DYNAMICS OF CARBON STOCK IN RICE BASED FARMING SYSTEMS OF *KARI* SOILS

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DECLARATION

I hereby declare that this thesis entitled **'Dynamics of carbon stock in rice based farming systems of *Kari* soils'** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **'Dynamics of carbon stock in rice based farming systems of *Kari* soils'** is a record of research work done independently by **Mr. Chethankumar S. (2017-11-093)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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LIST OF ABBREVIATIONS & SYMBOLS

% - Per cent
μm - Micro meter
Al - Aluminium
B - Boron
BD - Bulk density
C - Carbon
Ca - Calcium
$CaCO_3$ - Calcium carbonate
CD - Critical difference
CH_2O - Formaldehyde
cm - Centimeter
CO_2 - Carbon Dioxide
CRD - Completely randomized design
Cu - Copper
dSm^{-1} - deci Siemens per meter
EC - Electrical conductivity
et al - And others
Fe - Iron
Fig. - Figure
FYM - Farm yard manure
$g\ cm^{-3}$ - Gram per centimeter cube
$g\ kg^{-1}$ - Gram per kilogram
g - Gram
Gt - Gigatonnes
H - Hour
H_2SO_4 - Sulphuric acid
ha - Hectare
ha^{-1} - Per Hectare
i.e. - That is
K - Potassium
KAU - Kerala Agricultural University
$kg\ ha^{-1}$ - Kilogram per hectare
kg - Kilogram
$KMnO_4$ - Potassium permanganate
LC - Labile carbon
m - Meter
MBC - Microbial biomass carbon
Mg - Magnesium

mg kg^{-1} - Milligram per kilogram
ml - Milli litre
mm - Milli meter
mM - Milli molar
Mn - Manganese
N - Nitrogen
Na - Sodium
Nm - Nano meter
NS - Not significant
OC - Organic carbon
OM - Organic matter
P - Phosphorus
Pg - Peta gram
pH - Soil reaction
POC - Particulate organic carbon
ppm - Parts per million
rpm - Rotations per minute
S - Sulphur
SEm - Standard error of mean
Si - Silicon
SIC - Soil inorganic carbon
SOC - Soil organic carbon
SOM - Soil organic matter
TOC - Total organic carbon
viz. - namely
yr^{-1} - per year
Zn - Zinc

Introduction

1. INTRODUCTION

The soil organic carbon (SOC) pool is of great concern because it may represent a source as well as a sink of atmospheric CO_2 (IPCC, 2007) and its storage has been widely considered as a measure to mitigate global climate change through carbon sequestration in soil (Huang *et al.,* 2010). The soil may be subjected to loss and gain of organic C, depending on soil type, vegetation type, temperature, erosion, and land management. Land use and soil management practices play an important role in C sequestration in agricultural land as well. Some of the SOC fractions, such as labile carbon, particulate organic carbon (POC) and microbial biomass carbon (MBC) are known to be more sensitive indicators of soil management than total SOC (Chan, 2001; Gong, *et al.,* 2009). Soil organic matter plays a major role in maintaining quality of soil and ecosystem functionality. Changing patterns of land use and management practices have direct and indirect effects on soil organic pools, because of the changes in cropping practices, irrigation, tillage, fertilization, litter quantity and quality. Management practices or technologies that augment C input to the soil and reduce C loss or both, lead to net C sequestration in soil and reduce the greenhouse effect.

Rice is the major food crop in Asia and about 80 per cent of it is grown under flooded conditions. The flooded rice ecosystem has the capacity to store C in the soil and can behave as net C sink (Bhattacharyya *et al*., 2013). In the flooded conditions, the presence of standing water and the soil saturation decreases the organic matter decomposition, acting as significant sinks for C and nutrients (Mitsch and Gosselink, 2007).

Kuttanad is considered to be the rice bowl of Kerala with 16% of the total rice area and 30% of production in Kerala (GoK, 2014). The geographical area of Kuttanad is distributed in and around Vembanad lake in Alappuzha, Kottayam and Pathanamthitta districts. It is a special agro- ecological unit delineated to represent the water logged land which lies 1-2 m below mean sea level. Millions of years ago, these lands were covered with forests with abundant marshy vegetation. In succeeding geological ages, Arabian Sea advanced and engulfed these lands. The areas remained submerged below the ground level and got silted up to varying heights both by alluvium from the rivers and by the marine sediments. The sediments and soils in these areas have vast organic deposits along with fossils of timber and shellfish at different depths.

