CARBON DYNAMICS OF ACID SALINE *POKKALI* SOIL UNDER LONG TERM FERTILISER APPLICATION IN RICE

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Carbon dynamics of acid saline *pokkali* soil under long term fertiliser application in rice"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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ABBREVIATIONS

$BaCl_2$	Barium Chloride
C	Carbon
CEC	Cation Exchange Capacity
C_L	Labile Carbon
CLI	Carbon Lability Index
C_{NL}	Non Labile Carbon
CO_2	Carbon Dioxide
CPI	Carbon Pool Index
GHG	Greenhouse Gases
H_2SO_4	Sulphuric Acid
HCl	Hydro chloric acid
IPCC	Inter Government Panel On Climate Change
KAU	Kerala Agricultural University
MBC	Microbial Biomass Carbon
MRT	Mean Residence Time
NaOH	Sodium Hydroxide
PCM	Potential Carbon Mineralisation
PMT	Permanent Manurial Trial
POC	Particulate Organic Carbon
RRS	Rice Research Station
SOC	Soil Organic Carbon
T	Treatment
UNFCCC	United Nations Framework Convention On Climate Change
WSA	Water Stability Aggregate

CHAPTER 1

INTRODUCTION

Over the past 150 years the amount of atmospheric carbon has increased by about 30 per cent. There is a direct relationship between the increasing levels of carbon and the rising temperatures. A proposed method to reduce atmospheric carbon is to increase the global storage of carbon in soils. Soil is considered as the medium of global carbon cycle as it has twice the capacity to store C compared to the atmosphere (Davidson *et al.*, 2000). Soil act as a potential source or sink of C emissions, depending on its management.

Currently, the soil carbon store is the most overlooked aspect of agriculture with respect to the changing climate scenario. Studies on the impact of agriculture on the global climate and vice versa have focused on the emissions of green house gases (GHGs) namely carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The wetland rice soils have the immense potential to act as better source of GHGs. However, wetland soils are one of the most effective ecosystems for storing soil carbon due to their peculiar characteristics helping in the accumulation of organic matter and sediment and hence serves as carbon (C) sink (Schlensinger, 1997).

Pokkali soils are acid saline soils. Rich organic matter deposit under the submerged condition makes it highly acidic and inundation of sea water causes salinity. These fields are naturally connected to the Arabian Sea through backwaters and canals. *Pokkali* fields are tidal wetlands and are characterized by the accumulation of soluble salts, over and underlying acidic soil with toxic levels of iron and manganese (Padmaja *et al.*, 1994).

Highest soil organic densities had been found in paddy land which is attributed to natural fertility of wet and other lowlands and also by long term use of fertilizers and flooding which provide a strong supply of organic carbon and lower decomposition rate respectively (Fu *et al.*, 2001)

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Kyoto protocol focus on the development of carbon sinks to mitigate climate change and the studies may support for the carbon credits in the near future. Hence, the study of the dynamics of carbon sequestration will help in assessing the potential of wetland soils to mitigate the changing climate.

It is difficult to detect changes in soil organic carbon (SOC) in short term due to the slow formation of soil organic matter (SOM) (Malhi *et al.,* 2011). However, long-term experiments would be more useful for studying the changes in soil properties and other soil processes over time (Haynes, R., 1998). Long-term monitoring allows both the identification of current changes in the soil and prediction of future changes (Antil and Singh, 2007). It is well established that inorganic fertilizers serves to maintain or improve crop yields. Their application can induce changes in the physical, chemical, and biological properties of soil (Dick et al., 1996). These changes in the long-term are believed to have significant influences on quality and productive capacity of the soil (Acton and Gregorich, 1995).

Hence, the study on carbon dynamics of acid saline *pokkali* soil under long term fertilizer application in rice is envisaged providing an opportunity to examine the long-term effects of fertilizers on soil organic carbon pools with the objectives,

- To estimate the soil organic carbon (C) status in acid saline soil
- To assess the influence of long term fertilizer applications on soil carbon dynamics

CHAPTER 2

REVIEW OF LITERATURE

Pokkali field is prevalent in the coastal saline tracts of Kerala. Pokkali fields are able to produce paddy and shrimp rotationally in an organic way. *Pokkali* soils are inherently saline, and highly fertile. However, changes in soil and crop management practices in this rice systems, mainly affect the cycling of carbon (C) and other related soil properties.

2.1. *Pokkali* system of rice cultivation

Pokkali is a traditional system of paddy cultivation practiced in the coastal belt of Kerala in which a salt-resistant and tall variety of paddy (*Oryza sativa* L.), is grown during the months of May-June to September-October and is simultaneously followed by shrimp cultivation for the rest of the year (Sasidharan *et al.*, 2012). Paddy is harvested before water reaches high salinity levels and immediately after the harvest, the fields are utilized for prawn filtration (Rajendran *et al.*, 1993).

The variety of rice used is the renowned saline tolerant rice cultivar, *pokkali* hence the name, *pokkali* cultivation (Sasidharan, 2006). The term '*Pokkali*' refers to a salt tolerant rice variety largely cultivated in Ernakulam District. *Pokkali* in local language (Malayalam) means the one who stays tall (*Pokkam* = tall and *Ali* = that stays). *Pokkali* Rice has the Status of a Geographical Indication Species by Govt. of India under Section 13 of Geographical Indications of Goods Registration and Protection Act, 1999.

In Kerala, traditional and extensive shrimp culture is in practice and the total area under the traditional farming system is 12,986.6 ha, of which 84 per cent is under *Pokkali* fields. These fields are uniquely concentrated in the central 15 part of Kerala with Ernakulam and Vypeen Island. The farming areas are available in the districts of Kollam, Kottayam, Alappuzha, Thrissur, Malappuram, Kannur and Kasargod (Pillai *et al.,* 2003). *Pokkali* system is followed prominently in the coastal regions of Ernakulum, Alappuzha and Thrissur districts of Kerala state, India. According to recent statistics, there are about 4000 hectares of paddy fields under *pokkali* cultivation in Ernakulam district, while in Alappuzha and Thrissur it extends for about 3000 hectares and 2000 hectares respectively (Joy, 2013).

There had been many studies dealing with the *pokkali* rice - fish / prawn integration system (Panikkar, 1937; Purushan, 1987; Rajendran *et al.,* 1993), which describes different aspects of the integration of prawn culture in the post harvested *pokkali* fields through tidal water and then trapped in short term culture (Panikkar, 1952; Panikkar and Menon, 1956; Gopalan *et al.,* 1980; George *et al.,* 1993; Pillai, 1999). In *pokkali* lands of Kerala, rice is cultivated during the rainy season that lasts from June to October. These fields remain fallow after the harvest of rice and are utilized for traditional types of prawn culture (Tomy *et al.,* 1984). It is observed that *pokkali* fields produce about 1.5 t ha^{-1} of paddy during low saline phase and an equal of prawn and fish during the high saline phase (Purushan, 2002). Studies conducted on the cultivation practices of paddy in *pokkali* lands reveal that *Pokkali, Cheruvirippu, Chettivirippu* etc. were the traditional varieties suitable for cultivating in *pokkali* fields (Sasidharan, 2006). The Rice Research Station at Vytilla, Kochi itself has released high yielding rice varieties viz Vytilla 1 to 9 with built-in tolerance to salinity.

Pokkali rice is cultivated in the month of April with strengthening of outer bunds and setting up of sluices to control the level of water. When the soil is dry, it is heaped up to form mounds of about one meter base and a half meter height. With the onset of monsoon during May - June the salt is washed off from the soil and the water with dissolved salts is drained off from the field. When the soil and weather conditions become favourable for sowing, the mounds in the field are then raked and the top levelled. The sprouted seeds were sown on the top of the

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mounds. The *pokkali* attain a height of 40 - 45cm in 30 – 35 days. At about this stage, when field conditions become favourable the mounds are cut into pieces with a few seedlings and are uniformly spread in the field (Padmaja *et al.,* 1994). Aquatic and semi- aquatic weeds occur in the *pokkali* fields with plenty during the crop season. The crop matures in about 120 days. Harvesting takes place by October end. Only the panicles are cut and the rest of the stalk is left to decay in the water, which in time become feed for the prawns. (Gayatri and Raveendra, 2009)

It is the peculiarity of *pokkali* rice variety that the paddy seedling grows naturally without the addition of any inorganic fertilisers. The rice plants grow up to 2 meters in order to survive in the water logged field and bend over to collapse with only the panicles standing upright (Gayatri and Raveendra, 2009).

Pokkali lands are waterlogged, ill drained area subjected to tidal waves annually. These soils are subjected to tidal influence, soil acidity, salt - water intrusion and flooding consequently affecting the productivity. In these soils, salinity is induced when the influx of salt is greater than efflux, where this balance is maintained by climate, geomorphology etc. (Ponnamperuma, 1984).

The rice – fish / prawn system of *pokkali* replenishes the nutrients continuously, resulting in a sustainable yield of paddy and fish (Purushan, 2002). Rice – fish integration system increases the productivity and profitability of the rice production, meanwhile rendering the production into more organic and environmentally friendly (Padmakumar *et al.,* 2003).

2.2. Characteristics of *pokkali* soils

Pokkali soils are the predominant category among the three types of saline soils recognised yet in Kerala based on the location, extent and intensity of salinity and crop season (Padmaja *et al.,* 1994). Nevertheless, it is the smallest and contributes only 0.88 per cent of the total rice area of the Ernakulum district.

Pokkali lands comprise of low-lying marshes near streams, rivers and other water bodies. Soil characteristics of *pokkali* lands had been reviewed in the works of Padmaja *et al.* (1994). The study conducted on the profile characteristic reveals that the *pokkali* soils of Vytilla belongs to the fine loamy, mixed and iso hyperthermic family in the soil taxonomy and the study also states that it is developed from alluvial deposits (Varghese *et al.,* 1970).

Most of the saline soil of Kerala is acidic with a pH ranging from 3 - 6.8 in spite of high conductivity (Nair and Money, 1968). Majority of these soils has their electrical conductivity values higher than 14 dS m^{-1} (Varghese *et al.,* 1970). During rainy season, water becomes almost fresh, salt content reduces to trace and electrical conductivity ranges between 6-8 dS m^{-1} (Tomy *et al.,* 1984). The fertility and productivity of the *pokkali* soils are mainly regulated by the high and low tide that occurs twice daily (Tomy *et al.,* 1984 and Sasidharan *et al.,* 2004). These tides bring nutrients to the *pokkali* fields and remove the toxic concentration of heavy metals. Tidal influx contributes to the growth of a broad spectrum of beneficial microbes. Padmakumar *et al.* (2002) attributed the concentration of plant nutrients viz nitrates and phosphates in the estuarine location to the tidal influence.

These saline tolerant rice varieties grow well even when water salinity and soil electrical conductivity are less than the values, 6 mg g^{-1} and 6 dS m^{-1} respectively (Shylaraj and Sasidharan, 2005). Only as tall crops, with an expected height of nearly 2 m survives in the area as the fields are waterlogged throughout the year (Nambiar and Raveendran, 2009). The rice seedlings grow without the addition of any fertilizers, hence the productivity of the system is said to be purely organic (Thampy, 2002 and Vanaja, 2013).

Pokkali soils are acid saline in nature influenced by seawater inundation. The pH and electrical conductivity of *pokkali* has shown a decreasing trend during the first half of June, which might be due to the washing of *pokkali* soils during the monsoon and the dilution effect of the southwest monsoon respectively (Ashamol, 2014). According to Silas (1975), there is a high inflow of freshwater

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during the monsoon months, which is extended even far beyond the mouth of the harbour, hence reducing the pH and salinity of the soil.

Pokkali soils maintain medium to high organic carbon level. Total organic carbon in *pokkali* soils was high during the second half of April (before the paddy cultivation) which is attributed by the dead remains of the *pokkali* (Ashamol, 2014) that is in accordance with the conclusion that the premonsoon season is the most favourable time for organic matter accumulation. (Nandan and Abdul Aziz, 1996). The increased carbon content can also be attributed to the reduced temperature during the southwest monsoon.

The carbon storage in the soil increases with increase in precipitation and decrease in temperature, though not beyond a particular level of precipitation (Post W.M. *et al.,* 1982). The trapped dead remains are degraded by numerous micro organisms present in the coastal paddy fields of Kerala (Nambiar and Raveendran, 2009). The value of phosphate and nitrogen has increased in *pokkali* soil with time as the microorganisms' releases phosphate on decomposition of the dead matter (Ashamol, 2014). However, the fertility analysis studies conducted in *pokkali* soils reveals that the soil is deficient in phosphorus at its extreme level (Samikutty, 1977).

2.3. Carbon dynamics of long-term fertilization experiments

Significant changes in SOC and crop yields due to long-term fertilization had been reported in many studies conducted previously (Bhattacharyya *et al.,* 2010; Bi *et al.,* 2009; Diekow *et al.,* 2005; Manna *et al.,* 2007; Zhang *et al.,* 2009a).

Certain studies conducted on red soil indicated that long-term application of manure could increase significant SOC content than other minerals by 10.16 per cent - 21.35 per cent. The farmyard manure could induce high SOC content

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compared to green manure. There are also evidences of SOC enhancement after long-term manure application in paddy field (Yan *et al.,* 2007).

Long-term fertilization under maize – wheat cropping system resulted in a significant increase in total SOC stock. There are studies stating that long-term application of fertilizers ($N_{100}P_{22}K_{42}$) had no deleterious effect on microbial and biochemical soil quality parameters (Tripathi *et al.*, 2008).

Improvement in soil structure can be contributed by liming on a long-term basis (Castro and Logan, 1991). Liming has been reported to increase microbial biomass content and net mineralization of organic N (Badalucco *et al.,* 1992). Geethakumari *et al*., (2011) reported that a decline in active fractions of C and N after long-term cultivation of soil is observed resulting in depletion of soil fertility through reduction of labile sources of nutrients, faster decomposition and lower bio available nutrients.

The combined application of manures and chemical fertilizers has major effects on soil physico-chemical and biological properties, and crop yields (Hou *et al.,* 2012). Application of both inorganic and organic fertilizers maintain soil fertility and productivity by improving water holding capacity, porosity, and water stable aggregation and decreasing bulk density and surface crusting (Shen *et al.,* 2004; Chivenge *et al.,* 2010).

However, there are a number of studies indicating that soil fertility decline with continuous application of inorganic fertilizer without organic inputs (Edmeades, 2003; Graham *et al.,* 2002; Nie *et al.,* 2009). The soil analysis of a study on long-term intensive maize cropping with all straw harvested practiced over 20 years has resulted in great decreases of soil organic carbon (SOC), and a rapid decline of soil fertility and crop productivity (Yu *et al.,* 2006; Xu *et al.,* 2010; Kou *et al.,* 2012).

Many studies have shown that the application of organic manure with inorganic fertilizer in different types of soils can increase the amounts of soil organic carbon (SOC) in the long term (Cai and Qin, 2006; Tong *et al.,* 2009; Lou

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et al., 2011a; Xie *et al.*, 2012). However, chemical fertilization (Lou *et al.*, 2011c) can also affect the carbon sequestration rates in soils besides organic manure (Lou *et al.*, 2011b). Fertilization affects the soil organic carbon pool (Meng *et al.*, 2013). Long-term fertilization has a major affect on Particulate organic carbon (POC) (Galantini and Rosell, 2006).

It is difficult to detect changes in SOC in short term due to slow formation of SOM (Malhi *et al.*, 2011). However, long-term experiments are more useful for studying the changes in soil properties and processes over time (Haynes, R., 1998). Long-term monitoring allows both the identification of current changes in the soil and prediction of future changes (Antil and Singh, 2007). It is well established that inorganic fertilizers serve to maintain or improve crop yields. Their application can induce changes in the physical, chemical and biological properties of soil (Dick *et al.*, 1996). These changes in the long-term are believed to have significant influences on quality and productive capacity of the soil (Acton and Gregorich, 1995). Some studies claim that application of inorganic fertilisers have a diminishing effect on soil quality and productive capacity (Doran *et al.*, 1996; Gregorich *et al.*, 1996; Manna and Swarup, 2000) whereas other studies imply both positive and negative effects (Hera and Mihaila, 1981; Johnston, 1994) and no noticeable changes (Aref and Wander, 1998). These conflicting reports, call for research on the long term effects of inorganic fertilizer application on soil quality and productivity, more particularly on problem soils of the coastal regions where such information are lacking.

2.4. Climate change and carbon sequestration

Climate change has a significant impact on both life and natural resources. It poses a significant economic and environmental risk worldwide (Setegen *et al.*, 2011). There is overwhelming consensus amongst climate scientists that the Earth's warming in recent decades has been caused primarily by human activities that have increased the amount of greenhouse gases (GHGs) in the atmosphere. The main reason of climate change is the greenhouse effect, which leads to a direct and indirect effect. Direct effect leads to a significant change in rainfall intensity and amount along with abrupt change in temperature whereas indirect effect results a change of land use leading to soil erosion, a key element of degradation and loss of carbon flux from the soil (Allison *et al.*, 2006; Brevic, 2012). The United Nation Framework Convention on Climate Change (UNFCCC) as well as the Kyoto Protocol makes clear reference in reducing emissions by sources and removals by sinks in natural systems. Coastal wetlands and marine ecosystems sequester carbon within standing biomass, but even more within soils.

Soil act as a key element that stores the carbon and after erosion carbon escapes to the atmosphere which results in further increase in green house gases. Recent studies have suggested that soil erosion and sediment movement have important influences on carbon sequestration potential in soils and ecosystems (Smith *et al.,* 2001; Lal, 2005). "According to the IPCC second assessment report, over the course of the next 50-100 years, it may be possible to restore about two third of the estimated 55pg C lost to the atmosphere through cultivation of agricultural soils" (Cole *et al.*, 1996).

Soil carbon sequestration is the transfer of carbon dioxide from the atmosphere to the soil into a form that is not immediately reemitted and this process is mainly carried out through the crop residues and other organic solids. Thus, the soil serves to be the largest terrestrial stock of carbon (Biswas *et al.*, 1991). The sequestration of carbon minimises the emission from fossil fuel combustion and other carbon emitting activities while enhancing soil quality and long term agronomic productivity (Lal, 2004).

There are many factors that contribute to the loss of soil carbon stock. The components of the climate, precipitation and temperature are of prime importance of soil processes (Heinemann and Reichstein, 2008). Climate change is expected to have several effects on the soil system. Changes in atmospheric concentrations of CO_2, temperature, precipitation amounts and its pattern will modify the soil - plant system and influence decomposition rates, which will have impacts on soil organic carbon levels. Organic carbon in turn has a significant influence on soil 22 structure, soil fertility, microbial processes and populations in the soil, and other important soil properties.

It is widely believed that increase in temperature due to global climatic change will decrease the organic matter content of soils and increase the emission of greenhouse gases in the atmosphere (Jones *et al.*, 2005). Increased temperature is likely to have a negative effect on carbon allocation to the soil, leading to reductions in soil organic carbon and creating a positive-feedback in the global carbon cycle as global temperature rise (Gorissen *et al.*, 2004; Wan *et al.*, 2011). Temperature and precipitation is closely associated with SOC turnover. On a global scale mineralization of SOC has a positive correlation with rising temperature and negative correlation with increasing precipitation. This is illustrated by the fact that the amount of SOC is positively correlated with increasing latitudes from about 30^0 (Smith & Smith 2006). There is a strong relation between climate and soil carbon pools where organic carbon content decreases with increasing temperatures, because decomposition rates doubles with every 10^oC increase in temperature (Schlensinger, 1997).

2.5. Carbon sequestration of wetlands

Being potential carbon (C) sinks due to their ability to accrete matter in the soil and sediment, wetlands are one of the most efficient ecosystems for storing soil carbon (Schlensinger, 2003). It is estimated that wetlands contain nearly 350-535 Gt C, corresponding to 20-25 per cent of world's soil organic carbon (Gorham, 1998).

