substrate utilization and similar emission pattern. Soil C: N ratio is recognized as an important indicator of SOM quality found to have a critical role in the C mineralization leading to CH_4 evolution (Kuzyakov, 2010; MA et al. 2011). Balanced organic and non-organic treatments had maintained a uniform soil C: N ratios in both the fields that could be a reason for similar emission pattern. The DPW and reducing redox conditions prevailing favored the usual pattern of CH_4-C emission comparable to various previous reports (Tokida et al. 2013). Continuous flooding in the field during the crop seasons maintain a low redox potential favorable for CH_4 formation leading to high CH_4-C emissions. (Alberto et al. 2015; Hu et al. 2016). Which was supported by the significant negative relationship ($p<0.05$) between CH_4-C emission and DPW (Komiya et al. 2015). Mean soil redox (Eh) conditions was higher in the wet rice growing conditions likely to favoring methanogenesis thereby suppressing CH_4 oxidation by methanotrophy resulting in the increased CH_4 emission. The peaks of the methane flux were observed 74th days after transplanting of the rice plant irrespective of the treatments corresponding to the panicle initiation stage of crop development. The incorporation of fresh residual rice straw during CS-II could be the reason for enhanced CH_4-C emission compared to CS-I which was consistent with the result of Wang et al. 2016. Whereas decomposition of rice straw during the fallow season might have lead to a decrease in CH_4-C during CS-I (Tang et al. 2016).

N_2O-N emission from arable soils was the result of nitrification and denitrification process (Davidson et al. 1991). The complex process of N_2O-N emission from paddy soils are regulated not only by N input and the water regime but also by many other factors such as quality and quantity of fertilizer, temperature, soil texture, soil pH, and C: N ratio (Akiyama and Tsuruta, 2003). In the present study, N_2O-N emission fluxes were often low during the flooded period as it can be denitrified to N_2 under anaerobic conditions (Cui et al. 2016). N_2O-N flux peaks were observed for second and third weeks after the fertilizer input. This enhancement of N_2O and NO fluxes just after fertilizer application is widely observed (Bhattacharyya et al. 2013). Previous studies have indicated that the level of N fertilizer application is one of the main factors influencing soil N_2O emission. Aerobic and anaerobic soil conditions due to the alternate wetting and drying process also increase the soil N_2O emissions which are commonly stimulated by ORG and CMF treatments (Bell et al. 2016). During the study, N_2O-N emissions from the ORG and CMF plots were found minimal where N_2O-N emission is a microbial process that depends on available carbon and nitrogen sources available to microorganisms. Although net N mineralization rate was not determined in this experiment, the organic matter C: N ratio can be used as a general indicator of N mineralization rate in the first part of the decomposition process after organic and non-organic application. A negative relationship between net N mineralization and organic matter C: N ratio has been reported (Akiyama and Tsuruta, 2003). During the present study, the C: N ratios determined for ORG and CMF treatment was similar in both fields could be the reason for similar emission pattern. This can be explained by the higher bioavailability of the synthetic N fertilizer in CMF farming systems, whereas the N inputs in the organic systems consist mainly of farmyard manures and plant residues where N availability is much lower.

7.4.1 Soil Carbon and Nitrogen Relating to GHG Emissions

In the present study, the concentration of SOC, TN, and C:N markedly increased in the fertilized treatment plots, suggesting that balanced rate of fertilization, considered as an effective practice, could increase the soil C and N in the studied rice paddy system. Surface application of ORG and CMF fertilizers had increased the SOC in both treatment plots compared to the non-treated control with a SOC change by 15%. It is a general trend for soil C and N content markedly affected by fertilizer input (Kauer et al. 2015; Nyborg et al. 1999; Campbell et al. 2005). Global estimates of SOC measured in organically amended rice paddies averaged over 39 studies found slightly increase in SOC varying from 3.4 to 8 mg/kg (Tong et al. 2009; Sacco et al. 2015). Indicating that the treatment effect was minimum within the present study where the disparate composition of ORG and CMF did not make any significant changes in the soil C: N ratios. Their higher availability of C and N may have a positive effect on the SOC mineralization resulting in the depletion of native SOC. When compared to tropical paddy systems of Indo-Gangetic Plain (IGP) SOC stocks in cultivated tropical mineral soils are often low compared with other ecosystems (Boellstorff 2009). Furthermore, the possibility of relative stability of the C and N fractions in the soil that received inorganic mineral fertilizers for the last 50 years could also be a reason for decreased concentration of SOC in the treated soil. Few years of application of organic manures are hard to make any changes in the active fractions of SOC indicating that the current fertilizer practices and cropping conditions are primarily contributing to C and N source rather than sequestration.