Kuttanad soils are sub divided and named according to morphological conditions into *kayal, karappadam* and *kari*. Unlike *kayal* and *karappadam* soils of Kuttanad, *kari* soils extending to 9000 ha have a different genesis making it difficult for reaching high productivity. *Kari* soils are deep black in colour, heavy in texture, poorly aerated and ill drained. The name *kari* is derived from the deep black colour of soil where large mass of woody matter at various stages of decomposition occur embedded in these soils. The soils are affected by severe acidity and periodic saline water inundation with consequent accumulation of soluble salts. In these soils, free sulphuric acid is formed by oxidation of sulphur (S) compounds of organic residues or that accumulated in the soil from sea water by repeated inundation. The soils are low in available nutrient status. Besides, they contain toxic concentrations of iron (Fe), aluminium (Al) and unidentified toxic organic compounds (Chattopadhyay and Sidharthan, 1985).

In these soils the major rice based cropping system is rice followed by water fallow or rice followed by fish. The fish species usually reared is carp species which helps in reducing cost of tillage as the soil gets well puddled by the movement of fish. Also the grass carp among the carp species helps in feeding on the grass species and reduces weedicide usage; the heavy use of which being a serious problem in Kuttanad. The addition of organic matter into the rice field as a result of fish culture helps to reduce the use of chemical fertilizers in paddy crop. The recycling of crop residue as a source of fish feed upon decomposition is another advantage of the system. Study on the influence of rice cultivation, fish culture or keeping land as water fallow on the organic C stock of soils of these two systems can bring light into the effective management of these lands as a C sink.

According to IPCC (2001), the management of rice farming for positive climate impact must consider the combined effects of C storage and greenhouse gas emissions in soil. Estimating soil C pools in these systems would help to identify the carbon fractions which are dominant and help to prioritize land use system for C sequestration in soil which also has co-benefits of restoring soil fertility, improving crop productivity, profitability and reducing environmental pollution.

Hence the present study on “Dynamics of carbon stock in rice based farming systems of *Kari* soils” was carried out with the objective, to find out the influence of rice-fish and rice-water fallow systems on C stock and C dynamics in *Kari* soils of Kuttanad.

Review of literature

2. REVIEW OF LITERATURE

Wetlands are known to accumulate organic matter in the soil and sediment, serving as C sinks and making them one of the most effective ecosystems for soil C storage. Soil organic C (SOC) storage is considered as a measure to mitigate global climate change through C sequestration in soils. The loss or gain of organic C in soils depends on soil type, erosion, temperature, vegetation type and land management. Some SOC fractions, such as labile C, particulate organic C (POC), microbial biomass C (MBC) are considered as more sensitive indicators of soil management than total SOC. *Kari* soils are a major type of soil in Kuttanad which is high in organic matter content with fossils of wood in the sub surface. In these soils the major rice based cropping system is rice followed by water fallow or rice followed by fish. The research information pertaining to C dynamics and soil nutrient content in rice-fish and rice-water fallow system is reviewed in this chapter.

2.1 Carbon dynamics in rice soils

Wetlands are known to have a great role in global C cycles. They accumulate large amounts of organic matter in the soil and are highly productive ecosystems functioning as significant C sinks (Mitra *et al.*, 2005). Wetlands are estimated to account for one third of the world's organic soil C pool (Lal, 2008).

Globally rice cultivation covers an area of about 153 mha and has been proposed to have a great potential to sequester atmospheric CO_2 (IPCC, 2007). According to Xie *et al.* (2007), paddy upland soils and wetland soils are the two main types of soils where rice is being cultivated and wetland soils generally show greater potential of C sequestration and higher SOC density than upland soils. Ramesh *et al.* (2007) investigated various land use systems of semi-arid tropics (SAT) and they have shown that the paddy systems had highest organic C and nitrogen content irrespective of bioclimatic zones. Jarecki and Lal (2003) reported the SOC sequestration potential for rice as 401 kg C ha^{-1} yr^{-1}. Long term experiments suggest that the soil organic matter under rice-wheat system in Indo-Gangetic plains have declined (Bhandari *et al.,* 2002). On the other hand, prolonged submergence stimulates SOM accumulation and C sequestration in wetlands and sediments (Pampolino *et al.,* 2008).