Rapid decomposition and immediate release of C to the atmosphere especially from paddy fields limits the long-term storage of C in the soil. The balance between carbon input, output and the resulting storage is maintained by certain factors such as the topography and the geological position of wetland; the hydrological regime; the type of plant present, the temperature and moisture of the soil, pH and the morphology (Adhikari *et al.,* 2009). According to findings of certain studies conducted in Costa Rica and Ohio, tropical wetlands store 80 per cent more carbon than temperate wetlands (Bernal, 2008). Comparison of various wetland types reveals that peat land is highly important for carbon storage since it accounts for nearly 50 per cent of the terrestrial carbon storage with only 3 per cent cover of world's land area (Guo, 2007). Post *et al.,* (1982) reported that though wetlands cover only a total land area of 280 million ha worldwide, the average carbon density in the wetland is 723 t ha^{-1} which amounts to 202.44 billion tonnes of carbon in the whole wetlands of the world.

CHAPTER 3

MATERIALS AND METHODS

The present study was focussed on the assessment of carbon dynamics of *pokkali* soil under long-term fertiliser application in rice. Soil samples were collected from the plots of permanent manurial trial experiment (PMT) conducted since 1979 at Rice Research Station Vytilla, Kerala Agricultural University, Kerala. The study was conducted at Rice Research Station, Vytilla during the year 2015 - 2016.

3.1 Study location

A 37 year ongoing permanent manurial trial (PMT) on *pokkali* rice at Rice Research Station Vytilla, Kerala Agricultural University, Ernakulum district Kerala (N $9^{0}58'01.20''$ and E $76^{0}19'00.33''$) was selected for this study on assessment of carbon dynamics of acid *pokkali* soil under long term fertiliser application treatment in rice.

Ernakulum district has wet monsoon type of climate, experiencing heavy rainfall during southwest monsoon season (June-August) followed by northeast monsoon (September-March). Rainfall is considerably less during the other months of the year. The annual average rainfall ranges from 3233 mm to 3456 mm at different places of the district. The major part of the rain is received during the month of June, July and August during the southwest monsoon season. The southwest monsoon season contributes nearly 67.4 per cent of the total rainfall of the year, followed by the northeast monsoon, which contributes nearly 16.6 per cent and the balance of 16 per cent is received during the month of January to May as summer/pre monsoon showers. The maximum temperature is noticed during March and April months and the minimum temperature during December and January months. The maximum humidity is observed during May to October months (Irrigation department, Kochi, 2009).

The layout of the permanent experimental plot from which the soil samples were collected is shown in Figure 1. The experiment was laid out in a randomized block design with 10 treatments, each replicated four times with *pokkali* rice variety Vytilla 4. Each plot is of size 20 m^2, surrounded by 25 cm high soil bunds to prevent run-off.

The treatments consisted of nine plots with fertilizer treatments and one non-treated control plot (no fertilizer application). The control plot was introduced for the purpose of comparison of the parameters of observation. The fertilizer treatments included in the plots are detailed in Table 1. The N, P and K were supplied as urea, rock phosphate and muriate of potash, respectively.

R1	R2	R3	R4
T6	T3	T8	T2
T7	T4	T4	T9
T9	T2	T3	T6
T5	T9	T1	T4
T2	T5	T2	T10
T3	T1	T9	T8
T10	T10	T6	T1
T8	T8	T10	T7
T4	T7	T7	T5
T1	T6	T5	T3

Figure 1: Layout of the permanent experimental plot

Table 1: Treatment details of the experiment

TREATMENT CODE	TREATMENTS
T1	Control (no fertilizer)
T2	20 kg N ha^{-1}
T3	40 kg P ha^{-1}
T4	N and P at 20:40 kg ha^{-1}
T5	N, P and K at 20:40:20 kg ha^{-1}
T6	NPK 20:40:20 kg ha^{-1} + lime 1000 kg ha^{-1}
T7	NP 20:40 kg ha^{-1} + lime 1000 kg ha^{-1}
T8	P 40 kg ha^{-1} + lime 1000 kg ha^{-1}
T9	NPK 20:40:20 kg ha^{-1} (N as urea mud ball)
T10	NPK 20:40:20 kg ha^{-1} (N as neem coated urea)

Plate 1: Dried *pokkali* rice field during high saline phase (April - May)

Plate 2: Mounds prepared for sowing

Plate 3: Sowing of germinated seeds on the mounds

Plate 4: Field after fertiliser application

Plate 5: Rice seedling on mounds

Plate 6: Rice seedlings before transplantation

Plate 7: Transplantation of the rice

Plate 8: Transplanted rice

3.2. SOIL COLLECTION AND ANALYSIS

Two soil samples from each of the four replicated plots from the respective treatments were collected from two depths 0-15 cm, 15-30 cm during early May before cropping. Soils from each plot were pooled together to obtain one composite sample. Altogether 80 field moist soil samples were collected. Samples were air dried, ground to fine powder by using mortar, sieved and stored in airtight polythene bags for analysis of physical, chemical and biological properties. Microbial biomass carbon of soils was measured with the field moist soil and physico-chemical properties of soil were determined with air-dried soils.

3.3. SOIL QUALITY PARAMETERS

Table 2. Analytical methods of soil quality parameters

Parameters	**Method**	**Reference**
Soil pH	Potentiometric method	Jackson, 1958
Soil bulk density	Core method	Dakshinamurthy and Gupta, 1968
Total N	Kjeldhal method	Jackson, 1958
Available phosphorus	Bray's method	Bray and Kurtz, 1945
Available potassium	Morgan's extraction method	Jackson, 1958
Cation exchange capacity	$BaCl_2$ extraction method	Hendershot and Duquette, 1986
Soil organic carbon	Wet digestion method	Walkley and Black, 1934
Organic carbon fraction	Wet oxidation method	Chan *et al.*, 2001
Particulate organic carbon	Sodium hexa-meta phosphate dissolution method	Cambardella and Elliot, 1992
Potential carbon mineralisation	Alkali trap method	Anderson J.P.E., 1982
Microbial biomass carbon	Chloroform fumigation and extraction method	Jenkinson and Powlson, 1976
Aggregate stability	Wet sieve method	Yoder, 1936
Carbon lability index	C labile / C non-labile (CL/CNL)	Blair *et al.,* 1995
Carbon pool index	Sample total C / Reference total C	Blair *et al.,* 1995
Carbon turnover	PCM/SOC	Prior *et al.*, 2008

3.4. DETAILS OF THE ANALYSIS

3.4.1. Physical characterisation

3.4.1.1. Soil bulk density

Samples collected from the plots at two different depths (0-15 cm and 15-30 cm) were dried to a constant weight in an oven at 105°C. The bulk density of soil was calculated as the ratio of the mass of the dry soil to the total volume of soil.

3.4.2. Chemical characterisation

3.4.2.1. Soil pH

The pH of the wet soil was determined in a 1:2.5 soil water suspension potentiometrically using a pH meter.

3.4.2.2. Aggregate stability

Aggregate analysis was carried out by Yoder's wet sieving method (Yoder, 1936). Soil samples (50 g) was placed in the top of the sieves having openings of 5.0, 2.0, 1.0, 0.5 and 0.25 mm diameter and wet sieved in Yoder's apparatus for 30 minutes. The fractions retained on each sieve were transferred and dried to a constant weight at 105°C and the mean weight diameter (MWD) was calculated by the formula (Bavel ,1949) .

Mean weight diameter $= \Sigma d_i \times w_i$

Where d_i and w_i are the mean diameter in each size fraction and proportion of the total sample weight respectively.

3.4.2.3. Cation exchange capacity

The cation exchange capacity in the soil was estimated by the method proposed by Hendershot and Duquette (1986). The cations (Ca, Mg, Na, K, Al, Fe, Mn, Cu, and Zn) present in the exchangeable sites in the soil were replaced by 0.1 M $BaCl_2$ solution and cations in the extract were estimated. Four gram of soil sample was taken in a centrifuge tube and 40 ml of 0.1 M $BaCl_2$ was added .It was shaken for two hours and filtered through Whatman No. 42 filter paper. The filtrate was used for aspiration in Atomic Absorption Spectrophotometer for the determination of exchangeable Ca, Mg, Na, K, Al, Fe, Mn, Cu and Zn. Exchangeable Na and K were estimated with the help of flame photometer. Exchangeable Al was determined colorimetrically using aluminium acetate buffer (Hsu, 1963) with the help of a spectrophotometer. The sum of exchangeable cations expressed in C mol (P+) kg^{-1} was recorded as cation exchange capacity of the soils.

3.4.2.4. Available phosphorus

Available phosphorus in soil was extracted using Bray No 1 reagent (Bray and Kurtz, 1945) and estimated colorimetrically by reduced molybdate ascorbic acid blue colour method (Watanabe and Olsen, 1965) using a spectrophotometer.

3.4.2.5. Available potassium

Available potassium in soil was extracted using neutral normal ammonium acetate and its content in the extract was estimated by flame photometry (Jackson, 1958)

3.4.3. BIOLOGICAL CHARACTERISATION

3.4.3.1. Organic carbon

Organic carbon was estimated by wet digestion method (Walkley and Black, 1934)

3.4.3.2. Organic carbon fractions

3.4.3.2.1. Fraction 1 (F1) - labile fraction

Organic carbon oxidizible under 5 ml. H_2SO_4, apart from the 20 ml H_2SO_4 required for the Walkley and Black method of SOC determination corresponds to the labile fraction of organic carbon.

3.4.3.2.2. Fraction 2 (F2) - Recalcitrant fraction

The difference in oxidizible organic carbon extracted between 20 and 15ml H_2SO_4, apart from the 20 ml H_2SO_4 required for the Walkley and Black method of SOC determination corresponds to the recalcitrant fraction of organic carbon.

3.4.3.3. Microbial biomass carbon

Microbial biomass carbon in soil was estimated by chloroform fumigation and extraction method. For this, five sets of 10 g soil samples were taken, one set kept in an oven for the determination of moisture gravimetrically at 105^0C. Two sets were kept in a vacuum desiccators containing ethanol free chloroform for 24 hrs after the creation of vacuum using the vacuum pump. Then from the fumigated and non-fumigated samples, organic carbon was extracted using 0.5M potassium sulphate. To the 10 ml extract 0.2 m potassium dichromate, concentrated sulphuric acid and ortho phosphoric acid were added and kept on a hot plate at 100^0c for half an hour under refluxing condition. After that, 250 ml water was added and titrated.

3.4.3.4. Potential carbon mineralisation

40 g of soil was moistened with water to field capacity and placed in 1L jar containing vials with 5ml of 0.5 N NaOH to trap evolved CO_2 and 20 ml of water to maintain the humidity. Soils were incubated at 21°C for one hour. After 1 hr NaOH was removed from the jar and MBC concentration was determined by measuring CO2 absorbed in NaOH, which was back titrated with 1.5 mol L^{-1} $BaCl_2$ and HCL.

3.4.3.5. Particulate organic carbon

10 g of soil were dispersed in 50 ml of sodium hexametaphosphate and shaked for 16 hours. The dispersed solution was sieved and then collected the material retained on the sieve into a container and dried at 60^0C to constant mass and weight. The matter oozed out was collected separately and then SOC was analysed

3.4.3.6. Carbon lability index

It is the ratio of carbon labile (C_L) to the carbon non-labile (CNL) of the soil.

$$\text{LI per cent} = C_L/C_{NL}$$

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3.4.3.7. Carbon pool index

Carbon pool size index (CPI) was calculated as per Blair *et al.* (1995). It is the ratio of SOC of the sample to the SOC of the reference soil, which is the uncultivated soil.

CPI per cent = SOC sample / SOC reference

3.4.3.8. Carbon turnover

Carbon turnover was calculated as per Prior *et al.* (2008). It is the ratio of potential carbon mineralization (PCM) to total soil organic carbon (SOC). C turnover is unit less.

C turnover = PCM/SOC

3.5. STATISTICAL ANALYSES

The data recorded from the field experiment was analysed statistically using analysis of variance technique. Randomised block design was used in the analysis of weather and soil data.

Correlation and regression analysis were done between the yield parameters with the weekly mean values of maximum temperature, minimum temperature and rainfall to determine the effect of weather elements on the yield characters of *pokkali*. Correlation and regression were also carried out between certain soil parameters also. Regression equations were worked out from these observations. The different statistical software like Microsoft – excel and SPSS were used in the study for various statistical analyses.

CHAPTER 4

RESULTS AND DISCUSSION

Soil samples were analysed for the assessment of carbon dynamics of acid saline soil and to assess the effect of long-term fertilisers on the carbon dynamics of the soil. The results of the study are presented below.

4.1. Climatology of the location

Trend analyses of mean maximum and minimum temperature of Ernakulum for 10 years (2004 - 2014) is presented in Fig. 2 and Fig. 3 respectively. Analysis of mean maximum temperature data of past ten years reveals that there is an increase in the maximum temperature of the region. The temperature has increased from 30.1^{0}C in 2004 to 31.5 ^{0}C in the year 2014. Whereas, the mean minimum temperature does not follow an increasing trend. However, it is evident from the figure that the year 2012 has been marked with highest minimum temperature. The year 2012 were recognised as the warmest year.

The mean monthly rainfall data of the region is depicted in Fig. 4. Even though higher amount of rainfall is obtained during the southwest season as expected, a similar trend was not followed, when yearly data was considered. The year 2012 being warmest have showed a decreased rainfall during the respective year. However, no significant correlation was obtained for rainfall either with maximum temperature or with minimum temperature.

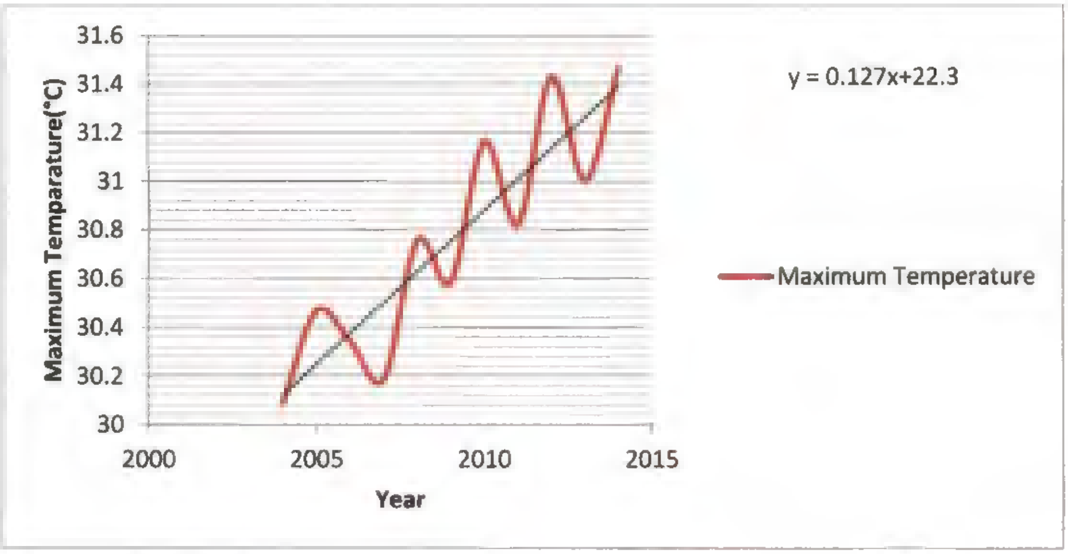

Fig 2: Mean maximum temperature (^{0}C) of the region (2004 - 2014)

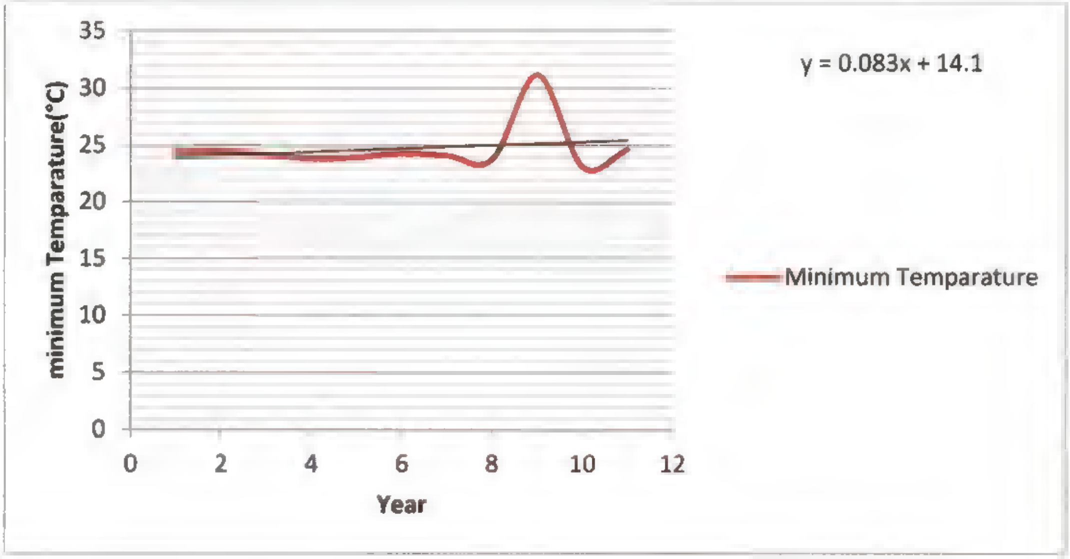

Fig 3: Mean minimum temperature (^{0}C) of the region (2004 - 2014)

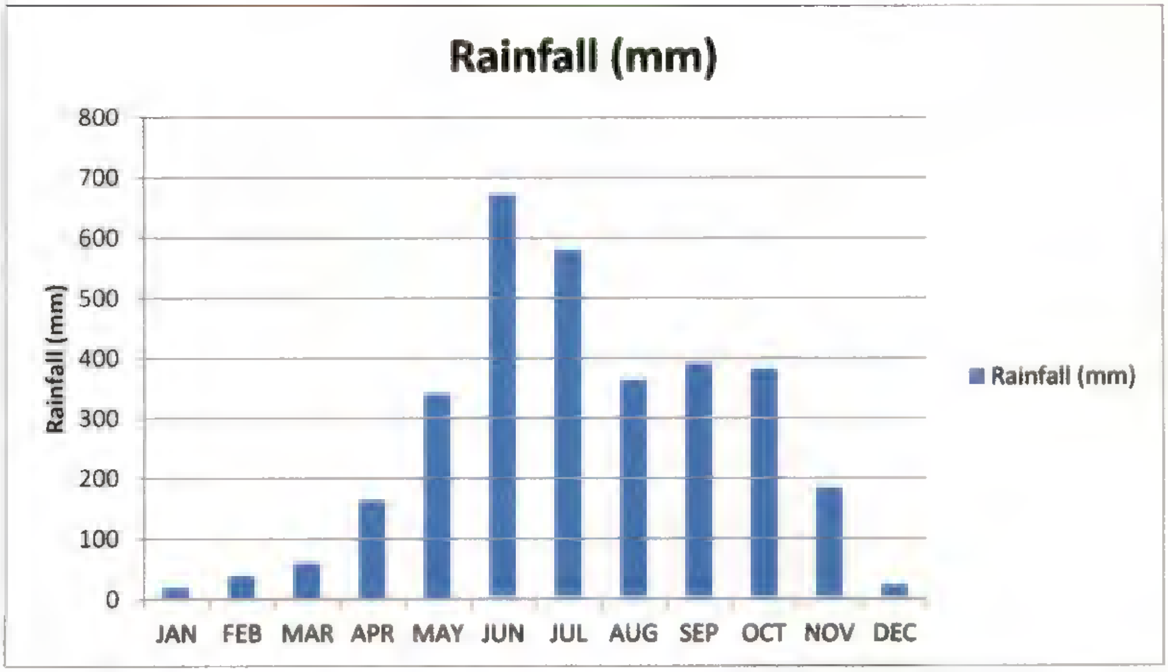

Fig 4: Mean monthly rainfall (mm) of past 10 years (2004 - 2014)

4.1.1 Weather influence on the grain yield of rice

The influence of weather on the grain yield of pokkali rice variety was studied for five years. The yield varied insignificantly among treatments irrespective of the treatments applied.

Heavy rainfall during the growth stages of pokkali would have affected the yield of the crop. The grain yield showed a strong significant positive correlation with rainfall (0.593, 0.509, 0.391, 0.413, 0.427, 0.397), maximum temperature (0.655, -0.547, 0.424, -0.547, -0.492, -0.385, -0.555) throughout its growth stages.