GHG emissions by mineralization of C and N irrespective of the ORG and CMF treatments dependent on the soil C: N ratio (Tong et al. 2009). A shift in input quality expressed as C: N ratio, an indicator of SOC quality may influence the organic decomposition. The dependence of C and N mineralization on soil C:N ratio resulting in the release of CO_2, CH_4 and N_2O has been well described for paddy soils (Šimek et al. 2014). In the present study, 7% increase in C: N ratio was observed in ORG compared to CMF treatments. The C: N ratio was observed below 6.4 and 6.1 in both the treatment respectively comparable with the previous studied reporting exogenous input of C: N ratio >10 causes negative priming effect (immobilization) and substrates with C to N ratio < 8 cause positive priming effect resulting in the mobilization of C and N from the system. (Kuzyakov et al. 2000; Thomsen et al. 2008; Li et al. 2010), this negative relation was clearly established in the PCA analysis in the present study (Fig. 7.8). Thus the relatively low and insignificant difference in the C:N ratio between treatments interfering with the retention of soil C and N could be the reason for similar GHG emission pattern from organic and CMF treatments.

To our knowledge, the present study represented the first detailed GHG fluxes during different soil management practices using organic and conventional mineral fertilizer in a tropical rice paddy system from southern India. The incorporation of ORG and CMF had enhanced the GHG emissions depending on the prevailing environmental variables, C and N availability. However the balanced fertilization pattern resulted in the insignificant differences in the GHG emission pattern among the ORG and CMF treatments. Even though there were enhancement in the soil C fractions, the narrow range in C:N ratio results in mobilization of C and N leading the depletion of native SOC. Also, the continued use of mineral fertilizers and cultivations for decades may have stabilized the SOC preventing its increase. Thus the enhanced mineralization and reduced retention of SOC had made these areas often vulnerable to degradation and environmental changes. In addition long term soil management in terms of fertilization need to be considered for better understanding of C balance in the tropical system and the impact of predicted climate change.

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Chapter - 8

SUMMARY AND CONCLUSION

Wetlands are prominent ecosystems lying at the interphase between terrestrial and aquatic ecosystems. Owing to its unique biogeochemical features they are capable of storing nearly 20–30% of earth's SOC with an average carbon sequestration rate of 20 –30 g C m^{-2} y^{-1} (Mitsch et al., 2013). Globally rice paddies share a significant portion of the wetlands and have a high carbon sequestration capacity, holding up nearly 466 to 2011 Gt C in soils and plant biomass. The primary source of carbon in paddy wetlands is directly through crop residue and indirectly by fertilizer inputs, vulnerable to decomposition and lost back to the atmosphere as both carbon dioxide and methane. As paddy wetlands are dynamic systems with flooding and drying events, carbon storage has many implications, functioning both as a major sink as well as a source of carbon micromanaging the emissions of major greenhouse gases (GHG).