The decomposition of organic matter in submerged soil is slower than well drained soil (Ponnamperuma, 1972). When the soils are flooded, the most marked changes in their composition is loss of air from the pore space and gradual accumulation of organic matter (Boyd, 2012). High productivity, high water table and low decomposition rate associated with waterlogged soils favour C storage within the soil, sediment and detritus (Whitting and Chanton, 2001). Under anaerobic conditions, both the decomposition of applied organic matter and mineralization of native SOC are slower than those under aerobic conditions (Guo and Lin, 2001). In flooded condition both decomposition of amended organic materials and mineralization rates of native soil organic C are considerably retarded compared with those under aerobic conditions. Therefore, flooding can enhance organic C accumulation in the soils (Zhang, 2004). Bronson *et al.* (1998) also reported an increase in C stocks in soil due to relatively slow rate of C mineralization under anaerobic conditions. Jenkinson (1988) opined that the rate of decomposition of soil organic matter is lessened in submerged soils, apparently due to excessively reduced conditions. The organic C stored in paddy soils is much higher than upland soils because of different biochemical processes and mechanisms mainly caused by the presence of flooded water in paddy soils (Guo and Lin, 2001). In submerged soils, formation of recalcitrant complexes with organic matter makes them less available for microbial attack. Moreover, the biological nitrogen fixation coupled with overall higher primary productivity and decreased humification lead to net accumulation of organic matter in wetland soils and sediments. Consequently, prolonged submergence promotes the formation of passive pools of SOC vis-a-vis C sequestration (Mandal *et al.,* 2008). In contrast, formation of humic compounds is increased under partially oxidizing conditions: If there is too much oxygen, mineralization occurs; if there is too little, oxidative polymerization is stifled. Frequent wetting and drying cycles avoid the stagnation that occurs under either oxidizing or reducing conditions and promote the oxidative polymerization reaction that stabilizes C (Post *et al.,* 2004). The mechanisms involved in preferential accumulation of organic matter in wetlands are ascribed mainly to anaerobiosis and the associated chemical and biochemical changes (Sahrawat, 2005). Intensive rice cropping helps in accumulation of phenolic lignin compounds which are resistant to microbial decomposition under submerged condition (Olk *et al.,* 2000). They concluded that the changes in SOC quality under submerged conditions might contribute to the slowdown of C decomposition in paddy soils. According to Kolar *et al.* (2006), the high SOM content with high TOC value in permanently waterlogged soils could be blocked in inert form or the mineralization process is limited. On the other hand, TOC reduction under critical limit negatively affects soil properties and productivity and balanced organic matter turnover is necessary for sustainable ecosystems (Stewart *et al.,* 2008).

2.2 Impact of fish culture on soil and rice yield

Food and Agricultural Organization (FAO, 1988) highlighted the advantages of rice-azolla-fish system as reflected in the greater grain yield, fish biomass, soil fertility, decreased incidence of weeds, pests, and diseases. Lightfoot *et al.* (1990) opined that integrated rice-fish system offered the possibilities of increasing rice yields by as much as 15% while continuous monocropping of rice led to a decline in soil microbial biomass and fertility. According to Lightfoot *et al.* (1993), stocking of fish in rice fields may contribute to the general fertility status of rice field. The enhancing effect of fish rearing on physico-chemical properties of soil and flood water has been reported by a number of researchers (Cagauan, 1995; Vromant and Chau, 2005). This has been related to the behavior of fish removing weeds and releasing nutrients by disturbing sediments (Kunda *et al.,* 2008). Increase in soil fertility due to fish rearing has been reported earlier and was attributed to either (1) additional nutrients from decomposing dead fish and from fish faeces, (2) fish perturbation of the soil-water interface leading to release of fixed nutrients, and (3) fish grazing on the photosynthetic aquatic biomass aiding in nutrient recycling and decreasing N losses. All these, either alone or in combination might have resulted into an increase in grain yield in rice (Cagauan, 1995). Fish perturbation of the soil–water interface might make the soil porous for nutrients to be readily absorbed by the rice roots (Vromant and Chau, 2005). Fresh water prawn culture in rotation with boro rice in low-lying agricultural areas of southern Bangladesh was found to be a profitable farming practice by Asaduzzaman (2006). Fish cultivation in paddy fields leads to the productivity of soil (Bakhshzad-Mahmoudi, 1997; Frei and Becker, 2005) and is followed by greater rice yield (Das *et al.*, 2002; Frei and Becker, 2005; Yong *et al.*, 2006) and provides greater interest for the farmer compared to rice monoculture fields through increased yield of the rice (Saikia and Das, 2008). The fish farming is an easy, sustainable and low-cost activity taking the potential facilities available in the paddy field, and if performed in a systematic and technical way, to have higher yield of rice and to produce high value protein and minerals through fish followed by positive and beneficial effects along with profit of selling the fish (Noorhossein and Bagherzadeh-Lakani, 2013).