Correlation matrices were developed for pokkali rice variety by using pooled data of the yield and weather parameters (Appendix 2), which concluded that the yield is highly correlated with weather parameters. Yield was estimated using multiple regression models.

$$\text{Yield} = 27.597 + 55.414\, T_{max3} - 48.721 T_{min25} + 2.388 RF_{17}$$

T_{max3} - maximum temperature (^{0}C) - week 3

T_{min25} - minimum temperature (^{0}C) - week 25

RF_{17} - Rainfall - week 17

Table 3: Grain yield (kg ha^{-1}) of pokkali in PMT (pooled mean of 2000 - 2014)

TREATMENTS	YIELD (kg ha^{-1})
T1	3025.7
T2	2828.2
T3	3091.1
T4	2743.2
T5	2704.6
T6	2619.1
T7	2594.2
T8	2809.2
T9	2503.1
T10	2581.6

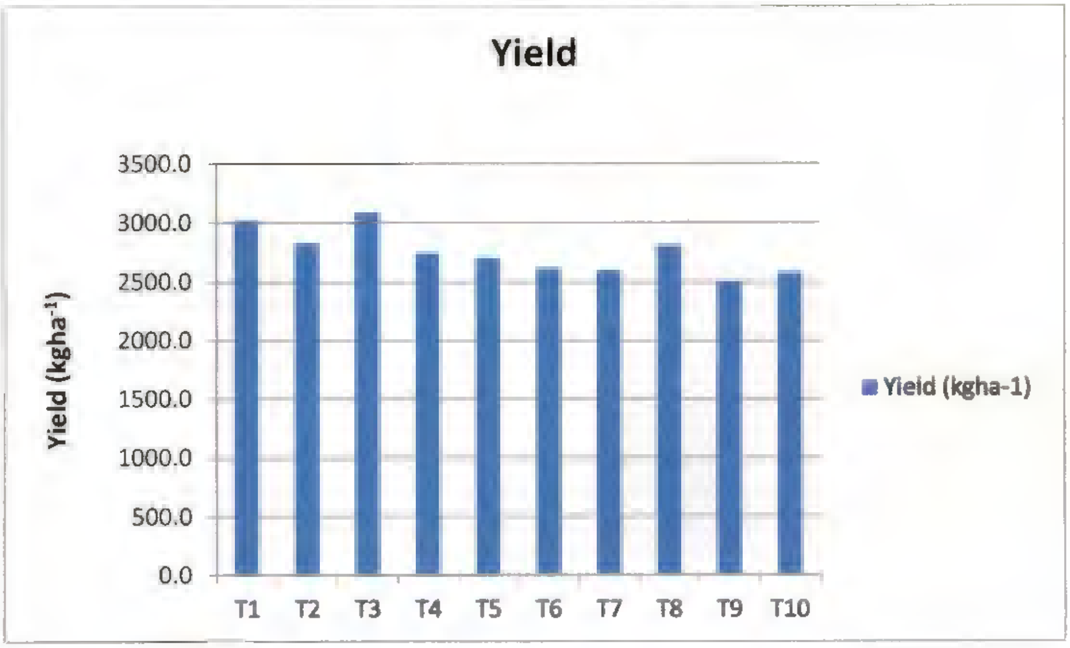

Fig 5: Grain yield of rice (pooled mean 2000 - 2014)

4.2. SOIL PHYSICAL ATTRIBUTES

4.2.1. Bulk density

The bulk density value varied from 0.66 Mg m^{-3} to 0.79 Mg m^{-3} and 0.70 Mg m^{-3} to 0.83 Mg m^{-3} at depths 0 - 15 cm and 15 - 30 cm respectively without any significance among the treatments (Table 4). The control plot with no fertiliser application has the bulk density value of 0.71 Mg m^{-3} and 0.83 Mg m^{-3} at depths 0 - 15 cm and 15 - 30 cm respectively. At the depth 0 - 15 cm treatment T10 with treatment NPK (Nitrogen as neem coated urea) showed the least value which may be attributed to the high organic matter content due to the presence of neem cake and a resulting changes in the compaction of soil particles. The highest value of bulk density at a depth of 0 - 15 cm was observed in the plot T3 with phosphorus treatment.

Chris (2014) reported that the bulk density of *pokkali* soils were low due to the organic matter content. Manure combined with chemical fertilizer produced a lower soil bulk density compared with chemical fertilizer only and no fertilizer (Hou *et al.*, 2012). Sasidharan (2004) and Chris (2014) reported a bulk density value of 0.67 Mg m-3 and 0.71 Mg m-3 respectively for *pokkali* soils of RRS, Vytilla. Hati *et al.*, (2006) observed that application of organic manure significantly reduced the bulk density of the soil at 0-30 cm depth.

Fig 6 shows the mean value of bulk density for different treatments. It is observed that bulk density was more at subsurface layer than at the surface layer attributing to the compaction of subsurface layer.

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Table 4: Mean value of bulk density (Mg m^{-3}) for different treatments

TREATMENTS	DEPTH	
	0- 15 cm	**15-30 cm**
T1	0.71	0.83
T2	0.75	0.76
T3	0.79	0.78
T4	0.76	0.80
T5	0.76	0.78
T6	0.77	0.79
T7	0.77	0.79
T8	0.76	0.75
T9	0.76	0.70
T10	0.66	0.77

0 - 15 cm P = 0.077; 15-30 cm P = 0.750

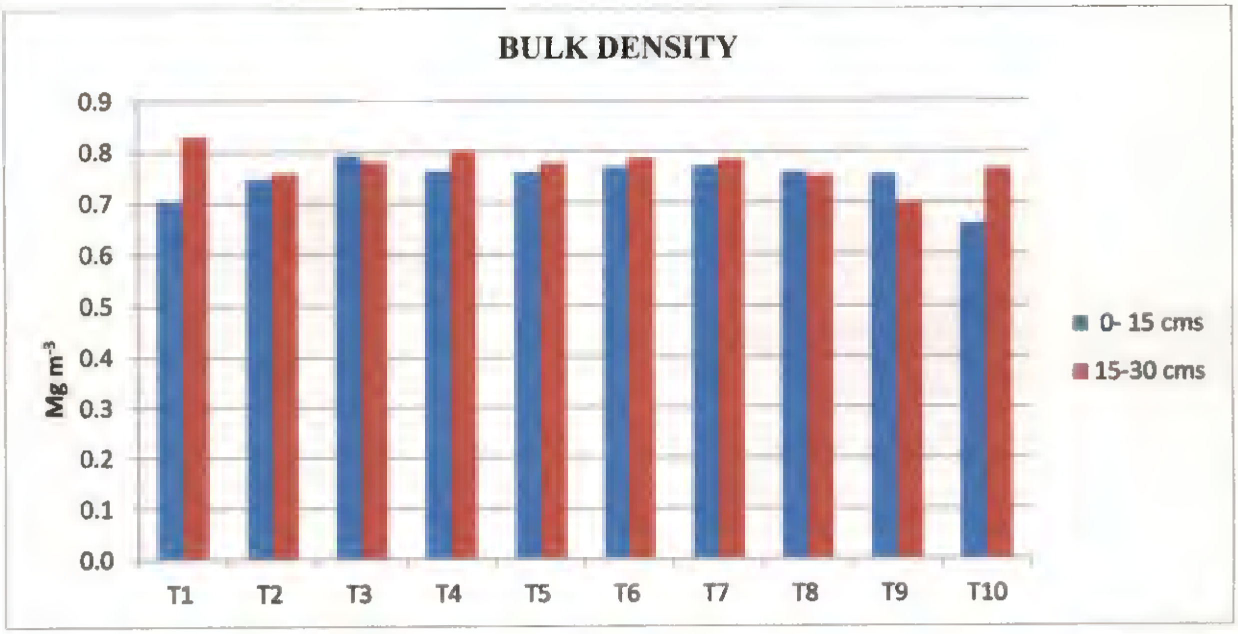

Fig 6 : Mean value of bulk density (Mg m^{-3}) for different treatments

4.3. SOIL CHEMICAL ATTRIBUTES

4.3.1. Soil pH

The pH values observed ranged from 3.3 to 3.8 at the depth 0 - 15 cm and 3.4 to 4.0 at 15 - 30 cm among different fertilizer treatments after 37 years (Table 5). In the present study, it was noticed that the soil was extremely acidic. This agrees with the observations made by Tomy *et al.*, (1984).

The treatment T8 (P 40 kg ha$^{-1)}$ along with lime 1000 kg ha^{-1}) has a higher value at both depths whereas the control plot shows the least values of pH. On comparison, higher values were observed for the treatment supplied with lime (T6, T7, T8) at both depths.

Aryalekshmi (2016) reported that *pokkali* soils are extremely acidic in nature. The studies reported that the pH of *pokkali* soils varied from 3.10 to 5.80 (Padmaja, 1994). Nair and Money (1972) reported that the soil pH ranged from 3 to 6.8 in the *pokkali* wetlands of Ernakulam district, Kerala. Tomy *et al.* (1984) reported that *pokkali* soils are acid saline in nature. The acid release from the sulphuric horizon might be the reason for the acidity of the soil.

Fig 7. Shows the mean values of pH of different treatments. In all the cases, the soil remained in an extremely acidic condition.

A higher value of pH is observed at 15 - 30 cm depth than at 0 - 15 cm depth. This may also be due to the percolation of the saline water. As soil samples were collected during early May, the salts and trace elements remained in the top of the soil profile that will be washed away later during submergence period caused due to rain.

Table 5: Mean value of pH for different treatments

TREATMENTS	DEPTH	
	0- 15 cm	15-30 cm
T1	3.3	3.4
T2	3.4	3.4
T3	3.6	3.5
T4	3.5	3.5
T5	3.3	3.8
T6	3.5	3.7
T7	3.7	3.8
T8	3.8	4.0
T9	3.5	3.6
T10	3.5	3.4

0 - 15 cm P = 0.125; 15-30 cm P = 0.289

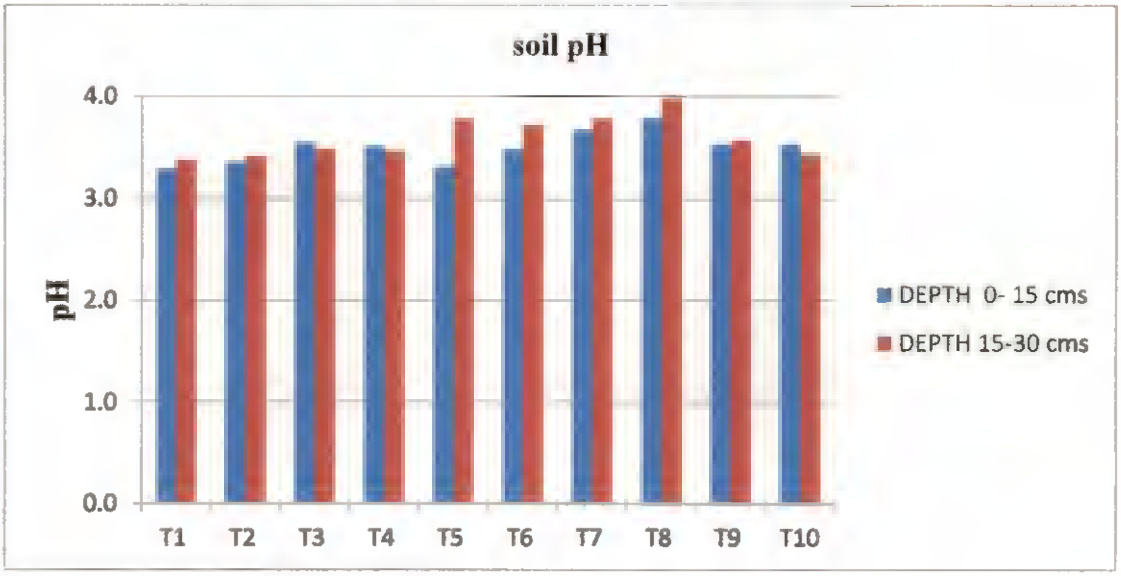

Fig 7: Mean value of pH for different treatments

Indraratna *et al.* (2002) reported that the increasing pH involved in the process of seawater inundation is due to the supply of bicarbonate alkali of seawater causing the neutralization of acidity and immobilisation of trace elements.

However, long-term application of chemical fertilizers did not show any significant variation in pH of soils at both depths, which conforms to Goyal *et al.* (1999) which may be due to high buffering capacity of the soils.

4.3.2. Cation exchange capacity

The mean values of cation exchange capacity showed a variation from 9.9 to 12.7 C mol (P^+) kg^{-1} (Table 6). The cation exchange capacity value varied significantly among different treatments. At surface higher value of CEC was observed for the treatment T8 (P along with lime) and lower value was observed for control plot. A similar trend was observed for the subsurface layer of the plots.

Chris (2014) reported cation exchange capacity value of 9.5 C mol (P+) kg^{-1} pokkali soil of RRS Vytilla. Higher value of CEC was recorded for surface than for subsurface soil confirming with the study of Varghese *et al.* (1970). Higher value of exchangeable Na and K was observed, which might be contributed by the salts of seawater.

Cation exchange capacity varied proportionately with pH. Under acidic condition, CEC value reduced considerably. The correlation coefficient (r) values for CEC and pH were 0.90, concluding that 81 per cent of variation in CEC could be explained by the acidity (Appendix 3).

Table 6: Mean value of CEC (C mol (P^{+}) kg^{-1}

TREATMENTS	DEPTH	
	0-15 cm	15 -30 cm
T1	9.90	6.70
T2	11.35	6.73
T3	12.53	7.00
T4	11.67	6.98
T5	10.87	7.85
T6	11.61	7.32
T7	12.74	7.85
T8	13.50	9.79
T9	12.17	7.03
T10	11.87	6.78

0 - 15 cm $P = 0.003$; 15-30 cm $P = 0.006$

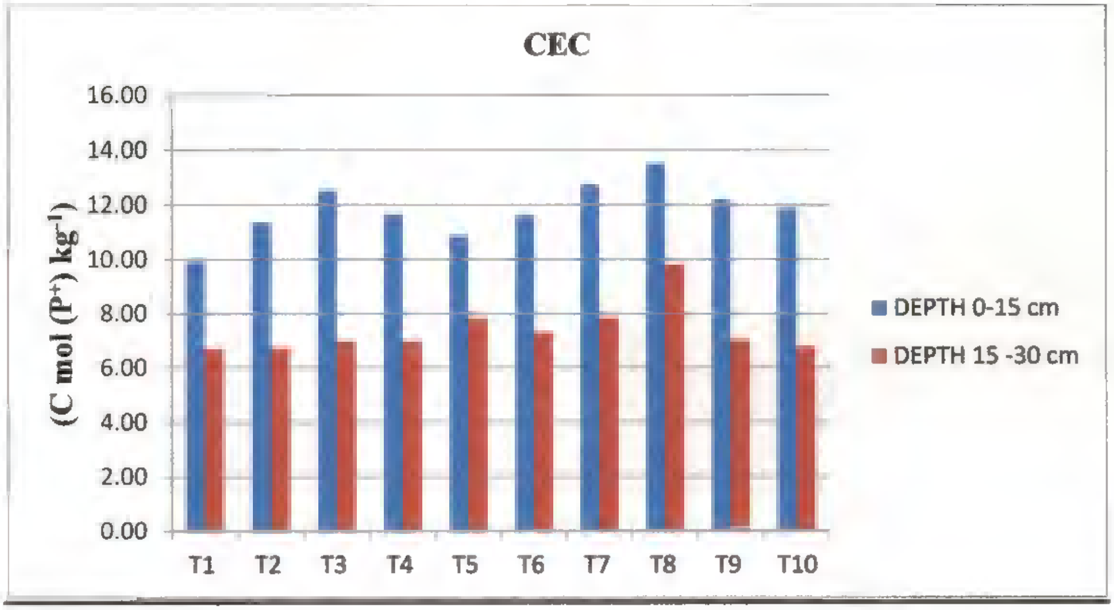

Fig 8: Mean value of CEC (C mol (P^{+}) kg^{-1})

4.3.3. Available phosphorus

Available phosphorous showed a high fertility status and have a significant variation among the treatments. The available phosphorus in *pokkali* soil ranges from 33.25 to 81.38 kg ha^{-1} and 49.06 to 79.94 kg ha^{-1} at 0 - 15 cm and 15 - 30 cm respectively (Table 7). The mean value of the available phosphorus is presented in fig 9. At a depth of 0 - 15 cm the value of available phosphorous was low for the treatment T2 with N application and higher value for treatment T4 with combined treatment of N and P. However, at the depth of 15 - 30 cm a less availability of phosphorous is observed in treatment T5 applied with NPK and highest value in treatment T10 with NPK along with neem cake treatment.

The value of available phosphorus content of *pokkali* soil was found to be 64.96 kg ha^{-1} in a study conducted by Aryalekshmi (2016). Chris (2014) observed a value 81.14 kg ha^{-1}, for the available phosphorous in *pokkali* soil. The high value of available phosphorus may be attributed to the acidic characteristic of *pokkali* soil. The control plot has a value of 74.06 kg ha^{-1} and 61.56 kg ha^{-1} at 0 - 15 cm and 15 - 30 cm respectively. When the soil is submerged, reduction occurs, as the pH of acid soil attains near neutrality the availability of P will be maximum at near neutral pH (Chris, 2014).

4.3.4. Available Potassium

The available potassium content differed significantly among the treatments at two depths. The values varied between 488.6 kg ha^{-1} to 693.28 kg ha^{-1} at 0 - 15 cm and 75.04 kg ha^{-1} to 268.80 kg ha^{-1} at 15 - 30 cm depth (Table 8). The mean value of available potassium is represented in Fig 10. The maximum value at a depth of 0 - 15 cm was observed for the treatment T5 with NPK treatment where N as neem coated urea and at 15 - 30 cm depth the maximum value was obtained for control plot. The minimum value of 488.60 kg ha^{-1} was obtained at 0 - 15cm for the tratment with N treatment and the value 75.04 kg ha^{-1} at 15 - 30 cm for treatment T3 applied with P treatment.

Higher value may be due to the presence of salt at the surface layer due to the saline water intrusion as the sample was collected during high saline phase.

Sasidharan (2004) noticed that the tidal action significantly contributes towards increased soil potassium of the *pokkali* wetland at Vytila, Ernakulam district. Available potassium in *pokkali* soil varied between 13 and 1777 kg ha^{-1}. (Anilkumar and Annie, 2010).

4.3.5. Total Nitrogen

The total nitrogen percentage of *pokkali* soil obtained during the analysis was not significantly different across the depths 0 - 15 cm and 15 - 30 cm. The values varied between 0.26 per cent to 0.28 per cent at 0 - 15 cm and 0.22 per cent to 0.26 per cent at 15 - 30 cm depth (Table 9). The mean value of total nitrogen is represented in Fig.11. Higher per cent of total nitrogen was observed at surface layer whereas sub surface layer marked a lower value. The treatments T3 and T7 marked higher percent at surface layer and T9 recorded higher total nitrogen at subsurface layer.

The C: N ratio of pokkali soil at RRS Vytilla is observed to be 11:1 indicating the presence of undecomposed organic matter, which may be, attributed for the decreased OC per cent at lower depths.

Irene (2014) has observed a C N ratio of 9:1 for pokkali soil of RRS, Vytilla.

However, fertiliser application does not have a significant effect on the total N of the soil.