Rice is one of the most important cultivated crops in India covering a total paddy harvesting area (35%) of 4,24,10,000 ha and producing about 125 million tons of rice (43%). The area under paddy cultivation in Kerala accounts for 1,96,870 Ha during 2015-2016 in which Paddy ecosystem in Palakkad, known as the rice granary of Kerala, India contributes to 81,120 ha (42.5%) in 2015-2016 (ENVIS-2016). During the period the Indian agriculture has an emission factor of 94,012.79 Gg (FAOSAT 2016), accounting nearly 13.5% of the global anthropogenic GHG emissions, contributing about 25%, 30% and 70% of CO_2, CH_4 and N_2O respectively (Stocker et al., 2013). Whereas the contributions of the rice paddies into the global C and N budgets, as well as factors influencing their fluxes from Kerala, southern India are still highly uncertain. So investigating the dynamics of carbon and nitrogen, process and magnitude of the total GHG emissions from paddy fields will provide information for regional greenhouse gas inventories and its mitigation measures. In this context, the study gives insights into the process and factors affecting C storage in an agro macro-watershed wetland ecosystem in Padayatti, Palakkad district, Kerala where cultivation dominated by rice paddies. Efforts were also made to compare the dynamics of C and N in soils under different soil management operations namely- Organic and Mineral fertilizer treatments with the objectives

1. Analyse the soil carbon sequestration potential and its dynamics.
2. Assess the emission potential and fluxes of GHG- methane, carbon dioxide and nitrous oxide in the paddy wetland.
3. Assess the effect of different soil management practices on GHG emissions.
4. Suggest measures adaptive for the adaptive management of paddy lands *vis-a-vis* global climate variability.

Chapter 1 General introduction gives a general introduction regarding the various processes and factors regulating the carbon dynamics and GHG emissions from paddy fields and other wetland ecosystems. The chapter ends with the significance of the study and listing the objectives of the study.

Chapter 2 study area sampling design and analysis, provide the details of the study area with a detailed description of each station, sampling strategies, method**s** of analysis and statistical tools used for the study.

Chapter 3 environment variables and soil carbon dynamics in paddy wetlands, describes the spatial and temporal variation in various environmental variables such as ambient air and soil temperature, rainfall, soil pH, Eh, soil moisture, paddy water level, available nitrogen, total nitrogen, available sodium, calcium, potassium and carbon fractions- total carbon (TC), total organic carbon (TOC) and total inorganic carbon (TIC) were discussed. During the observation period, environmental variables are found highly significant in influencing the dynamic process of carbon sequestration and GHG emissions. In the study, the mean ambient temperature was 25.77 ± 3.1 ^{o}C that reaches a maximum of 35.4 ±

2.1 °C in the summer months of April-May. Soil surface temperature (0-5cm) ranged from 22 ± 2.62 ^{o}C to 28 ± 2.46 ^{o}C, with a mean value of 24.6± 2.6 ^{o}C. The soil type of the area was typical laterite type found in the central tropical Kerala, India and classified as ultisols with sandy clay loam texture. The main soil properties of paddy wetland soils (0–20 cm) of Padayatti- Palakkad were, pH 6.6±3.5, redox potential (Eh) -145±105, total carbon 12.07±1.5, total nitrogen 0.18±0.02%, NH_4-N 13.0±0.1mg Kg^{-1}, available phosphorus 0.75 ± 56 mg Kg^{-1}, available potassium 0.0069 ± 0.47 mg Kg^{-1}, available sodium 0.0044 ±0.11 mg Kg^{-1} and available Calcium 0.0027 ± 1.06 mg Kg^{-1}. The carbon and nitrogen stock estimated from the Padayatti wetlands during the present study was 8.4 x10^{-4} Pg for TOC, 0.075 Pg for TC, 0.042 Pg for TIC and 0.0152 Pg for TN (1Pg = 10^{15}g). It is evident from the study that the C and N stock from Padayatti wetland was low compared to similar paddy ecosystems like Indo-Gangetic plains- India. The increased rate of mineralization and reduced retention of SOC may be the reason for low carbon stock and sequestration rate. However in addition to all an average sequestration rate of 0.957 Mg C ha^{-1} in first crop season and 1.1369 Mg C ha^{-1} in second crop season was observed during 2013-2014.