According to Padmakumar *et al.* (1988), fish farming in paddy-fields is known to improve the soil conditions leading to increase in rice yield. Rice-fish rotation is also considered to be effective in suppressing weeds, pests, and diseases. An investigation made by Padmakumar *et al.* (1988) wherein fish varieties such as Indian major carps, *Etroplus*, *Cyprinus*, and *Macrobrachium rosenbergi* were polycultured, fish yield up to 1005 kg per ha without incurring any additional expenses on feeding or manuring was achieved and rotational farming of rice and fish was found to be a viable option for Kuttanad. As compared to the practice of simultaneous farming that requires several modifications in the paddy-fields, utilization of paddy-fields for rotational farming permitted adoption of better management practices for both rice and fish (Padmakumar *et al.*, 1990).

Omofunmi *et al.* (2016) investigated the impact of pond effluents on soils, where the pH of effluent discharged soils were relatively higher than that of non-effluent discharged soils. The pH is one of the principal factors affecting nutrients availability in the soil. The organic C content and concentrations of both micronutrients and macronutrients were higher in effluent discharged soils. The contributions of catfish effluents to the nutrients content of the soil were quite appreciable.

2.3 Carbon pools

The soil C pool is divided into organic and inorganic components. The soil organic C (SOC) pool is derived from the leftovers of C in plants and animals. The soil inorganic C (SIC) pool is derived from the parent material as primary Cates of minerals such as calcite, dolomite and gypsum and from sequestration of atmospheric CO_2 as secondary Cates. Soil organic and inorganic C pools are estimated to be 1550 and 950 Pg respectively (Batjes, 1996).

Total C in soil is the sum of both the organic and inorganic C which is estimated to be 2157-2293 Pg of C for the upper 100 cm (Batjes, 1996). According to Schlesinger (2000), SOC is considered to be the largest global terrestrial C pool and estimated to stock about 1500-2000 Pg of C in various organic forms. The other global estimates of soil organic C pool, ranges from 1115 to 2200 Pg of C (Batjes, 1992), 1220 Pg of C (Sombroek *el al.,* 1993), and 1576 Pg of C (Eswaran *et al.*, 1993), respectively. SOC pool is highly reactive, highly dynamic and a strong determinant of soil quality. The total organic C pool in Indian soils is estimated to be 9.55 Gt at 0.3 m depth and 30 Gt at 1.5 m depth (Bhattacharyya *et al.*, 2009). The reserves of inorganic C (as Cate) stored in soils have been estimated to be 780-930 Pg of C (Schlesinger, 1982), and 720 Pg of C (Sombroek *et al.*, 1993), which can be released by weathering.

Inorganic C in soil occurs largely in Cate minerals, such as calcium Cate ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). Some kind of soils, particularly the acid and strongly weathered ones, do not contain appreciable amounts of inorganic C because the Cates originally present in the parent material have been dissolved. Large Cate concentrations are common in the soil of dry areas, as well as in soil formed by calcareous parent materials such as Rendzinas and some Lithosols (Batjes, 1996).

Depending on land uses, soil can be a net sink or source of CO_2. Various land use systems have varied potentials for C sequestration (Blanco *et al.*, 2007) due to differential soil organic C and aggregation dynamics (Six *et al.*, 1998). Bell (2009) reported that about 40-80 Pg of C can be sequestered in soils over next 50-100 years through sustainable soil management. Singh *et al.* (2003) reported that the active soil organic C was highest in surface soil compared to subsurface soil under rice-wheat cropping system.