Table 7: Mean value of available phosphorous (kg ha^{-1}) for different treatments

TREATMENTS	**DEPTH**	
	0- 15 cm	**15-30 cm**
T1	74.06	61.56
T2	33.25	52.50
T3	65.44	79.94
T4	81.38	55.25
T5	53.44	55.88
T6	60.56	54.13
T7	73.63	80.19
T8	83.19	60.38
T9	71.31	49.06
T10	75.88	82.00

0 - 15 cm P = 0.000; 15-30 cm P = 0.000

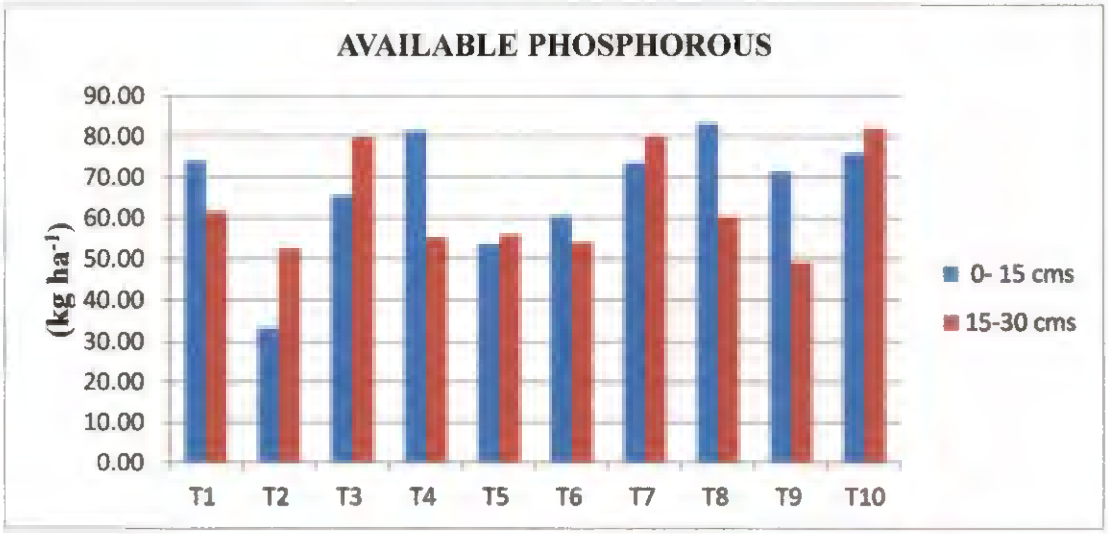

Fig 9: Mean value of available phosphorus for different treatments

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Table 8: Mean value of available potassium (kg ha^{-1}) for different treatments

TREATMENTS	DEPTH	
	0- 15 cm	**15-30 cm**
T1	545.75	268.80
T2	488.60	168.56
T3	499.80	75.04
T4	514.92	126.84
T5	642.32	106.12
T6	530.04	122.08
T7	558.60	116.76
T8	522.20	116.76
T9	635.04	112.84
T10	693.28	83.44

0 - 15 cm P = 0.019; 15-30 cm P = 0.000

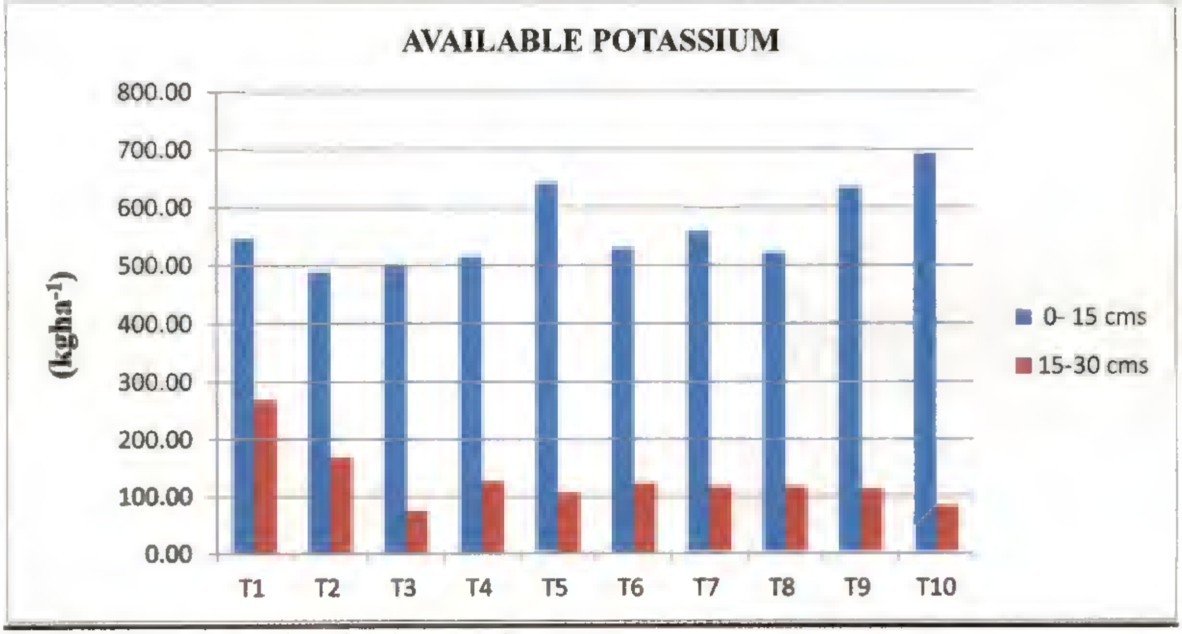

Fig 10: Mean value of available potassium

Table 9: Mean value of nitrogen (per cent) for different treatment

TREATMENTS	**DEPTH**	
	0- 15 cm	**15-30 cm**
T1	0.26	0.23
T2	0.27	0.23
T3	0.28	0.25
T4	0.26	0.22
T5	0.26	0.22
T6	0.27	0.23
T7	0.28	0.23
T8	0.26	0.22
T9	0.26	0.26
T10	0.27	0.23

0 - 15 cm P = 0.830; 15-30 cm P = 0.431

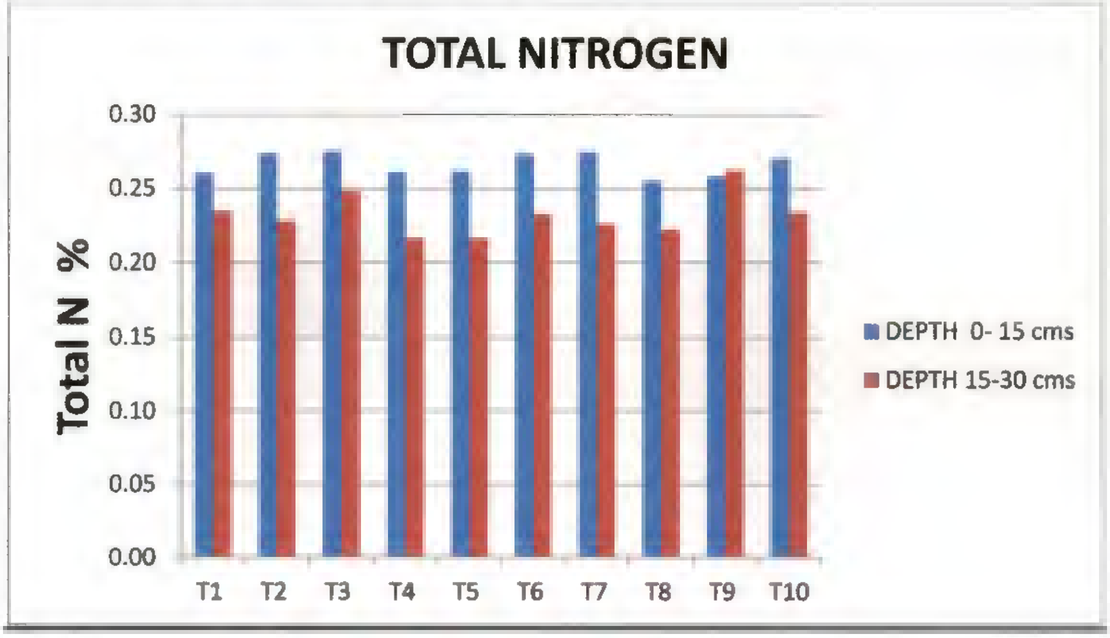

Fig 11: Mean value of available nitrogen (per cent) at two depths

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4.3.6 **Aggregate stability**

The distribution of water stable aggregates in acid saline pokkali soils of permanent experimental plots varied significantly between different aggregates size, treatments and depths (Table 10).

In surface soils (0 - 15 cm) the water stable aggregates of 2 - 5 mm dominated over other sizes. It was followed by aggregates of 1.0-2.0 mm and then 0.5-1.0 mm sized aggregates. The content of 2 - 5 mm and 1.0-2.0 mm sized aggregates were almost same.

As the depth increased from 0 - 15 to 15 - 30 cm, the percentage of smallest aggregates increased by more than two times at the expense of a tremendous decrease in aggregates of higher size.

It is observed that as the depth increased the amount of smaller aggregates increased. The treatments under study also showed variation in the amount of differently sized aggregates in soils from different depths although they do not follow any trend. The results showed that the surface soil contained the higher amount of larger aggregates and the amount suddenly decreased to the minimum level with increasing depth.

The higher values found in surface soils may be due to the adhesiveness of higher organic carbon. The larger aggregates steadily decreased with depths showing a good relation with organic carbon percentage. The aggregate stability depends on the interaction between the primary particle and organic constituents to form the stable aggregate, which is influenced by various factors related to soil environmental conditions and management practices (Ayoubi et al., 2011).

Table 10: Mean value water stable aggregates (per cent) for different treatment

DEPTH	TREATMENTS	AGGREGATES					MWD = Σd_i x w_i
		<0.25	0.25-0.5	0.5-1	1.0-2.0	2.0-5.0	
0 - 15 cm	T1	4.88	2.62	7.37	26.28	23.75	64.89
	T2	5.32	2.11	4.49	29.53	26.15	67.60
	T3	5.06	2.02	4.98	29.30	30.40	71.76
	T4	4.78	1.92	3.65	32.46	35.93	78.73
	T5	4.56	2.30	4.37	34.58	27.48	73.28
	T6	4.37	2.43	4.65	31.23	37.08	79.74
	T7	3.46	2.07	5.27	33.78	38.03	82.60
	T8	3.70	2.22	4.91	36.93	35.98	83.72
	T9	3.41	2.10	5.39	36.57	42.45	89.92
	T10	4.45	2.24	3.59	33.03	37.38	80.68
15 - 30 cm	T1	10.70	0.65	0.26	0.37	0.46	12.44
	T2	10.34	0.98	0.30	0.51	0.38	12.50
	T3	10.59	0.77	0.39	0.57	0.11	12.44
	T4	10.16	1.39	0.30	0.57	0.06	12.50
	T5	9.92	1.38	0.40	0.47	0.34	12.51
	T6	9.91	1.48	0.49	0.27	0.34	12.49
	T7	9.74	1.56	0.48	0.30	0.42	12.50
	T8	9.60	1.58	0.48	0.31	0.54	12.50
	T9	9.69	1.39	0.46	0.29	0.61	12.44
	T10	9.80	1.26	0.39	0.44	0.61	12.51

4.4. BIOLOGICAL ATTRIBUTES

4.4.1. Soil organic carbon

Organic carbon status is comparatively high for *pokkali* soils when compared to other soil types .The percentage of organic carbon in soil varied from 2.96 to 3.19 and 2.51 per cent to 3.05 per cent at 0 - 15 and 15 - 30 cm depths respectively (Table 11)

At a depth of 0 - 15 cm, the high value of SOC was observed for T3 and T7 treated with phosphorous and NP along with lime respectively and the least SOC percentage was observed in treatement T8 with P and lime application.

However a general trend was not observed at a depth of 15 - 30 cm. At 15 - 30 cm the high value of SOC was observed in the plots treated with NPK (Nitrogen as urea mud ball) and the least SOC percentage is observed in plot treated with N and P and also in the plot treated with NPK. Whereas considering the mean SOC percentage at 15 cm and 30 cm depth, the top soil exhibited higher SOC percentage (Fig 12).

Aryalekshmi (2016) recorded 3.30 percentage of organic carbon in *pokkali* soil. Generally, the acid sulphate and acid saline soils of Kerala is characterised by rich organic matter content, which agrees to high organic carbon status observed. The increased SOC in 36 years among fertilizer treatments may be due to addition of carbon source through organic and inorganic fertilisers, root biomass and crop residues (Kaur *et al.*, 2008). Studies reveals that it takes about 30 to 40 years for some cropping systems to develop an equilibrium level of SOC (Miles and Brown, 2011).

Table 11: Mean value of soil organic carbon (per cent) for different treatments

TREATMENTS	**DEPTH**	
	0- 15 cm	15-30 cm
T1	3.02	2.72
T2	3.17	2.65
T3	3.19	2.88
T4	3.03	2.51
T5	3.04	2.51
T6	3.17	2.70
T7	3.19	2.62
T8	2.96	2.58
T9	3.00	3.05
T10	3.14	2.72

0 - 15 cm P = 0.830; 15-30 cm P = 0.431

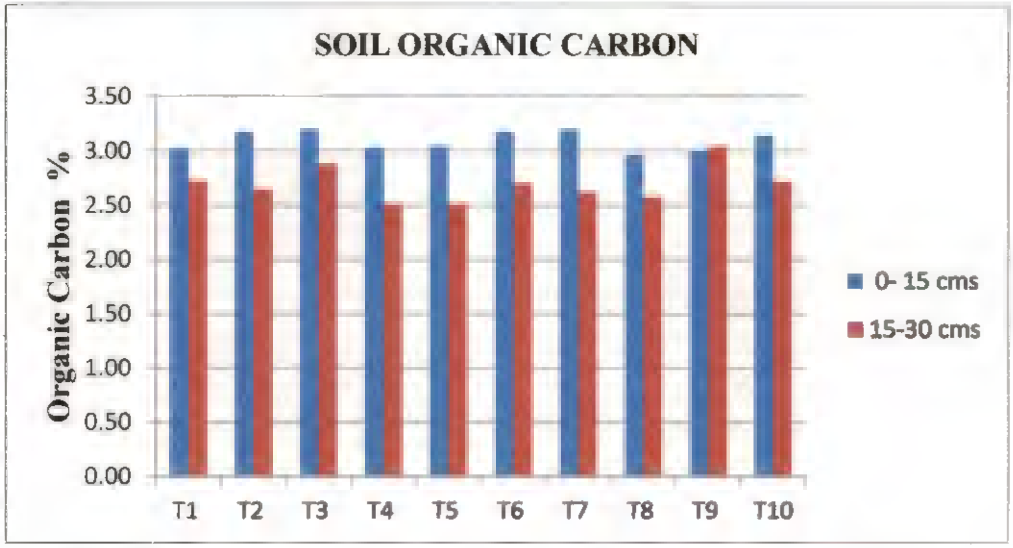

Fig 12: Mean value of soil organic carbon (per cent) at two depth

The organic carbon percentage is higher at surface soil compared to the soil at lower depth. The variation in SOC content at different soil depths of various sites may be attributed to the accumulation of varying amounts of root biomass, root exudates and plant residues left in respective soil layers (Sharma *et al.,* 1992; Brar and Pasricha, 1998; Padre *et al.,* 2007). The occurrence of top soil carbon sink in cultivated soils may be due to the carbon input in the form of fertiliser application and manuring. Many workers researchers (Campbell and Zentner, 1993, Clark et al., 1998, Padre et al., 2007, Kaur et al., 2008) have also reported increased SOC content by the use of chemical fertilizers on the top soil layers. High input of fertilizers in the top layers in cultivated soils might have enhanced the plant growth and resulted in more addition of root biomass, root exudates and plant biomass (Brar, 2012). Similar results were also reported by Sharma *et al.* (1992) and Kaur *et al.* (2008). Due to increased soil based disturbances like tillage activities in the cultivated sites, the top soil OC might have lost rapidly without contributing much to the sub soil sink and this can be attributed to the low SOC at lower depths.

However, there was no significant difference in mean soil organic carbon percentage between the treatments at both depths, which can be attributed to the inherent high organic matter content of *pokkali* soil.

4.4.2. Carbon fractions

The concentration of labile (C_L) and non-labile (C_{NL}) fractions of SOC based on its varying degree of lability was observed to vary between the treatments with a considerable general trend. The percentage value of labile carbon varied between 1.88 to 2.0 and 0.86 to 1.09 at 0 - 15 cm and 15 - 30 cm respectively. Further, the percentage of non-labile carbon varied between 1.08 to 1.20 and 1.69 to 1.95 at 0 - 15 cm and 15 - 30 cm respectively (Table 12).

At 15 cm labile fraction dominated and at 30 cm non-labile fraction dominated over non-labile and labile fraction respectively (Fig 15 and Fig 16).

The higher proportion of non-labile carbon fraction at lower depth of soil may be attributed to the less availability of organic matter and the faster conversion of organic inputs and labile carbon fractions to unavailable recalcitrant forms and its persistence. Conversely, a high proportion of labile carbon counterpart is observed in the surface soil, which may be due to the application of fertilisers. These carbon sources are highly vulnerable towards decomposition and mineralisation and hence the soil based disturbances in the cultivated sites prevent the conversion of these labile counter parts into recalcitrant pools. According to Brar *et al.* (2012), labile carbon content may be produced due to the priming effect of applied inorganic N on fresh organic material in the soil, which stimulates the microbial activity resulting in the decomposition of soil organic matter.

4.4.3. Carbon lability index

The value varied between 1.6 to 1.7 and 1 to 1.2 at depths 15 cm and 30 cm respectively. The higher value of lability index for the treatment T8 with P along with lime at surface layer, whereas at subsurface layer higher value was observed for the T5 treated with NPK.

The Carbon Lability Index (CLI) represents the importance of losing carbon in the form of labile forms and the loss of labile carbon is of greater consequence than the loss of non- labile carbon (Blair *et al.*, 1995).