Chapter 4 Carbon balance investigating the seasonal phasing and magnitude of respiratory and assimilatory process, NEE, diurnal variations and cumulative emissions of CO2-C are discussed in this chapter. During the study soil management operations such as wetting and drying and quality and quantity of fertilizer inputs are found highly influential in determining the CO2-C emissions from the system. The soil C:N ratio has also found significant in determining the magnitude of CO2-C emission and its sequestration rate in the system. In the present study, NEE showed a net sink of CO2-C during the crop growing seasons with an average rate of -1.59 and -2.1 t C ha-1.

During the study, a significant positive increase in total soil CO_2-C emissions was observed during summer fallow, panicle initiation, and field preparation. Total soil CO_2 flux increased soon after transplantation in first crop season and had its highest emission during panicle initiation. While it decreased towards harvesting period influenced by mid-season drainage, but no such variations were observed in the second crop season. The dynamics of total CO_2-C in paddy field varies with the phase change in soil wet and dry conditions. CO_2-C emissions increase with the drained summer fallow seasons, due to the aerobic decomposition of soil organic matter. However, there was increased CO_2-C pulse event of 28.90 ± 4.95 g $m^{-2}d^{-1}$ was observed during the ploughing and field preparation period followed by first crop season in September 2013 indicating soil fertilizer inputs had a significant positive effect on CO_2-C emissions. Significant positive correlations were observed ($p<0.0041$) between C:N ratio and CO_2-C fluxes indicating the interdependence of C and N inputs in CO_2-C emissions.

Chapter 5 methane flux- diurnal and seasonal variations from rice paddy soils, discusses the factors influencing the diurnal, seasonal and spatial variations in CH_4-C emissions about paddy plant physiology, soil, and environmental variables. In the present study methane emission covaried with crop growth, increasing with the early crop to panicle initiation while it decreases towards the ripening stages. Fluxes of methane followed a similar seasonal pattern during both the first and second crop seasons varying significantly between flooded crop growing season (June to February) and summer fallow (March to May) period. Generally, in the tropical flooded paddy soils, CH_4 evolves as an end product of acetate cleavage by acetoclastic methanogens in the anoxic soil zones. Several physical and chemical factors (temperature, pH, redox potential), water regime, fertilizer application, and agricultural practices (direct seeding, transplanting) determine emission of CH_4 from rice fields. Among these factors, soil redox potential and pH are crucial in controlling the anaerobic decomposition of soil organic matter leading to the production of methane. Static chamber based methane emission studies on paddy wetlands revealed that methane emission was high during the flooding to the panicle initiation stages, at low Eh, while methane emission was low after the flowering and the ripening stages at high Eh in the paddy field with intermittent irrigation. In the present study, average values for pH in the soil ranged from 6.0 to 7.5, which favors the optimum for the growth of methanogenic bacteria. In addition to pH, the soil oxidation-reduction potential (Eh) plays a significant role in the production of methane, as the obligatory anaerobic methanogenic bacteria requires Eh of about −200 mV or less to grow. The average methane emission was observed lowest during the summer fallow period (March to May), with an average value of 1.529 mg^{-1} m^{-2} h^{-1} having the highest Eh value ranging from -50.1 to -30.14 mV. CH_4 emission at the panicle initiation was mainly due to the release of root exudates and organic materials from the rice plants. The decline in CH_4 emission from rice field at the ripening stage was due to a decline in conductance of the rice body for CH_4 transport. The decline in conductance was possibly due to the reduced permeability of the root epidermal layer as a consequence of aging.

Chapter-6 nitrous oxide fluxes and dynamics from paddy soils, deals with the spatial, seasonal variations and cumulative emissions of N_2O about environmental and soil management activities. During the study variation in N_2O emission was observed between dry and wet crop seasons. The highest emission was observed at the end of first crop season (0.76 mg m^{-2} h^{-1}) whereas lowest was observed during summer fallow months of April (-0.017 mg m^{-2} h^{-1}). A seasonal similarity in emission was observed between the first and second crop season, which increases with the vegetative growth of the paddy and decreases toward the harvest. N_2O emissions from paddy fields had a positive response towards N fertilizer application and are one of the leading factors influencing its emission. Aerobic and anaerobic soil conditions due to the alternate wetting and drying process also increase the soil N_2O emissions which are commonly stimulated by organic and non-organic soil amendments. Duel peaks of N_2O emissions occurred in both the seasons immediately after the top dressing. The cumulative N_2O emissions estimated were 76.3 ±8.1 mg m^{-2} h^{-1}.