According to Chacko *et al.* (2014), soil C storage capacity refers to the C sequestration potential of the soils and highest SOC sequestration was found under abandoned paddy fields followed by coconut plantations. The higher magnitudes of POC which is a subset of SOC was found in Coconut plantations than that of abandoned and cultivated paddy fields. Shao-xian *et al.* (2012) reported that organic amendments and crop residues (rice stubble and roots) are the major C sources in paddy fields.

2.3.1 Soil organic carbon

Soil organic C is a measure of soil organic matter which is derived from the plant residues, soil organisms and manures, which decay through various processes and at different rates depending on their composition, soil condition and climate. The components like carbohydrates and proteins, break down rapidly where as lignin a complex chemical in wood is slowly decomposed by fungi and bacteria (Brady and Weill, 1996).

The soil organic C (SOC) plays an important role in sustaining soil quality, environmental quality and crop production (Baver and Black, 1994) as it affects physical, chemical, and biological properties of the soil (Sainju and Kalis, 1990).

Management of soil organic matter determines the soil organic C content in any soils (agriculture and forest) (Baldock and Nelson, 2000). For example, it is generally accepted that following of rice based cropping practices would enhance the accumulation of soil organic C (Lal, 2002). Surface soils contain greater organic matter which decreases with increase in depth and related soil fertility components also follow the same pattern (Waiker *et al.,* 2004). Soil organic C increased with years of rice cropping, but decreased with depths. The organic C content was highest in the 0-10 cm depth, followed by the 10-20 cm, and then became smaller with increasing depths (Zhang, 2004).

2.3.2 Labile carbon pool

The labile organic C pool refers to a readily metabolized component of soil organic matter (SOM). This biologically active C pool plays a major role in soil productivity and is known to be a major soil nutrient reservoir (Wander and Traina, 1996). According to Weil *et al.* (2003), it enhances the soil food web.

According to Paul *et al.* (1997) and McLauchlan and Hobbie (2004), the labile C pool has a greater turnover rate or shorter mean residence time ranging from several weeks to months or years, compared to recalcitrant pools. Light fraction of organic C undergoes rapid mineralization due to the labile nature of its constituents and lack of protection by soil colloids (Turchenek and Oades, 1979).

The labile C fractions *i.e.*, microbial biomass C (MBC), particulate organic C (POC), hot-water extractable C (HWC), dissolved organic C (DOC), and permanganate oxidizable C ($KMnO_4$–C)] respond very quickly to any changes in management practices than SOC and are thus used as early and sensitive indicators of SOC changes (Haynes, 2000).

2.3.3 Particulate organic carbon

Particulate organic C (POC) is biologically active fraction of SOC and source of energy for the soil microbes (Cambardella and Elliot, 1992; Gregorich and Janzen, 1996) and responds more quickly to soil management practices (Bayer *et al.,* 2001).

POC is considered as an intermediate fraction of SOC between active and slow fractions that change rapidly over time due to the changes in land uses. C accumulation in particulate organic matter is rapid under minimum soil disturbance and can be an early indicator of changes in SOC under different management practices (Cambardella and Elliott, 1992; Carter, 2002).

Mohanty *et al.* (2009) reported that rearing fish such as common carp that are bottom feeders bring minerals and organic matter from the sediment into suspension through feeding activity. This resulted in increased water turbidity and particulate organic mater (POM) in the rice field.

Higher POC and MBC were observed in agroforest and fallow field compared to grain cropping, where living roots were present and active for 3-6 months due to the labile C in the root exudates (Huang *et al.,* 2010).

2.4 SOIL PROPERTIES

2.4.1 Bulk density

Hammel (1989) observed that bulk densities in the top 300 mm of silt loam soil were higher with zero tillage than with minimum tillage or conventional tillage treatments. Hoffman (1990) also observed that bulk densities of zero tillage and minimum tillage increased from the surface of the soil to a depth of 150 mm.

Smith and Doran (1996) have revealed that high soil bulk density caused by soil compaction could lead to low aeration and root growth with subsequent low C accumulation.

Bhattacharyya *et al.* (2009) found that the physical and chemical properties of red and black soils were related to the content of organic and inorganic form of C in soils. Direct and indirect relations between SOC, soil inorganic C (SIC), soil drainage and BD were observed among 52 benchmark soils from the semi-arid tropics in India. Soil organic C (SOC) is positively correlated with total clay but soil inorganic C (SIC) shows a negative correlation. SOC and bulk density (BD) are negatively correlated where as SIC and BD indicate a positive correlation.