Table 12: Mean value of soil organic carbon fractions (per cent) for different treatments

TREATMENTS	LABILE CARBON (per cent)		NON LABILE CARBON (per cent)	
	0- 15 cm	15-30 cm	0- 15 cm	15-30 cm
T1	1.91	0.93	1.11	1.79
T2	1.99	0.89	1.19	1.75
T3	2.00	1.01	1.20	1.87
T4	1.92	0.83	1.12	1.69
T5	1.92	0.83	1.12	1.69
T6	1.99	0.92	1.19	1.78
T7	2.00	0.88	1.20	1.74
T8	1.88	0.86	1.08	1.72
T9	1.90	1.09	1.10	1.95
T10	1.97	0.93	1.17	1.79

C_L :- **0 - 15 cm P = 0.430 ; 15-30 cm P = 0.831** C_{NL} :- **0 - 15 cm P = 0.524 ; 15- 30 cm P = 0.831**

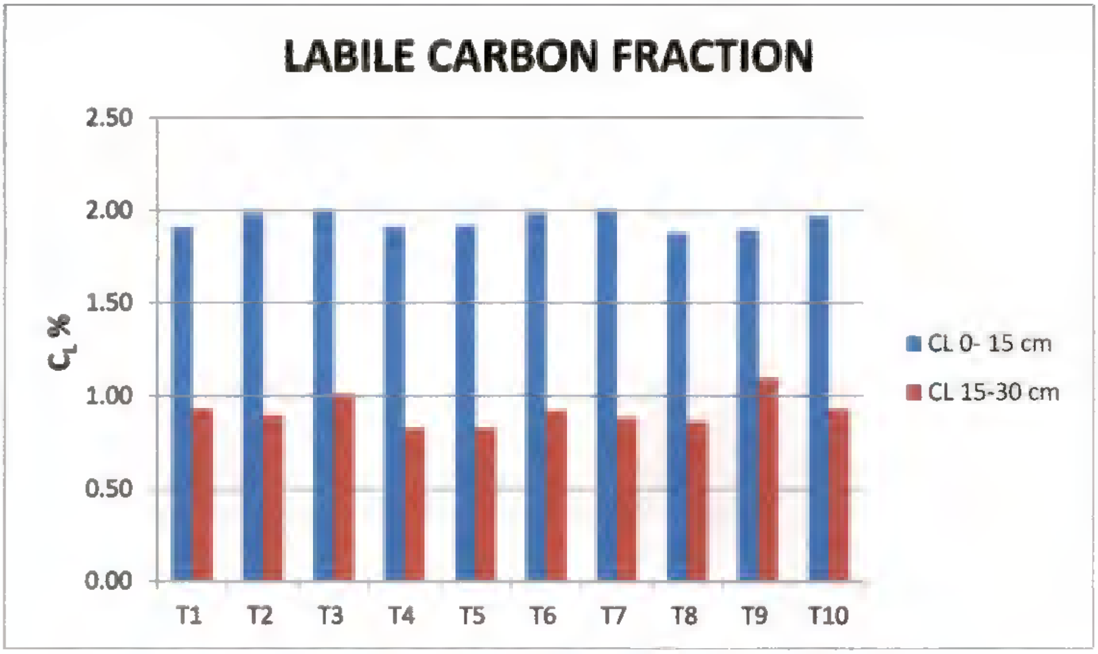

Fig 13: Mean value of labile carbon fractions (per cent) for different treatments at two depths

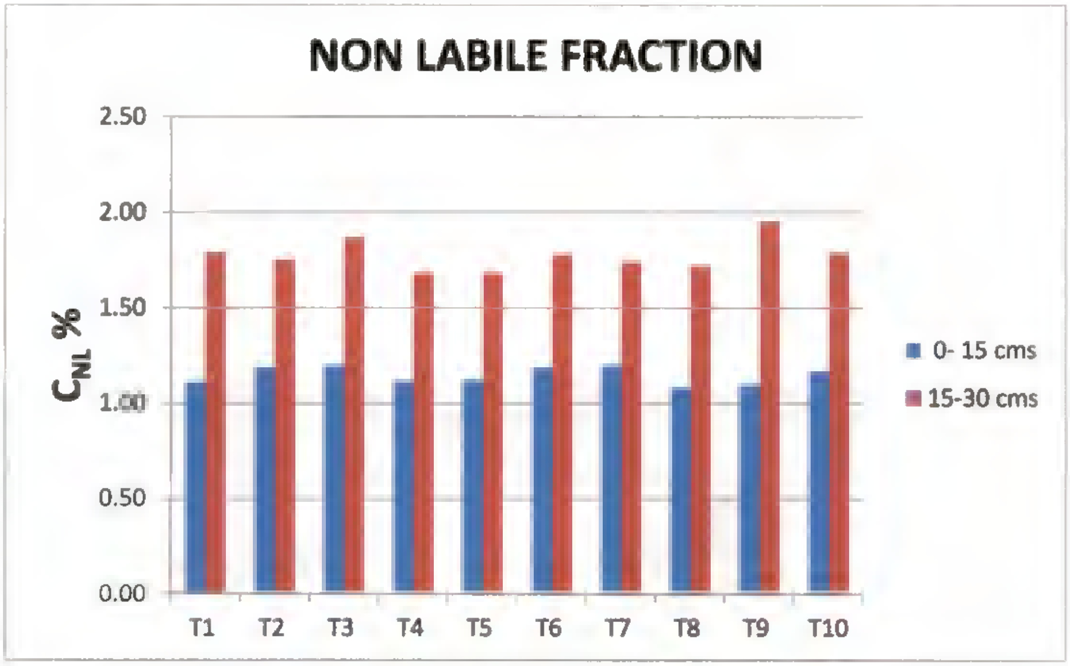

Fig 14: Mean value of labile carbon fractions (per cent) for different treatments at two depths

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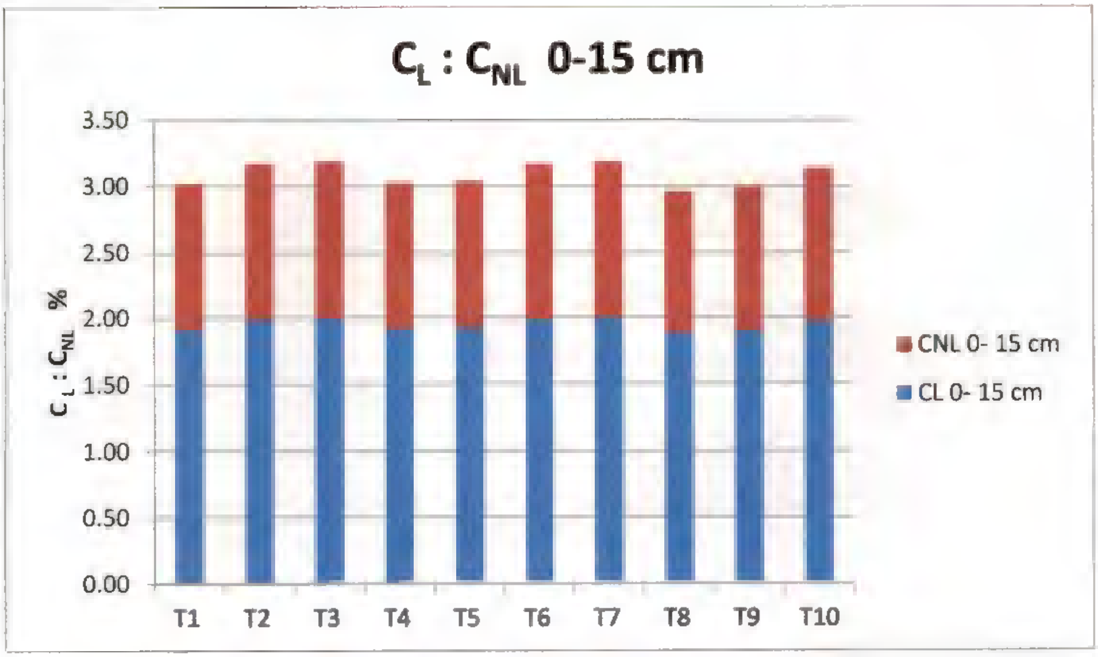

Fig 15: Proportion of carbon fractions at depth 0 - 15 cm

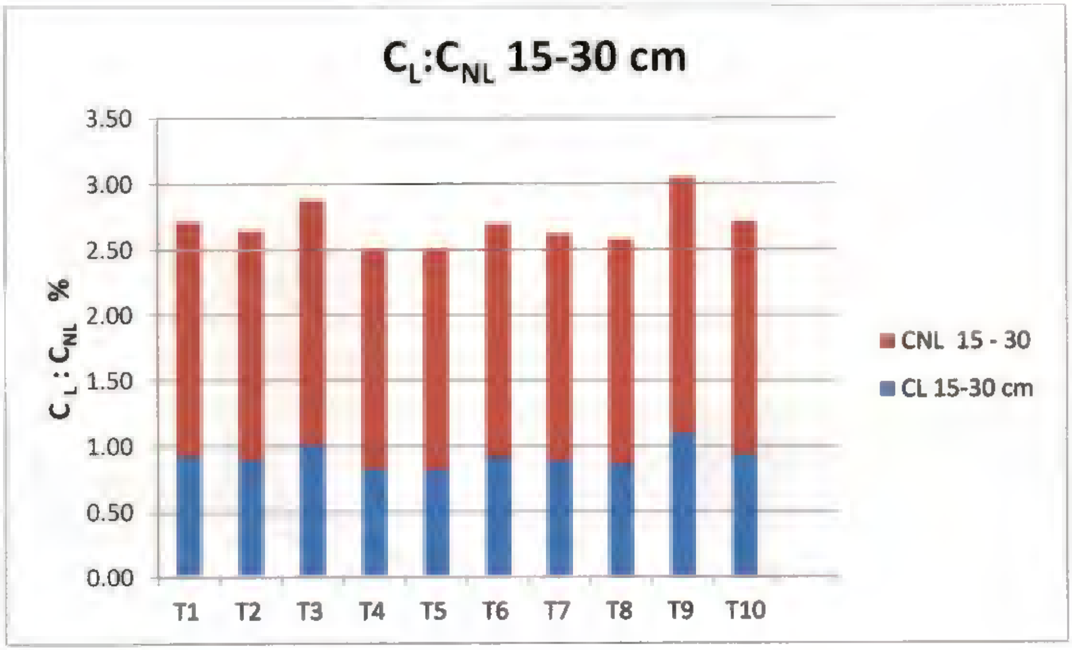

Fig 16: Proportion of carbon fractions at depth 15 - 30 cm

Table 13: Mean value of carbon lability index at two different depths

TREATMENTS	CARBON LABILITY INDEX	
	0-15 cm	15-30 cm
T1	1.72	0.52
T2	1.67	0.51
T3	1.67	0.54
T4	1.72	0.49
T5	1.71	0.49
T6	1.67	0.52
T7	1.67	0.51
T8	1.74	0.50
T9	1.73	0.56
T10	1.68	0.52

0 - 15 cm P = 0.830; 15-30 cm P = 0.431

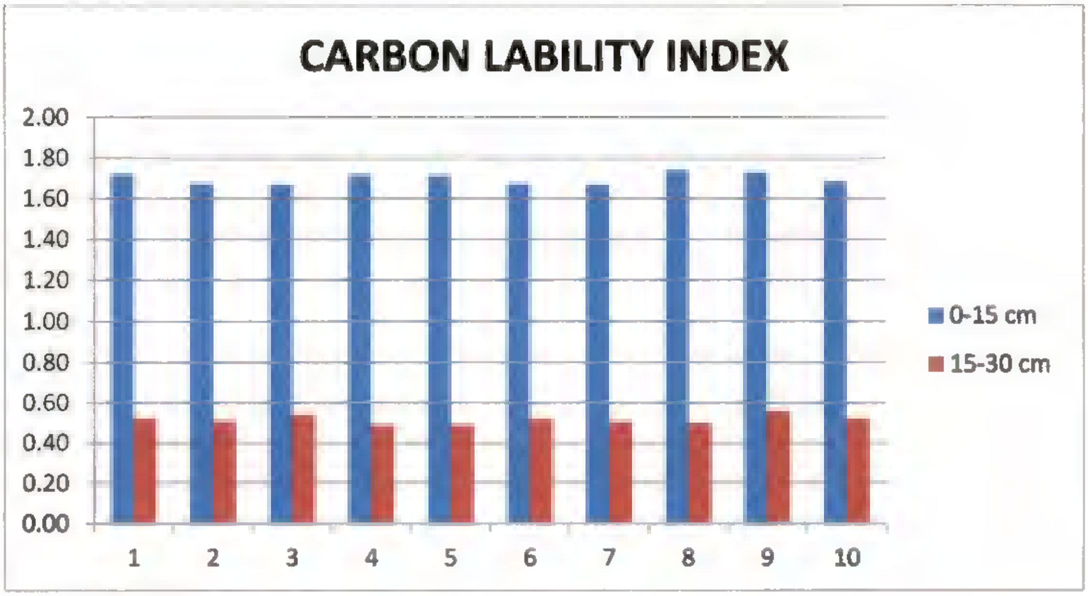

Fig 17: Mean value of carbon lability index at two depth

4.4.4. Particulate organic carbon (POC)

The POC content of the soils significantly varied between 1.75 to 2.13 per cent at 0 - 15 cm and 2.06 to 2.64 per cent at 15 - 30 cm (Table 14). The maximum value at 15 cm was recorded in the treatment T6, (NPK along with lime application) and minimum value recorded in the treatment T8 with P along with lime application. In most of the treatments, the concentration of POC was comparatively low at the top 15 cm whereas at 30 cm value increased considerably.

In all the sites, POC contributed more than half of SOC at 0 - 15 cm and more than 80 per cent of SOC at 15 - 30 cm . The percentage contribution of POC to SOC varied between 59 to 63 per cent at 0 - 15 cm and 72-97 per cent at 15 - 30 cm. The low value of POC in the surface of the cultivated land is quite noticeable (fig.18)

The POC has been defined as an intermediate fraction of SOC between active and slow fractions that change rapidly over time due to changes in management practices. This may be the reason for low POC level in the top soil (Camberdella and Elliott, 1992; Chan, 1997; Bayer *et al.*, 2001). As reported by Bongiovanni and Lobartini (2006) the POC content adversely affected by cultivation practices and soil disturbances. Land based activities including ploughing, land clearance and tampering might have led to the destruction of macro-aggregates which may result in the rapid decomposition of this important organic carbon reserve in the soil (Six *et al.*, 1999; Six *et al.*, 2004). Being more labile, POC is a more sensitive indicator of change than SOC due to land use and management. The low POC value at 0 - 15 cm level illustrates this fact. The POC present in organic matter can accumulate rapidly under the land management systems that minimize soil disturbance. Hence, it can be considered as an early indicator of changes in C dynamics under different land uses and management systems (Cambardella and Elliot, 1992). Furthermore, being a fraction of SOC, its variations under different land use practices can yield important information about the mechanisms of C sequestration (Six *et al.*, 2002).

Table 14: Mean value of particulate organic carbon (per cent) at two depths

TREATMENTS	**POC**	
	0- 15 cm	**15-30 cm**
T1	1.81	2.15
T2	1.97	2.06
T3	2.02	2.26
T4	1.78	2.09
T5	1.84	2.18
T6	2.13	2.17
T7	1.88	2.20
T8	1.75	2.19
T9	1.82	2.18
T10	1.89	2.64

0 - 15 cm P = 0.813; 15-30 cm P = 0.191

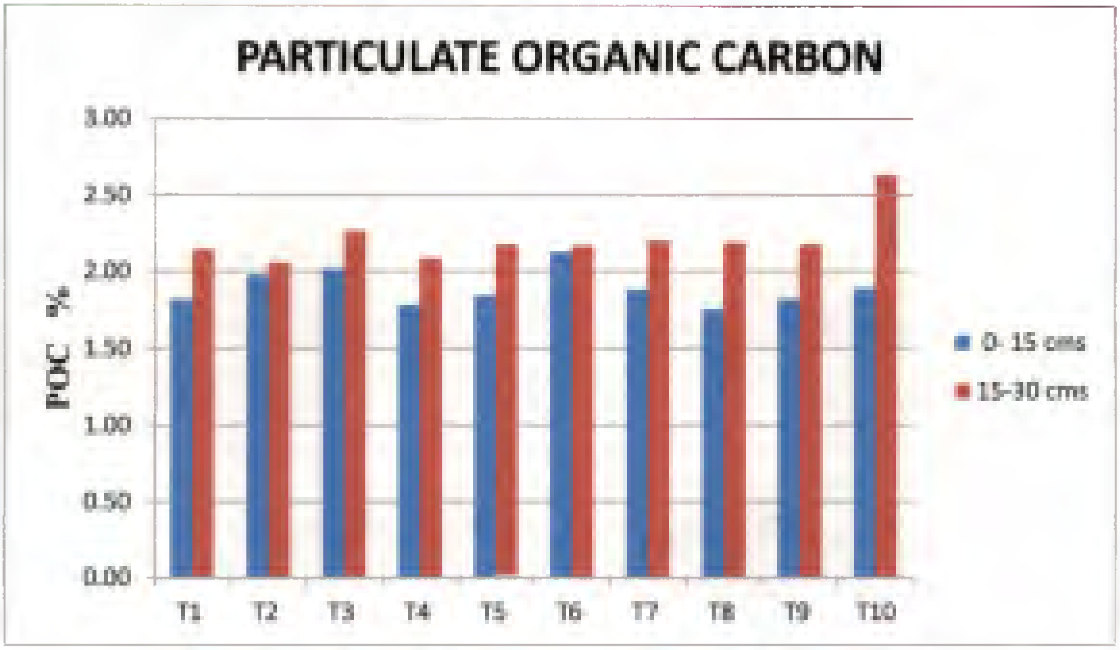

Fig 18: Mean value of particulate organic carbon (per cent) for different treatments at two depths

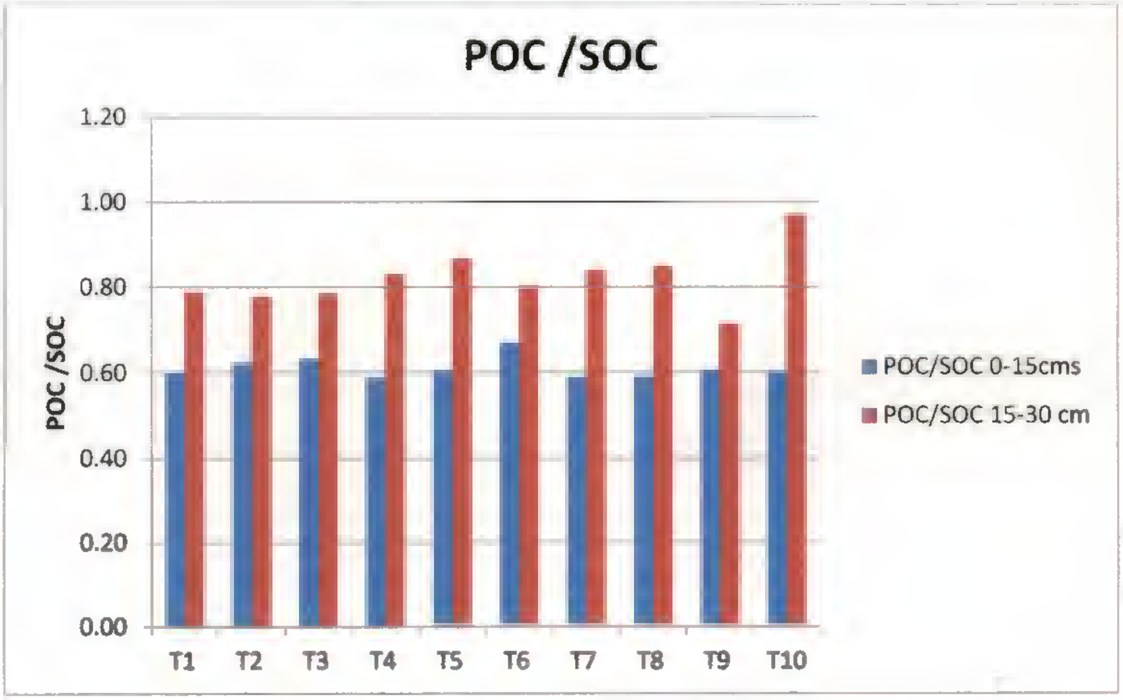

Fig 19: Contribution of POC to SOC for different treatments at two depths

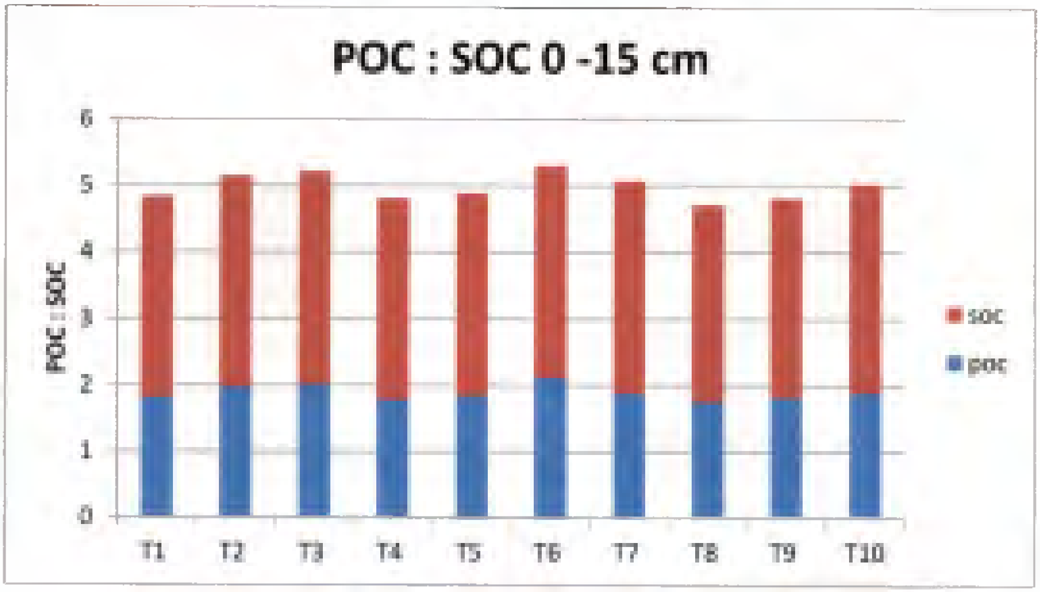

Fig 20: Proportion of particulate organic carbon to soil organic carbon at depth 0 - 15 cm