Chapter-7 organic and conventional mineral fertilizer effects on GHG emissions, as soil management had a significant role in regulating the carbon and nitrogen in paddy wetlands, this chapter discusses the dynamics of carbon and nitrogen along with CO_2-C, CH_4-C and N_2O-N emissions from paddy fields treated with organic (ORG) and conventional mineral fertilizers (CMF). In the rice paddy system, soil treatments by organic and conventional mineral fertilizers lead to a general increase in the soil CO_2-C, CH_4-C and N_2O-N emission compared to the unfertilized control. Compared to other tropical rice paddies the elevated GHG flux was observed during the present study. Increase in GHG may be attributed to higher C inputs, directly via organic fertilizers, and indirectly via increased root biomass and rhizodeposition due to better crop productivity as a result of mineral fertilization along with the prevailing environmental conditions. Even though there was an increase in soil C and N fractions due to organic and mineral fertilizer treatments lack significant variations were observed, where the availability of C and N may have a positive effect on the SOC mineralization resulting in the mobilization, thereby depleting the native SOC. The principal component analysis (PCA) results also revealed the opposition between GHG emissions and the C:N ratio indicating they are inversely correlated. Thus the relatively low and insignificant difference in the C:N ratio between treatments interfering with the retention of soil C and N could be the reason for similar GHG emission pattern. Thus ORG manures and CMF with adequate nitrogen input will limit the mineralization of native soil SOC favoring the increase of soil carbon reserve pool and reducing GHG, could be a viable option to mitigate global warming and to sustaining soil health.

In this regard, findings from this study suggest some recommendations put forth for proper sustainable management of Padayatti rice paddy along with similar agro wetland ecosystem of the country

❖ From the study, it has been concluded that, the agrobiodiversity zones of Padayatti, the rice granary of the state is a reseavoir of soil carbon and associated nutrients nourishing the system along with the GHG emissions, that have a strong bearing on the farming practices primarily in the organic and fertilizer amended zones. Tradiational, including organic and amended farming practices have had its preferential influence in structuring the carbon , the biogeochemistry and its different fractions in the successful farming operations. But our study has not evolved any discriminating evidence in the mode of farming influencing the carbon utilization and transfer in the ecosystem (sequestration) in the Padayatti wetland.

- The carbon and its variants structuring the Padayatti soil and its spinoffs measured mainly as GHG's, have significantly contributed to the global GWP, an essential indicator of the changing climate scenario of our wetlands especially in the agricultural sector, that have a strong footprint on our livelihood. Such changes have converted our agricultural lands essentially paddy lands into a source rather than a sink of carbon which can be regulated only by effective farming practices through judicious policy decisions by government agencies.

- The study has refocused our thinking on the need for a "Carbon Neutral Farming Technology"suitable to our environment, whereby the scientific management of this farm, based on the input and output of carbon based sources can be achived for meeting our goals for sustainable food security objectives. So soil carbon management as outlined in the study needs to be adopted in the agricultural sectors so as to maintain a pristine environment without any effects to the increasing climate change issues.

- Necessary policy guidelines as outlined in wetland act, the agricultural regulations and others are to be amended to include carbon assessment and management as a criteria on the quality of the farming methods and its role in managing the climate change scenario of the respective zones of the state.

- Carbon should be adopted as tool/ indicator for measuring the productivity of the agricultural land as suggested in the study, and further, the government and non-governmental agencies should also prepare for model agro-climatic zones along the state that will perpetuate ideal carbon neutral farming practices.

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