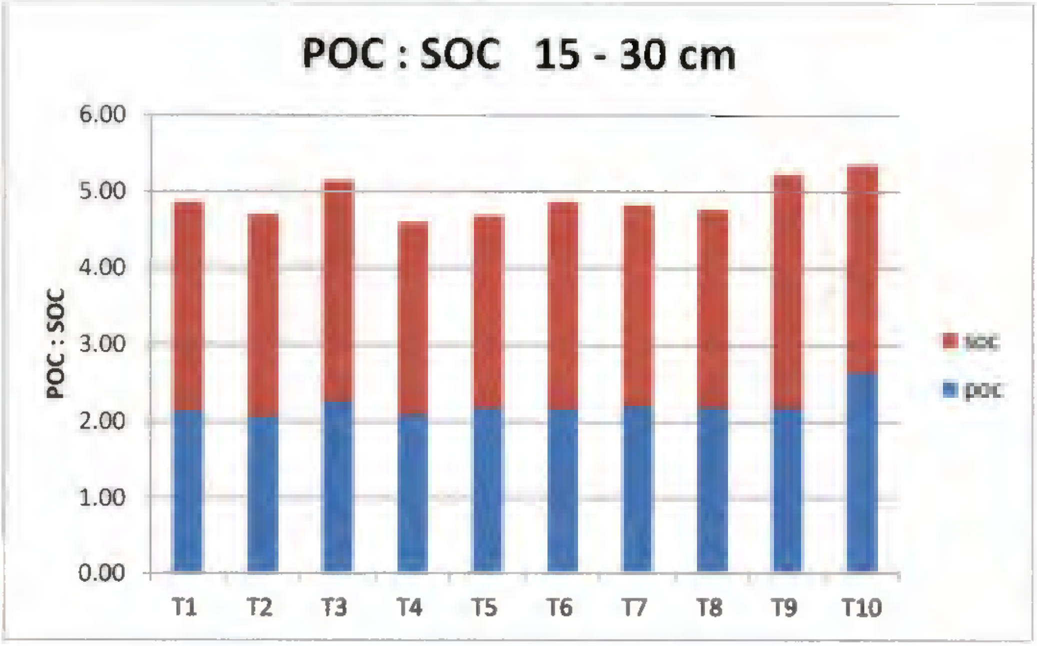

Fig 21: Proportion of particulate organic carbon to soil organic carbon at depth 15 - 30 cm

4.4.5. Potential carbon mineralisation (PCM or C_{Min})

The potential carbon mineralisation (PCM) or C_{Min} values of the treatments are given in the Table 15 and Fig 22. The values varied significantly between 11.35 to 7.05 mg CO2- C g^{-1} at a depth of 0 - 15 cm and 6.98 to 3.45 mg CO2- C g^{-1} at depth of 15 - 30 cm. The highest value of PCM was recorded for treatment (T8 NPK along with lime application) and lowest value observed in treatment T10 (NPK applied where nitrogen is as neem coated urea) at 0 - 15 cm depth. At depth of 15 - 30 cm, higher value of 6.98 mg CO2- C g^{-1} was observed in T10 with NPK (N as neem-coated urea) whereas minimum value was observed for the control plot as 8.40 mg CO2- C g^{-1} and 3.45 mg CO2- C g^{-1}. In the present study, the top soil recorded high PCM values whereas the lower depths recorded comparatively lower figures

4.4.6. Carbon turnover

Carbon turnover significantly differed among the treatments. T10 and T6 showed a lower and higher value respectively at 0-15 cm depth. T4 and T1 showed the lowest and higher values at 15-30 cm depth .Whereas, treatment T10 with neem cake at a depth of 0-15 cm and control plot at a sub-surface layer showed a narrow value enabling the sink capacity of soil and hence the chance of losing the carbon in the form of carbon dioxide is comparatively less. Existence of aerobic condition during the high saline phase would have increased the microbial activity and hence high C mineralization. Continuous cropping and long term application of fertilisers might have increased the disruption of aggregates making the microbial accessibility to organic carbon promoting the C mineralization process (Solomon *et al.*, 2002).

Table 15: Mean value of PCM (mg CO2- C g^{-1}) for at two depths

TREATMENTS	DEPTH	
	0- 15 cm	15-30 cm
T1	8.40	3.45
T2	8.30	4.43
T3	8.60	3.93
T4	7.80	6.53
T5	9.75	5.70
T6	11.35	5.70
T7	8.10	4.50
T8	9.88	5.70
T9	9.53	6.75
T10	7.05	6.98

0 - 15 cm P = 0.001; 15-30 cm P = 0.000

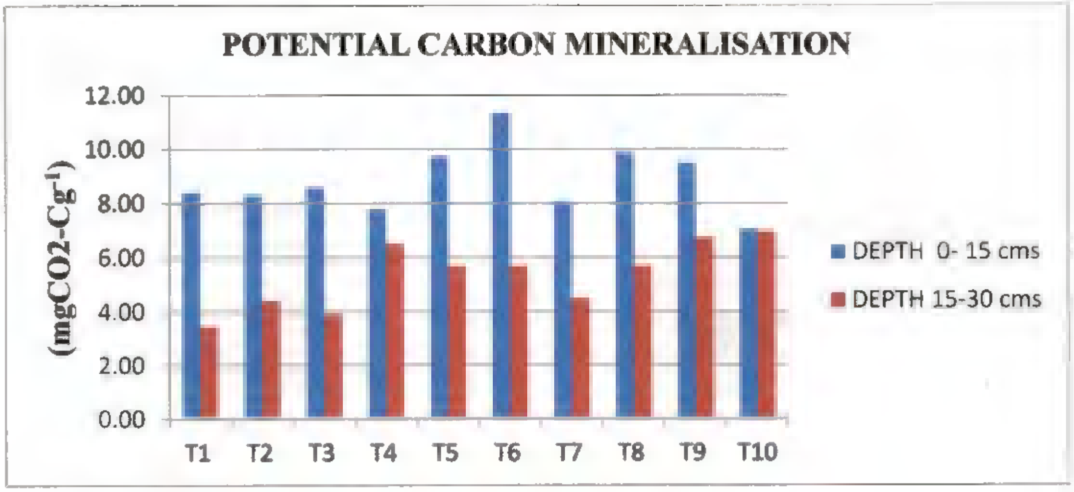

Fig 22: Mean value of potential carbon mineralisation (mg CO2-C g^{-1}) for different treatments at two depths

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Table 16: Mean value of carbon turnover for different treatments at two depths

TREATMENTS	DEPTH	
	0- 15 cm	15-30 cm
T1	2.78	1.27
T2	2.62	1.67
T3	2.69	1.36
T4	2.57	2.60
T5	3.21	2.27
T6	3.58	2.11
T7	2.54	1.72
T8	3.33	2.21
T9	3.18	2.22
T10	2.25	2.57

4.4.7. Microbial biomass carbon

The MBC of soils varied between the treatments with the highest magnitude in treatment T2 (Table 17).The other treatments followed a decreasing order of magnitude as T4<T1 < T8 <T10 <T7 <T5 < T9 <T3 <T6.

There are reports stating that variation in MBC of soils between the treatments could be related to the difference in the soil organic carbon contents (Jenkinson and Ladd 1981). This is substantiated from several reports of long-term field experiments (Schnu¨rer et al., 1985; Anderson and Domsch 1989; Witter et al. 1993). Present study revealed that organic carbon along with mineral nutrition is necessary for the existence of soil microbes and the generation of soil microbial biomass. In the present study it was observed that the application of N, P and K in variable quantities have resulted in variable soil MBC which contradicts the opinion of Goyal *et al.* (1999). He opined that balanced application of nutrients in the form of fertilizers resulted in higher MBC than when it was applied in reduced or skipped doses. Zhong and Cai (2007) from a 13-year application of inorganic fertilizers for flooded rice crops, reported that which the MBC was significantly higher in the treatments fertilized with P than those in the treatments without P fertilization. The treatment T8 and treatment T10 recorded statistically similar organic carbon content whereas it varied statistically with respect to their soil MBC contents. This may be due to the fact that the microbial biomass responds much earlier than total soil organic matter level due to changes in crop and fertilizer management practices or environmental conditions (Brookes 1995; Nayak *et al.* 2007).

Chris (2014) observed a MBC value of 208 µ g g-1 for paddy alone system of Pokkali cultivation

Table 17: Mean value of microbial biomass carbon (μ g g-1) for different treatments at two depths

TREATMENTS	MBC
T1	301.36
T2	354.55
T3	336.82
T4	283.64
T5	319.09
T6	336.82
T7	319.09
T8	301.36
T9	336.82
T10	319.09

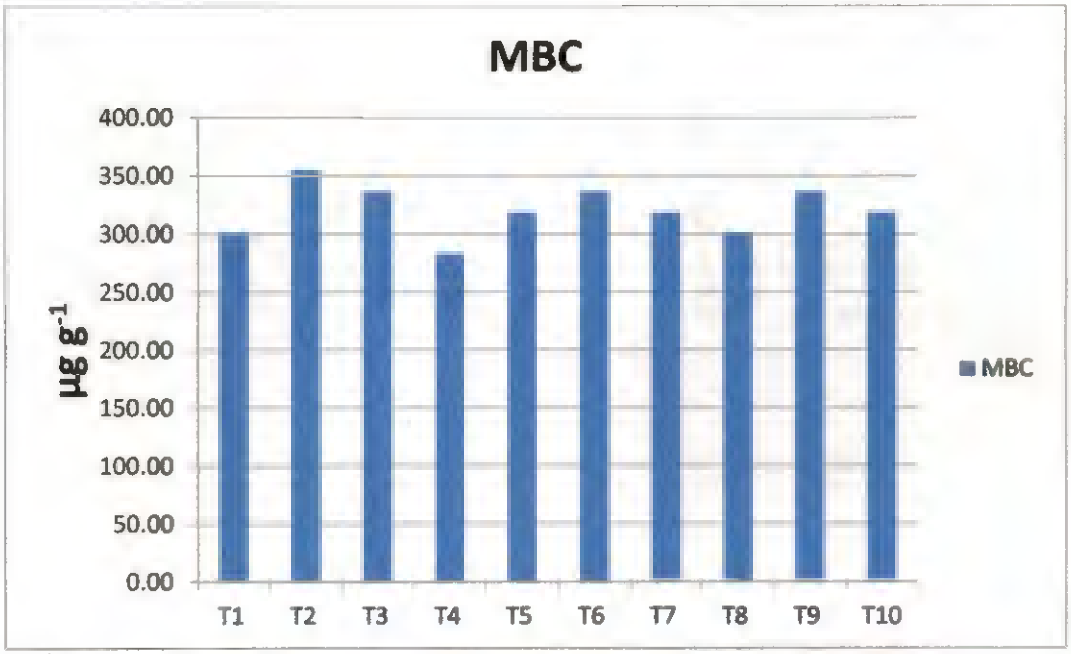

Fig 23: Mean value of microbial biomass carbon (μg g-1) for different treatments at two depths

CHAPTER 5

SUMMARY

Present study entitled carbon dynamics of acid saline *pokkali* soil under long term fertiliser application in rice was conducted with the objective to estimate the soil organic carbon (C) status in acid saline soil and to assess the influence of long term fertilizer applications on soil carbon dynamics

For this purpose soil samples were collected from the plots of permanent manurial trial experiment (PMT) conducted since 1979 at Rice Research Station Vytilla, Kerala Agricultural University, Kerala. Altogether 80 samples were collected from the experimental plot laid out in randomized block design with 10 treatments, each replicated four times with *pokkali* rice variety Vytilla 4. Each plot is of size 20 m^2, surrounded by 25 cm high soil bunds. The soil samples were then analysed for physical chemical and biological properties viz soil bulk density, pH, total N, available phosphorus, available potassium, cation exchange capacity (CEC), soil organic carbon (SOC), particulate organic carbon(POC), potential carbon mineralization (PCM) or (C_{min}), microbial biomass carbon (MBC), organic carbon fractions [carbon labile (C_L) and carbon non labile (C_{NL}) or recalcitrant], aggregate stability [water stable aggregates (WSA)], carbon lability index(CLI), carbon pool index (CPI) and carbon turnover.

The findings of the study are summarized below

- Bulk density recorded a lower value with no marked effect of fertilizer application since 37 years.
- The pH of the soil was not significantly different among the treatments.
- The organic carbon content of *Pokkali* soil was high and hence the soil possessed a higher fertility. The surface layer of the soil recorded higher percentage of organic carbon than the subsurface layer.

- A higher value of labile carbon was recorded at the surface and non labile carbon at the sub surface layer indicated its conversion to recalcitrant pool so as to prevent emission into atmosphere.
- The PCM values ranged from11.35 to 7.05 mg CO_2- C g^{-1} at a depth of 0 - 15 cm and 6.98 to 3.45 mg CO_2- C g^{-1} at depth of 15 - 30 cm.
- There was no significant variation in MBC.
- Correlation between MBC and SOC was significant.
- No significant variations were obtained for pH, Bulk density, organic carbon, carbon fractions among the treatments although variations in values were seen among treatments.
- The application of different treatments has significantly influenced the nutrient status of the soil as there were wide variations in the status of available nutrients.
- The present study indicates that the high content of non labile carbon in te subsurface showed the ability of *Pokkali* soil for carbon sequestrations. The labile carbon present in the surface soil resulted in the availability of nutrients to the plants which was evident from the high nutrient status of the control plot .all carbon fractions in the present study indicates the ability of *Pokkali* soils to sequester carbon. So the *Pokkali* ecosystem has to be maintained as such to mitigate the ill effects of global warming in the present climate change scenario.

REFERENCES

Acton, D.F. and Gregorich, L.J. 1995. The health of our soils: Toward sustainable agriculture in Canada. *Agric. Agri-food Canada*. CDR Unit, Ottawa.

Adhikari, S., Bajracharaya, R.M. and Sitaula, B.K. 2009. A review of carbon dynamics and sequestration in wetlands. *J. of Wetlands Ecol.***2**: 42–46.

Allison S. D., Lu Y., Weihe C., Goulden M. L., Martiny A. C., Treseder K. K. 2013. Microbial abundance and composition influence litter decomposition response to environmental change. *Ecology* 94, 714–725. 10.1890/12-1243.1.

Allison, S.D., Czimczik, C.I. and Treseder, K.K. 2006. Microbial activity and soil respiration under nitrogen addition in Alaskan boreal forest. *Glob. Change Biol.* 14: 1156-1168.

Anderson, J. P. E. 1982. Soil respiration. In Methods of soil analysis, part 2, 2nd ed., ed. A. L. Page, R. H. Miller, and D. R. Keeney, 837–871. Madison, Wisc.: ASA and SSSA.

Anderson, T.H., Domsch, K.H. 1989. Ratio of microbial biomass carbon to total organic carbon in arable soils. *Soil Biol. Biochem*. 21:471–479.

Anilkumar, K. and Annie, K. 2010. Developing protocol for organic rice production in *pokkali* tracts. *Proceedings of thirty first ZREAC Workshop*,12th August 2011,Regional Agricultural Research Station, Kumarakom, Kerala Agricultural University, pp. 8 - 9 .

Antil, R.S. and Singh, M. 2007. Effects of organic manures and fertilizers on organic matter and nutrients status of the soil. *Arch. Agron. Soil Sci*. 53(5): 519–528.

Aref, S. and Wander, M.M. 1998. Long-term trends of corn yield and soil organic matter in different crop sequences and soil fertility treatments on Morrow Plots. *Adv. Agron.* 62: 153–197.

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Arya Lekshmi V , 2016. Silicon availability of tropical soils with respect to rice nutrition. PhD. thesis. Department of Soil Science and Agricultrural Chemistry, College of Horticulture , Kerala Agricultural University, Thrissur, Vellanikkara.

Ashamol, A., Mercy, T.V.A. and Shaju, S.S. 2014. Effect of Rotational *Pokkali* cultivation and Shrimp farming on the Soil Characteristics of two different *Pokkali* field at Chellanam and Kadamakudi, Kochi, Kerala, INDIA. *Int. Res. J. Environment Sci.* 3(9): 61-64.

Ayoubi, S., Khormali, F., Sahrawat, K. L. and Rodrigues de Lima, A.C. 2011. Assessing impacts of land use change on soil quality indicators in a Loessial soil in Golesten province, Iran. *J. Agric. Sci. Tech.* 13:727 - 747.

Badalucco, L.; Gelsomino, A.; Dell'orco, S. Greco, S. & Nannipieri, P. 1992.Biochemical characterization of soil organic compounds extracted by 0.5 M K2SO4 before and after chloroform fumigation. *Soil Biol. Biochem.*, 24:569- 578.

Bavel, V. C. H, 1949. Mean weight diameter of soil aggregates as a statistical index of aggregation. *Soil Sci. Soc. Am. Proc.* 14:20–23.

Bayer, C., Martin-Neto, L., Mielniczuk, J., Pillon, C.N. and Sangoi, L. 2001. Changes in soil organic matter fractions under subtropical no-till systems. *Soil Sci. Soc. Am. J.,* 65:1473–1478.

Bernal, B. and Mitsch, W.J. 2008. A comparison of soil carbon pools and profiles in wetlands in Costa Rica and Ohio. *Ecol Eng*. 34:311–323.

Bhattacharyya, R., Ved Prakash Kundu, S., Srivastva, A.K., Gupta, H.S. 2010. Long term effects of fertilization on carbon and nitrogen sequestration and aggregate associated carbon and nitrogen in the Indian sub-Himalayas. *Nutr. Cycling Agroecosyst.* 86: 1–16.

Bi, L.D., Zhang, B., Liu, G.R., Li, Z.Z., Liu, Y.R., Ye, C., Yu, X.C., Lai, T., Zhang, J.G., Yin, J.M. and Liang, Y. 2009. Long-term effects of organic amendments on the rice yields for double rice cropping systems in subtropical China. *Agric. Ecosyst. Environ.* 129 (4): 534–541.

Biswas, T. D., Narayanasamy, G., Goswami, N. N., Sekhon, G. S., & Sastry, T. G. 1991. Soil Related Constraints in Crop Production. *Indian Soc. Soil Sci. Bull.* 15, New Delhi, India. 176.

Blair, G.J., Rod, D., Lefroy, B., Lisle, L. 1995. Soil carbon fractions, based on their degree of oxidation, and the development of a carbon management index for agricultural systems. *Aust. J. Agri. Res.* 46: 1459– 1466.

Bongiovanni, M.D. and Lobartini, J.C. 2006. Particulate organic matter, carbohydrate, humic acid contents in soil macro and micro aggregates as affected by cultivation. *Geoderma*. 136: 660-665.

Brar, B.S. and Pasricha, N.S. 1998. Long-term studies on integrated use of organic and inorganic fertilizers in maize–wheat–cowpea croppin g system on alluvial soil of Punjab. In: Swarup A, Reddy DD, Prasad RN (Eds.), Long-term Soil Fertility Management Through Integrated Plant Nutrient Supply. *Proceedings of a National Workshop*, 17th April 1998. Indian Institute of Soil Science Bhopal, 154 –160.

Brar, J., Singh, K., Wang, J. and Kumar, S. 2012. Co - gasification of coal and biomass: A Review. *Int. J. of For. Res.* 363058, doi:10.1155/2012/363058. 10: 16.

Bray, R. H. and Kurtz, L. T. 1945. Determining total, organic and available forms of phosphate in soils. *Soil Sci. Soc. Am. J.* 64: 2115-2124.

Brevik, E.C., 2012. Soils and climate change: Gas fluxes and soil processes. *Soil Horizons.* 53(4): 12 -23.

Brookes, P.C., 1995. The use of microbial parameters in monitoring soil pollution by heavy metals. *Biol. Fertil. Soils*. 19:269–279.

Cai, Z. C. and Qin, S.W. 2006. Dynamics of crop yields and soil organic carbon in a long-term fertilization experiment in the Huang-Huai-Hai Plain of China.*Geoderma*. 136: 708-715.

Cambardella, C.A. and Elliot, E.T. 1992. Particulate Soil organic matter changes across a grassland cultivation sequence. *Soil Sci. Soc. Am. J.* 56: 777-783.

Campbell, C.A., Zentner, R.P. 1993. Soil organic matter as influenced by crop rotations and fertilization in an aridic Haploporoll. *Soil Sci. Soc. Am. J.* 57: 1034–1040.

Castro, C. and Logan, T. J. 1991. Liming effects on the stability and erodibility of some Brazilian Oxisols soil. *Soil Sci Soc Am J.* 55:1407–1413.

Chan, K. Y., Booowman, A. and Oates, A. 2001. Oxidizible organic carbon fractions and soil quality changes in an oxic paleustalf under different pasture leys. *Soil Sci.* 166:61- 67.

Chan, K.Y. 1997. Consequences of changes in particulate organic carbon in vertisols under pasture and cropping. *Soil Sci. Soc. Am. J.* 61: 1376 – 1382.

Chivenge, P., Vanlauwe, B. and Six, J. 2010. Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis.*Plant and Soil.* 10: 626-655.

Chris Joseph, 2014. Quality assessment of *pokkali* soils under different land uses. MSc. thesis. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, Vellanikkara.

Clark, M.S., Horwath, W.R., Shennan, C. and Scow, K.M. 1998. Change in soil chemical properties resulting from organic and low input farming practices. *Agron. J.* 90: 662–671.

Cole, V., Cerri, C., Minami, K., Mosier, A., Rosenberg, N. and Sauerbeck, D., 1996. Agricultural options for mitigation of greenhouse gas emissions. In: Watson, R.T., Zinyowera, M.C. and Moss, R.H. (Eds.), *Climate Change 1995: Impacts, Adaptation and Mitigation of Climate Change.* Cambridge University Press, Cambridge, UK, pp. 744–771.

Dakshinamurthy, C. and Gupta, R. P., 1968. *Practicals in Soil Physics*, New Delhi: IARI.

Davidson, T.E., and Stahl, M. 2000. The influence of organic carbon on nitrogen transformation in five wetland soils. *Soil Sci. Soc. Am. J.* 64:1129-1136.

Dick, R.P., Breakwell, D.P. and Turco, R.F. 1996. Soil enzyme activities and biodiversity measurements as integrative microbial indicators. In: Doran, J.W. and Jones, A.J., (Eds.), *Methods for assessing soil quality*. Special publication no. 49. Madison (WI): *Soil Sci. Soc. Am.* pp. 247–271.

Diekow, J., Mielniczuk, J., Knicker, H., Bayer, C., Dick, D.P. and Kögel-Knabner. 2005. Carbon and nitrogen stocks in physical fractions of a subtropical Acrisol as influenced by long-term no-till cropping systems and N fertilisation. *Plant Soil.* 268 (1): 319–328.

Doran, J.W., Sarrantonio, M., Liebig, M.A. 1996. Soil health and sustainability. *Adv Agron.* 56:1–54.

Edmeades, D. C. 2003. The long-term effects of manures and fertilizers on soil productivity and quality: A review. *Nutrient Cycling in Agroecosystems*. 66: 165-180.

Fu, B. J., Guo, X. D., Chen, L. D., Ma, K. M. and Li, J. R. 2001. Land use changes and soil nutrient changes: a case study in Zun hua county, Hebei Province. Acta Ecol. Sin. (in Chinese). 21(6): 926–931.

Galantini, J. and Rosell, R. 2006. Long-term fertilization effects on soil organic matter quality and dynamics under different production systems in semiarid Pampean soils. *Soil and Tillage Research*, 87: 72-79.

Gayatri, R.N. and Raveendran, K. 2009. Exploration of Untapped Potentiality of Coastal Paddy Fields of Kerala (India) - A Case Study. *Middle-East J. Sci. Res.* 4(1): 44-47.

Geeta kumari, Mishra, B., Kumar, R., Agarwal, B.K and Singh, B.P. 2011. Long-term effects of manure, fertilizer and lime application on active and passive pools of soil organic carbon under maize-wheat cropping system in an Alfisol. *Journal of the Indian Society of Soil Science*. 59(3): 245-250.

George, K. M., George, T.U. and Sasidharan, N.K. 1993. Improvement of *pokkali* rice (eds.). Nair, R.R., Nair, K.P.V. and Joseph, C.A. *Rice in wetland eco system*. Kerala Agricultural University. Trichur, 24-26.

Gopalan, U.K., Purushan, K.S. and Rao, T.S.S. 1980. Case studies on the economics of an improved method of paddy field shrimp culture in Vypeen Island. *Proceedings of the National symposium on shrimp farmers*. Bombay. 175-186.

Gorham, E. 1998. The biochemistry of northern peatlands and its possible responses to global warming. In: Woodwell, G.M., Mackenzie, F.T. New York (eds.). *Biotic Feedbacks in the Global Climatic Systems*. Oxford University Press, 169- 187.

Gorissen, A., A. Tietema, N.N. Joosten, M. Estiarte, J. Peñuelas, A. Sowerby, B.A. Emmett, and C. Beier. 2004. Climate change affects carbon allocation to the soil in shrublands. Ecosystems 7:650–661. doi: 10.1 007/s10021-004-0218-4.

Goyal, S., Chander, K., Mundra, M.C., Kapoor, K.K. 1999. Influence of inorganic fertilizers and organic amendments on soil organic matter and soil microbial properties under tropical conditions. *Biol Fertil Soils*. 29:196–200.

Graham, M. H., Haynes, R. J. and Meyer, J.H. 2002: Changes in soil chemistry and aggregate stability induced by fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. *Eur. J. of Soil Sci.* 53: 589–598.

Gregorich, E. G., Ellert, B.H, Drury, C.F. and Liang, B.C. 1996. Fertilization effects on soil organic matter turnover and corn residue C storage. *Soil Sci. Soc. Am. J.* 60:472–476.

Guo, L., Falloon, P., Coleman, K., Zhou, B., Lin, E. and Zhang, F. 2007. Application of the RothC model to the reslts of long term experiment on typical pland soils in Northern China. *soil use mgmnnt*. 23: 63-70

81A

Hati, K.M., Swarup, P., Sing, D., Misra, A.K. and Ghosh, P.K. 2006: Long-term continuous cropping, fertilization and manuring effects on physical properties and organic carbon content of a sandy loam soil. *Aust. J. Soil Res.* 44(4): 487-495.

Haynes, R.J. and Naidu, R. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: A review. *Nutrient Cycling in Agroecosystems* 51: 123–137.

Heimann, M. and Reichstein, M. 2008. Terrestrial ecosystem carbon dynamics and climate feedbacks. *Nature* 451: 289–292.

Hendershot, W.H. and Duquette, M. 1986. A simple barium chloride method for determining cation exchange capacity and exchangeable cations. *Soil Sci. Soc. Am. J.* 50:605-608.

Hera, C., Mihaila, V. 1981. The changing of some agrochemical indices of the soil by the application of the fertilizers. Analele ICCPT. 47:319–327.

Hou, X., Wang, X., Li, R., Jia, Z., Liang, L., Wang, J., Nie, J., Chen, X., Wang, Z. 2012. Effects of different manure application rates on soil properties, nutrient use, and crop yield during dryland maize farming. *Soil Res.* 50: 507–514.

Hsu, P.H., 1963. Effect of initial pH, phosphate and silicate on the determination of aluminium with aluminon. *Soil Sci*. 96:230-238.

Indraratna, B., Glamore, W.C. and Tularam, G.A. 2002. The effect of tidal buffering on acid sulphate soil environments in coastal areas of New South Wales. *Geotech. and Geol. Engi.* 20: 181doi: 10. 1023/A: 1016075026487.

Irene Elizabeth John. 2014. Wet soil analysis for nutrient prescription in paddy soils. MSc. thesis. Department of soil science and agricultural chemistry, College of Horticulture, Vellayanikkara, Trichur, Kerala.

Jackson, M. L.1958. *Soil Chemical Analysis*. Prentice Hall of India Private Ltd., New Delhi, 498p.

82

Jenkinson, D. S. and Ladd, J. M. 1981. Microbial biomass in soil: Measurement and Turnover. In: Paul, E.A., Ladd, J.M. (eds). *Soil bio chem.* (Vol. 5). NY, USA: Marcel Dekker. p. 415–471.

Jenkinson, D. S. and Powlson, D. S, 1976. The effects of biocidal treatments on metabolism in soil - I. Fumigation with chloroform. *Soil Biol. Biochem.* 8:167-77.

Johnston, A. E. 1994. The Rothamsted classical experiments. In: Leigh, R. A, Johnston, A. E. (eds). *Long-term experiments in agricultural and ecological sciences.* Wallingford, UK: CAB International. p. 9–37.

Jones, C., Mc-Connell, C., Coleman, K., Cox, P., Falloon, P., Jenkinson, D., & Powlson, D. 2005. Global climate change and soil carbon stocks; predictions from two contrasting models for the turnover of organic carbon in soil. *Glob. Chg. Biol.*, 11(1), 154-166.

Joy, A. 2013. Development Impact on *Pokkali* Fields A Case of International Container Transshipment Terminal, Vallarpadam, Kochi. *J. Hum. Soc. Sci.*, 10(5): 1–5.

Kaur, Brar, B.S., Dhillon, N. 2008. Soil organic matter dynamics as affected by long-term use of organic and inorganic fertilizers under maize–wheat cropping system. *Nutr. Cycl. Agroecosys.81*: 59–69.

Kou, T. J., Zhu, P., Huang, S., Peng, X. X., Song, Z. W., Deng, A. X., Gao, H. J., Peng, C., Zhang, W. J. 2012. Effects of long term cropping regimes on soil carbon sequestration and aggregate composition in rain fed farmland of Northeast China. *Soil and Tillage Research*. 118: 132-138.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. *Science*, 304(5677), 1623-1627.

Lal, R. 2005. Soil Erosion and Carbon dynamics. So*il and Tillage Res.* 81: 137 - 142.

93

Lou, Y. L., Xu, M. G., Wang, W., Sun, X. L. and Liang, C. H. 2011b. Soil organic carbon fractions and management index after 20 year of manure and fertilizer application for greenhouse vegetables. *Soil Use and Management*. 27: 163-169.

Lou, Y. L., Xu, M. G., Wang, W., Sun, X. L. and Zhao, K. 2011c. Return rate of straw residue affects soil organic C sequestration by chemical fertilization. *Soil Tillage Res.*, 113: 70-73.

Lou, Y.L., Wang, J. K. and Liang, W. J. 2011a. Impacts of 22-year organic and inorganic N managements on soil organic C fractions in a maize field, northeast China. *Catena*, 87: 386-390.

Malhi, S., Nyborg, M., Goddard, T. and Puurveen, D. 2011. Long-term tillage, straw management and N fertilization effects on quantity and quality of organic C and N in a black chernozem soil. *Nutr. Cycl. Agroecosys. 90*: 227–241.

Manna, M.C. and Swarup, A. 2000. Effect of integrated use of organic and fertilizer N on soil microbial biomass dynamics turnover and activity of enzymes under legume-cereal system in a swell-shrink (Typic Haplustert) soil. *Korean J Environ Agric*. 19:375–381.

Manna, M.C., Swarup, A., Wanjari, R.H., Mishra, B. and Shahi, D.K., 2007. Long-term fertilization, manure and liming effects on soil organic matter and crop yields. *Soil Tillage Res*. 94 (2): 397–409.

Meng, Q. F., Yang, J. S., Yao, R. J., Liu, G. M. and Yu, S. P. 2013. Fertilization affects biomass production of *suaeda salsa* and soil organic carbon pool in east coastal region of China. *J. Integrative Agric.*, 12: 1659- 1672.

Miles, R.J. and Brown, J.R. 2011. The Sanborn Field experiment: Implications for long-term soil organic carbon levels. *Agron. J.103*: 268–278.

Nair, P.G and N.S. Money. 1968. Studies on some chemical and mechanical properties of salt affected rice soils of Kerala. *Agric. Res. J. Kerala* 10 (1): 51-53.

Nambiar, G.R. and Raveendran, K. 2009. Exploration of Untapped Potentiality of Coastal Paddy Fields of Kerala (India) – A Case Study, *Mid. – East J. Scien. Res* ., 4(1), 44–47.

Nandan, S.B. and Abdul Aziz, P.K.1996. Organic matter of sediments from the retting a non-reusing areas of Kadinamkulam estuary, southwest coast of India. *Indian J. Mar. Sci.,* 25: 25-28.

Nayak, D.R., Jogadeesh Babu, Y. and Adhya, T.K. 2007. Long-term application of compost influences microbial biomass and enzyme activities in a tropical *Aeric Endoaquept* planted to rice under flooded condition. *Soil Biol. Biochem.* 39:1897–1906.

Nie, S.W., Gao, W.S., Chen, Y.Q., Sui, P., Eneji, A.E. 2009: Review of current status and research approaches for nitrogen pollution in farmlands. *Agric. Sci. China.*8(7): 843-849.

Padmaja, P., Geethakumari, V.L., Harikrishnan Nair, K., Chinnamma, N.P., Sasidharan, N.K. and Rajan, K.C. 1994. *A glimpse to problem soils of Kerala.* Kerala Agricultural University, Thrissur. 116 pp.

Padmakumar, K.G., Anuradhakrishnan, Manu, P.S., Shiny, C.K. and Radhika, R. 2002. Thanneermukkom barrage and fishery decline in Vembanad Wetlands, Kerala. (eds.) Kamalakshan Kokkal., Premachandran, P.N. and Bijukumar, A. *Wetland conservation and Management in Kerala.* State committee on Science, Technology and Environment, Trivandrum, Kerala. 27 – 36.

Padmakumar, K.G; Anuradha Krishnan. and N.C. Narayanan. 2003. Rice – fish farming system development in Kuttanad, Kerala - changing paradigms. Priorities and strategies for Rice Research in High Rainfall Tropics. Kerala Agricultural University, Thrissur. 104 – 120.

Padre, T., Ladha, J.K., Regmi, A.P., Bhandari, A.L., Inubushi, K. 2007. Organic amendments affect soil parameters in two long-term rice–wheat experiments. *Soil Sci. Soc. Am. J.,* 71: 442–452.

Panickkar, N.K. and Menon, M.K. 1956. Prawn fisheries of India. *Proceedings of Indo – pacific fish council,* 6 (3): 328 – 344.

Panikkar, N.K. 1937. The prawn industry of Malabar Coast. *J. Bombay. Nat. Hist. Soc.* 9 (2): 343 – 353.

Panikkar, N.K. 1952. Possibilities for the expansion of fish and prawn cultural practices in India. *Current. Sci. 21* (2): 29 – 33

Pillai, S.M. 1999. Traditional and Improved Shrimp farming in the *Pokkali* fields of Kerala. *J. Indian Soc. Coastal Agric. Res.* 17 (1 and 2): 171 –181

Pillai, S.M., 2003. Fishery and production of shrimps from perennial and seasonal fields of Kerala. *Indian J. Fish.*, 50(2): 173-180.

Ponnamperuma, F.N. 1984. Role of cultivar tolerance increasing rice production in saline lands In: Staples, R.C. and Toemnnniessen, G.H. (Eds.), *Salinity Tolerance in Plants*. Willey-Interscience, New York. pp 255-271.

Post, W.M., Emanuel, W.R., Zinke, P.J. and Stanenberger, A.G. 1982. Soil carbon pools and world life zones. *Nature.* 298; 156-159.

Prior, S. A. , Torbert, H.A., Runion, G. B. , Rogers, H. H. and Kimball, B. A. 2008. Free-Air CO_2 Enrichment of Sorghum: Soil Carbon and Nitrogen Dynamics. *J. Environ. Qual.* 37:753–758.

Purushan, K.S. 1987. Economics on traditional prawn farming in Kerala. *Seafood. Exp. J.*19 (4): 15 – 19.

Purushan, K.S. 2002. Wetland eco-system development and Management in relation to *Pokkali* areas. In: Kokkal, K., Premachandran, P.N. and Bijukumar, A (eds).*Wetland Conservation and Management in Kerala*. State Committee on Science, Technology and Environment, Thiruvananthapuram, Kerala, pp.46– 55.

Rajendran, C.G., George, T.U., Mohan, M.V. and George, K.M. 1993. Problems and prospects of integrated agriculture in *Pokkali* fields (eds.) Nair, R.R; Nair,

86

K.P.V. and Joseph, C.A. *Rice in Wetland ecosystem.* Kerala Agricultural University, Trichur. 276 – 279.

Samikutty, V. 1977. Investigations on the salinity problems of Pokkali and Kaipad areas of Kerala. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 122p.

Sasidharan, N. K. 2004. Enhancing the productivity of the rice, fish/prawn farming system in *pokkali* lands. Ph.D thesis. Dept. of Agronomy. College of Horticulture, Vellayanikkara, Trichur, Kerala.

Sasidharan, N.K. 2006. *Pokkali*-The world acclaimed farming system model. In: Balachandran, P.V., Louis, V. and Padmakumar, K.G. (eds). *Rice- Fish Integration through Organic Farming.* Agro-Tech Publishing Academy, Udaipur, pp. 75–86.

Sasidharan, N.K., Abraham, C.T. and Rajendran, C.G. 2012 Spatial and temporal integration of rice, fish and prawn in the coastal wetlands of central Kerala, India, *J. Trop. Agri.,* 50(1-2): 15–23

Schlensinger, W.H. 1997. *Biogeochemistry: An analysis of global change.* 2nd ed. San Deigo, CA: Academic Press

Schlesinger, W.H. 2003. The Carbon Cycle: Human perturbations and potential management options. pp. 25-44. In: J.M.Griffin (ed.).*Global Climate Change: The Science, Economics, and Politics.* Edward Elgar, Cheltenham, UK.

SchnÜrer, J. and Rosswall, T. 1982. Fluorescein dia cetate hydrolysis as a measure of total microbial activity in soil and litter. *Appl. Environ. Microbiol.* 43:1256–1261.

Setegen, S.G., Rayner, D., Melesse, A.M., Dargahi, B., Srinivasan, R., & Wörman, A. 2011. Climate change impact on agricultural water resources variability in the Northern Highlands of Ethiopia (1st ed.). In Melesse, M. Assefa (Eds.), Nile River Basin: Hydrology, Climate and Water Use. Springer

Sharma, K.N., Bhandari, A.L., Rana, D.S. 1992. Long-term Influence of ingredient of crop technology in pigeon pea-wheat sequence on crop yields and soil fertility changes. *J. Res*., Punjab Agricultural University. Ludhiana, 28: 125–131.

Shen, J., Li, R., Zhang, F., Fan, J., Tang, C. and Rengel, Z. 2004. Crop yields, soil fertility and phosphorus fractions in response to long- term fertilization under the rice monoculture system on a calcareous soil. *Field Crops Res*. 86:225–238.

Shylaraj, K.S. and Sasidharan, N.K. 2005. VTL5: A high yielding salinity tolerant rice variety for the coastal saline ecosystems of Kerala. *J. Trop. Agric*., 43(1– 2): 25–28.

Silas, E.G. and Pillai, P.P. 1975 Dynamics of zooplankton in a tropical estuary with a review on the plankton fauna of the environment, *Bull. Dept. Mar. biol. Oceanogr*. Univ. Cochin. 7: 329-335.

Six, J., Bossuyt, H., Degryze, S., Denef, K. 2004. A history of research on the link between micro aggregates, soil biota, and soil organic matter dynamics. *J. Soil Till. Res*. 79: 7-31.

Six, J., Conant, R.T., Paul, E.A., Paustian, K. 2002. Stabilization mechanisms of soil organic matter: implications for C saturation of soils. *Plant Soil*. 241: 155-176.

Six, J., Elliott, E.T. and Paustian, K. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Sci. Soc. Am. J*., 63: 1350– 1358.

Smith, S.V., Renwick, W.H., Buddemeier, R.W. and Crossland, C.J. 2001. Budgets of soil erosion and deposition for sediments and sedimentary organic carbon across the conterminous United States. Global Biogeochemistry Cycles. 15: 697 – 707.

Smith, T. M. and Smith, R. L. 2006. *Elements of Ecology*. San Francisco: Benjamin Cummings. 658 pp.

Solomon, D., Fritzsche, F., Lehmann, J., Tekalign, M., Zech, W. 2002. Soil organic matter dynamics in the sub humid agro ecosystems of the Ethiopian highlands:

88

evidence from natural C-13 abundance and particle-size fractionation. *Soil Sci. Soc. Am. J.,* 66: 969–978.

Thampy, D.M., 2002. Development of fisheries in the wetland ecosystem of Kerala. In: .Kamalakshan Kokkal, P. N. Premachandran and A. Bijukumar (Eds.), Wetland Conservation and Management in Kerala. State Committee on Science, Technology and Environment, Thiruvananthapuram, Kerala, pp. 141-145.

Tomy,P.J., George,T.U. and Suseela Jose.1984. *Pokkali* Cultivation in Kerala. *Technical bulletin -10,* Kerala Agricultural University. Trichur, Kerala. pp 1-20.

Tong, X. G., Huang, S. M., Xu, M. G., Lu, C. A. and Zhang, W. J. 2009. Effects of the different long-term fertilizations on fractions of organic carbon in fluvo-aquic soil. *Plant Nutrition and Fertilizer Science*, 15:831-836. (in Chinese)

Tripathi, S., Chakraborty, A., Bandyopadhyay, B. K. and Chakrabarti, K. 2008. Effect of long-term application of fertilizers on soil quality and rice yield in a salt affected coastal region of India. *Arch. Agron. Soil Sci.*, 54 (4): 439-450.

Vanaja, T. 2013. Kaipad – A unique, naturally organ ic, saline prone rice ecosystem of Kerala, India, *Am. J. Envi. Pro.* 2(2): 42–46.

Varghese, T., Thampi, P.S. and Money, N.S. 1970. Some preliminary studies on the *pokkali* saline soils of Kerala. *J. Indian. Soc. Soil Sci.* 18: 65-70.

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37: 29-38.

Wan, Y., E. Lin, W. Xiong, Y. Li, and L. Guo. 2011. Modeling the impact of climate change on soil organic carbon stock in upland soils in the 21st century in China. Agric. Ecosyst. Environ. 141:23–31. doi:10.1 016/j.agee.2011.02.004.

Watanabe, F.S. and Olsen, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and NaHCO3 extracts from soil. *Soil Science Society of America Proceedings*, 29: 677 – 678.

Witter, E., Martensson, A.M. and Garcia, F.V. 1993. Size of the microbial biomass in a long-term field experiment as affected by different N-fertilizers and organic manures. *Soil Biol. Biochem.* 35: 659–669.

Xie, L. J., Wang, B. R., Xu, M. G., Peng, C. and Liu, H. 2012. Change of soil organic carbon storage under long term fertilization in black and grey-desert soils. *Plant Nutrition and Fertilizer Science*. 18: 98-105. (in Chinese)

Xu, X. Z., Xu, Y., Chen, S. C., Xu, S. G. and Zhang, H. W. 2010. Soil loss and conservation in the black soil region of Northeast China: A retrospective study. *Environmental Science and Policy*.13: 793-800.

Yan, D., Wang, D. and Yang, L. 2007. Long-term effect of chemical fertilizer, straw, and manure on labile organic matter fractions in a paddy soil. *Biology and Fertility of Soils*. 44: 93-101.

Yoder, R. E. 1936. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *J. Am. Soc. Agron.*, 28: 337-351.

Yu, G., Fang, H., Gao, L. and Zhang, W. 2006. Soil organic carbon budget and fertility variation of black soils in Northeast China. *Ecological Research*. 21: 855-867.

Zhang, H.M., Wang, B.R., Xu, M.G., Fan, T.L., 2009a. Crop yield and soil responses to long term fertilization on a red soil in southern China. *Pedosphere* 19 (2):199–207.

Zhong, W.H. and Cai, Z.C. 2007. Long-term effects of inorganic fertilizers on microbial biomass and community functional diversity in a paddy soil derived from quaternary red soil. *Appl. Soil Eco.* 36 (2/3):84–91.

CARBON DYNAMICS OF ACID SALINE *POKKALI* SOIL UNDER LONG TERM FERTILISER APPLICATION IN RICE

by

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ABSTRACT OF THE THESIS

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ABSTRACT

The amount of carbon in the atmosphere has increased by 30 per cent. The rising temperatures and carbon dioxide concentration and uncertainty in rainfall associated with climate change may have direct relationship with increased levels of carbon dioxide. One proposed method to reduce atmospheric carbon dioxide is to increase the global storage of carbon in soils with an added benefit in simultaneous enhancement in agricultural production. Soil organic carbon (SOC) is one of the main carbon reservoirs in the terrestrial ecosystem. It is important to study SOC dynamics and effects of organic carbon amendments in paddy fields and saline soils because of their vast expansion

Objectives of the study were to estimate the soil organic carbon (C) status in acid saline soil and to assess the influence of long term fertilizer applications on soil carbon dynamics. Samples were collected from the experimental plot laid out in randomized block design with 10 treatments, each replicated four times with *pokkali* rice variety Vytilla 4 at RRS Vytilla, Kerala.

The study revealed the baseline soil characteristics especially the soil carbon and its counterparts. Vertical distribution of SOC showed the storage profile of carbon and in cultivated sites a topsoil carbon sink (mostly labile carbon) is identified owing to increased fertiliser inputs whereas a potential subsoil sink (non labile carbon) is identified vertically downwards.

However, the high content of non labile carbon in the subsurface showed the ability of *Pokkali* soil for carbon sequestrations. The labile carbon present in the surface soil resulted in the availability of nutrients to the plants which was evident from the high nutrient status of the control plot .all carbon fractions in the present study indicates the ability of *Pokkali* soils to sequester carbon. Therefore, the *Pokkali* ecosystem has to be maintained as such to mitigate the ill effects of global warming in the present climate change scenario.

APPENDICES

Weekly Weather Data - Maximum Temperature (^{0}C)

APPENDIX 1

WEEK	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	33.2	32.4	30.4	33.1	33.0	33.3	32.2	33.2	33.8	29.7	32.6	33.7	34.6
2	32.7	33.1	31.7	33.2	33.3	32.3	31.9	33.2	32.9	31.6	32.6	33.1	33.2
3	30.7	32.6	30.7	33.2	32.6	32.8	32.1	32.2	30.0	31.7	33.2	33.4	34.1
4	31.9	33.1	30.2	32.6	29.5	32.0	31.9	30.3	31.3	30.7	32.9	32.9	33.6
5	31.3	32.6	29.6	31.6	31.0	32.5	31.5	31.0	32.1	30.9	32.7	30.6	33.3
6	29.1	31.9	29.5	30.3	31.6	30.5	30.9	30.5	30.8	30.5	31.9	29.2	31.7
7	30.6	29.7	30.4	28.8	30.4	27.8	31.2	30.5	34.1	29.4	30.3	29.3	32.0
8	31.0	29.9	30.7	30.0	29.7	30.1	30.8	30.1	30.0	29.7	31.7	29.5	32.9
9	30.3	28.9	29.5	29.7	30.8	29.8	30.9	28.6	31.6	30.0	30.9	31.3	31.8
10	30.0	30.1	28.8	29.6	28.9	30.2	30.2	30.1	31.0	29.8	30.1	30.7	30.2
11	30.1	29.4	29.5	28.7	30.2	28.6	30.7	29.0	31.6	31.0	31.3	29.9	30.0
12	29.7	30.5	29.8	29.6	30.5	28.7	28.5	30.9	30.7	30.2	30.9	29.8	30.6
13	28.3	31.0	28.2	29.6	30.4	29.1	30.3	30.3	33.1	29.4	31.5	30.7	28.3
14	29.3	30.7	29.3	30.6	28.1	29.4	29.9	30.4	31.6	29.9	29.4	31.4	28.6
15	28.2	29.8	29.3	30.8	29.4	30.2	29.7	30.1	29.6	30.3	30.0	30.4	30.7
16	30.3	28.7	30.1	30.5	30.4	29.7	30.5	29.8	29.8	31.6	30.2	30.8	30.4
17	30.1	30.0	29.7	28.4	30.7	29.3	30.1	28.8	30.3	32.2	30.3	30.8	30.1
18	29.9	30.7	29.8	28.4	29.2	29.7	29.7	30.6	30.7	32.4	30.5	29.6	30.9
19	30.7	30.6	30.1	30.2	29.2	29.1	30.9	29.9	32.8	32.5	31.4	30.5	30.4
20	31.7	31.1	30.3	31.0	29.8	30.2	31.2	30.4	30.9	32.3	31.9	31.6	31.0
21	31.1	28.9	29.3	31.1	30.2	30.5	31.4	29.6	32.0	30.8	32.0	31.1	31.3
22	29.3	30.7	31.1	30.7	30.2	30.5	31.3	30.8	29.2	30.7	32.7	31.2	31.1
23	30.0	31.0	31.2	31.5	30.8	30.3	31.3	32.0	31.5	30.7	31.8	31.1	31.7
24	30.6	30.8	32.3	30.0	30.9	30.5	30.1	31.7	30.9	30.9	32.6	30.8	31.6
25	31.1	33.4	31.1	31.3	28.7	29.8	31.8	31.4	30.8	32.0	32.7	31.1	34.1
26	30.8	31.2	28.8	30.1	30.3	30.6	30.6	29.6	30.2	29.2	31.2	30.9	32.6
27	29.1	31.1	29.5	28.9	30.2	29.0	28.3	30.0	30.3	30.3	31.0	30.7	30.7
28	29.9	29.5	29.8	29.9	30.4	28.6	30.3	30.5	29.3	32.1	28.6	30.6	30.0
29	32.1	31.5	30.9	31.2	30.7	30.5	31.1	29.7	30.5	31.7	32.2	31.9	31.3
30	30.5	31.6	31.2	29.6	29.3	30.0	31.5	32.3	31.6	30.5	32.0	31.7	30.9

Weekly Weather Data - Minimum Temperature (^{0}C)

WEEK	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	26.5	25.7	24.8	26.0	26.2	26.2	25.5	26.4	25.9	33.5	25.6	25.7	24.9
2	26.2	27.0	25.3	26.4	26.8	25.6	25.3	25.0	27.1	32.8	25.2	25.7	25.4
3	24.7	27.6	24.4	26.7	25.4	25.6	25.5	24.3	25.7	33.3	26.1	24.8	25.4
4	26.1	27.5	24.2	26.2	23.8	25.5	25.1	24.3	25.9	33.3	25.1	24.2	25.6
5	24.9	27.0	24.5	24.8	24.4	25.1	23.9	25.0	24.3	29.7	24.5	22.4	24.5
6	23.9	25.3	24.1	24.8	25.3	23.6	24.2	23.8	23.3	31.6	23.5	21.6	23.6
7	24.1	23.9	25.6	23.7	25.3	22.6	24.5	24.3	24.7	31.7	23.2	22.4	24.5
8	25.9	23.7	24.9	23.6	23.9	23.8	23.7	23.9	24.0	30.7	23.5	22.0	24.9
9	24.7	23.3	24.6	23.4	24.9	23.2	23.9	22.7	23.3	30.9	22.9	22.1	24.1
10	24.6	24.0	23.6	24.3	23.7	23.1	23.4	23.4	24.1	30.5	22.5	22.2	23.8
11	24.9	23.7	24.4	24.1	24.0	22.8	23.5	23.6	23.9	29.4	24.2	22.1	23.7
12	24.2	24.3	24.5	24.1	24.8	23.0	23.1	24.4	23.0	29.7	23.6	21.8	23.8
13	23.4	24.8	23.9	23.1	24.0	23.1	24.3	24.1	23.2	30.0	24.7	22.2	23.0
14	23.3	25.1	23.9	25.1	23.4	23.2	23.4	24.8	24.5	29.8	22.6	23.4	23.5
15	23.6	23.5	23.6	24.3	23.4	24.8	23.8	24.3	24.0	31.0	23.0	22.9	24.9
16	24.9	24.1	25.3	24.9	24.7	23.6	24.0	24.0	23.6	30.2	23.0	23.1	25.2
17	24.6	23.7	24.7	23.9	25.1	22.9	23.3	23.8	24.5	29.4	22.8	23.2	23.9
18	24.1	24.6	24.5	23.7	23.3	23.6	23.2	25.0	23.9	29.9	23.3	22.9	25.1
19	24.7	24.5	24.3	25.1	23.8	23.7	23.7	24.3	23.5	30.3	23.4	23.1	24.5
20	24.5	24.7	24.4	24.6	23.5	23.7	24.0	23.8	23.4	31.6	23.7	23.4	24.7
21	25.0	24.4	23.8	24.1	24.4	23.6	23.9	23.3	23.7	32.2	23.6	22.5	25.4
22	23.9	23.9	24.1	23.9	23.8	23.9	24.2	24.2	24.2	32.4	24.0	23.0	24.9
23	24.2	24.9	24.4	24.9	23.0	23.5	23.9	24.7	23.4	32.5	23.0	22.7	24.6
24	25.1	24.4	24.3	24.3	24.1	23.3	23.4	25.0	23.9	32.3	23.8	22.6	24.1
25	24.5	26.7	24.9	24.2	23.1	23.0	24.2	24.9	25.4	31.3	26.0	23.5	25.9
26	25.5	24.2	23.7	23.8	23.4	24.2	23.0	23.7	23.1	32.0	22.3	23.1	25.7
27	24.2	24.5	24.0	23.4	22.8	23.5	22.1	23.4	22.0	29.2	24.1	22.7	25.9
28	25.0	24.3	25.5	24.9	23.1	23.2	23.6	24.4	23.4	30.3	22.1	24.3	24.5
29	25.5	25.3	24.3	24.9	23.9	24.1	23.8	23.5	24.4	32.1	24.0	24.0	24.6
30	24.9	24.0	24.0	24.0	23.5	23.0	24.0	25.2	23.1	31.7	23.6	23.0	24.2

Weekly W[illegible] Data - Rainfall (mm)

WEEK	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1	3.1	27.0	63.3	0.8	0.1	17.1	1.2	0.2	10.1	7.9	6.3	1.6	7.3
2	13.1	1.8	11.4	1.5	0.4	9.1	2.5	9.4	1.8	0.0	2.9	3.4	16.0
3	17.8	3.9	31.1	3.7	14.9	1.4	4.7	23.0	13.6	0.3	0.0	1.7	0.0
4	24.2	0.4	20.2	8.6	35.4	4.3	2.2	31.0	19.1	3.4	1.1	3.0	3.6
5	13.4	2.2	28.3	17.3	13.9	1.4	15.7	23.5	17.5	44.7	3.1	29.2	12.3
6	6.7	17.4	22.8	24.2	0.3	27.0	11.4	18.3	44.0	16.4	6.1	27.9	25.4
7	19.6	27.7	10.7	51.9	25.4	44.0	13.0	29.5	15.3	28.3	16.5	46.7	21.1
8	49.5	36.5	8.2	16.9	44.1	27.5	10.5	14.4	35.4	15.2	7.4	59.6	13.8
9	20.2	26.0	10.5	19.7	10.0	21.4	14.8	41.3	27.7	6.3	12.4	36.0	9.2
10	18.1	8.9	26.8	14.8	49.6	39.7	9.9	13.2	10.4	16.2	25.1	25.9	31.7
11	8.6	27.9	5.1	18.6	14.0	39.9	22.6	33.6	31.1	30.1	3.7	29.1	22.1
12	36.6	10.2	13.2	13.8	5.6	23.4	15.8	6.7	14.9	18.8	8.1	19.3	23.4
13	27.3	7.8	19.2	22.5	4.1	13.8	3.1	8.7	12.4	39.1	3.6	42.3	60.4
14	11.7	20.4	8.5	4.1	39.0	21.4	18.8	2.4	4.3	16.7	15.7	3.3	26.3
15	4.8	11.8	11.7	4.4	23.4	0.8	5.9	8.7	12.0	8.4	21.6	5.4	0.6
16	46.6	21.4	0.1	12.8	0.0	5.2	0.9	5.7	8.7	9.4	11.8	2.9	16.4
17	0.0	12.1	1.4	36.7	0.0	15.8	45.0	20.1	0.4	24.9	17.6	8.4	22.7
18	19.3	0.0	5.9	14.2	22.8	37.5	16.1	0.1	19.1	34.9	14.6	10.0	2.6
19	6.6	3.7	11.6	3.3	17.3	29.7	18.8	10.3	13.1	6.3	8.3	23.0	3.4
20	2.2	0.0	9.9	2.2	24.0	21.2	0.1	21.5	42.0	0.9	0.6	0.8	16.6
21	4.8	28.0	33.8	6.5	14.8	4.3	3.1	16.4	26.6	0.0	2.7	2.2	13.1
22	1.2	24.8	7.2	11.3	21.9	15.8	8.4	0.1	17.9	12.1	5.6	3.0	11.3
23	0.0	2.4	10.0	1.8	21.0	21.1	22.1	0.1	30.7	3.4	18.0	7.3	11.7
24	4.9	9.5	21.8	50.3	14.9	15.8	12.0	0.0	14.0	3.3	3.9	13.6	11.6
25	41.5	0.2	0.9	31.7	73.3	26.9	41.4	23.1	23.9	5.9	0.9	10.4	0.8
26	3.4	13.7	32.4	19.4	43.1	10.2	26.4	17.6	33.6	8.5	2.4	8.7	3.3
27	10.1	8.3	10.6	42.1	14.3	8.1	29.2	35.8	35.9	4.1	4.3	4.5	13.0
28	0.0	19.1	0.0	0.6	3.3	25.3	8.1	3.1	9.9	3.3	5.4	0.0	42.8
29	0.0	0.0	0.0	0.0	0.7	2.2	0.0	13.3	1.6	3.7	8.1	3.3	46.7
30	5.0	13.1	38.0	28.9	12.5	26.9	0.9	0.2	24.7	3.6	5.6	0.8	12.8

Grain Yield of pokkali (kg ha^{-1})

YEAR	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
2002	2365	2850	2700	2400	2315	2415	2250	2415	2575	2575
2003	2425	2115	2640	2290	2505	2515	2115	2790	2315	2375
2004	2015	2240	2625	2275	2290	2075	2100	2190	2025	2140
2005	4375	4040	4250	4225	4190	4225	4440	4375	3965	4265
2006	4575	4315	4490	4525	4450	4400	4190	4250	4240	4025
2007	4125	4490	4250	4100	3965	4025	3900	4100	4240	4065
2008	3813	3988	3863	3625	3875	3488	3875	4088	3488	3638
2009	2650	2500	2763	2863	2700	2788	3025	2963	2650	2588
2010	1874	1953	2573	2224	2023	1744	1871	2608	2016	2500
2011	3005	3050	2925	2763	3200	2944	3125	2844	2794	2098
2012	3395	2975	3305	2880	3235	2820	3045	3195	2820	3025
2013	3863	2573	3305	2240	2250	2415	2115	2224	2023	2505
2014	2991	3590	3347.5	3608.75	2815	3172.5	2815	3175	2862.5	2780

APPENDIX 2

Correlation matrices for *pokkali* yield and weather parameters

YLD	T_{max} ^0C	T_{min} ^0C	Rainfall(mm)
week 1	NS	NS	NS
week 2	NS	NS	NS
week 3	0.654819	NS	NS
week 4	NS	NS	NS
week 5	NS	NS	NS
week 6	NS	NS	NS
week 7	-0.54691	NS	0.59258
week 8	NS	NS	NS
week 9	NS	NS	NS
week 10	NS	NS	0.508934
week 11	NS	NS	NS
week 12	NS	NS	NS
week 13	NS	NS	NS
week 14	NS	NS	0.391046
week 15	0.424074	NS	NS
week 16	NS	NS	NS
week 17	NS	NS	0.413137
week 18	-0.54734	NS	NS
week 19	-0.49184	NS	0.426944
week 20	NS	NS	NS
week 21	NS	NS	NS
week 22	NS	NS	NS
week 23	NS	NS	NS

week 24	NS	NS	0.396503
week 25	-0.3846	-0.39499	NS
week 26	NS	NS	NS
week 27	NS	NS	NS
week 28	NS	NS	NS
week 29	NS	NS	NS
week 30	-0.55531	NS	NS

APPENDIX 3

Correlation table for CEC v/s pH at 0 - 15 cm depth

		CEC	pH
	Pearson Correlation	1	$.952^{**}$
CEC	Sig. (2-tailed)		.000
	N	10	10
	Pearson Correlation	$.952^{**}$	1
pH	Sig. (2-tailed)	.000	
	N	10	10

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

Correlation table for CEC v/s pH at 0 - 15 cm depth

		CEC	pH
CEC	Pearson Correlation	1	.916**
	Sig. (2-tailed)		.000
	N	10	10
pH	Pearson Correlation	.916**	1
	Sig. (2-tailed)	.000	
	N	10	10

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