Ahukaemere and Akpan (2012) reported that the average bulk density of the soil varied from 1.31-1.43 g cm^{-3}. Bulk density increased with depth in all the farms studied.

2.4.2 pH and EC

Carter (1996) opined that soil organic matter accumulation and storage was greatly affected by soil properties such as soil particle size, pH, quantity and kind of clay minerals and internal drainage. Soil acidification can result in decreased decomposition rates of organic matter (Paustian *et al.,* 1997) and have positive impact on soil organic C content.

Soil pH changed in the following orders among various land use practices: catfish pond soils > paddy soils > forest soils (Han *et al.,* 2007). The subsoil showed higher potential acidity compared to surface soils (Indira and Covilakom, 2013).

Addition of organic matter to soil would result in increase or decrease in the soil pH. The presence of weakly acidic chemical functional groups of soil organic molecules makes soil organic matter an effective buffer. The diversity in functional groups gives the organic matter an ability to act as buffer over a wide range of pH. Good correlations have been observed between soil buffering capacities and the organic matter content (Tan *et al.*, 2007).

Omofunmi *et al.* (2016) investigated the impact of pond effluents on soils, the results shown that pH of effluent discharged sites were relatively higher than that of non-effluent discharged sites. The effluent discharged site is more alkaline than other sites. The pH of the effluent discharged soil was significantly different ($p \geq 0.05$) from the non effluent discharged sites. The pH is one of the principal factors affecting nutrients availability in the soil. The pH affects the physical, chemical, and biological properties of the soil. At very acid or alkaline pH levels, organic matter mineralization is slowed down or stopped because of poor microbial activity linked to bacteria (Omofunmi *et al.,* 2016). Smith and Doran (2006) highlighted that most microorganisms have an optimum pH range for survival and function and Bacteria, and Fungi that aided decomposition performed well at pH range of 5-9 and 2-7 respectively.

The pH of pond effluent discharged soils were relatively higher than that of non effluent discharged soils as reported by Omofunmi *et al.* (2016)

Stalin *et al.* (2006) reported that soil EC increased slightly when the organic and inorganic fertilizers were applied for ten years continuously.

2.4.3 Available macronutrients

Nitrogen in soil is present mostly in organic form, the fraction present as amino-acids, peptides and easily decomposable proteins is called available form of nitrogen (Banerjea, 1967).

Greater accumulations of organic C and total N in the plow layer of soil could be explained by increased input of plant residues, reduced decomposition rate of organic residues, and increased N fixation in the rice production system (Roger and Ladha, 1992). Lian (1993) reported from the long-term experiments of Asia that continuous manure application increased soil organic matter and nitrogen content, but the increase was less significant in tropical and subtropical countries than in temperate regions due to more rapid turnover of organic C. The nutrients including N and P increased rapidly in the top layer of the soil and slowly in the bottom layer (Zhang, 2004).

Rice-fish systems are often related with recycling of nutrients, improvements in resource utilization and increase in soil fertility due to accumulation of nitrogen (Li, 1988; Lightfoot *et al.*, 1992; Sastradiwirja, 1992; Frei and Becker, 2005). The nitrogen, phosphorous, and potassium contents of the soil and water increased significantly when fish are stocked in rice fields (Oehme *et al.*, 2007). Mohanty *et al.* (2009) reported an increased organic C, available N and P in soil, which was likely due to (1) the additional nutrients from the fish feed and feces and (2) fish grazing on the photosynthetic aquatic biomass and other components of the system, thereby aiding in nutrient cycling, minimizing N losses (Cagauan, 1995) and facilitating P release from the sediment (Breukelaar *et al.,* 1994).

Phosphorous is mostly available to plant uptake between the soil pH 6.0 to 6.5, and the availability decreases outside this range. Highly acidic organic soils (pH <4) showed Al toxicity and P deficiency (Kidd and Proctor, 2001). The acid sulphate soils of kuttunad possesses low pH (high acidity). Besides these, the soils contain high range of iron and aluminium content which causes fixation of phosphorus (Audebert and Sahrawat, 2000; Dixit, 2006; Suswanto *et al.,* 2007).

Low soil pH leads to decrease in basic cations such as Ca and Mg, causing their insufficiency for plant growth. In acidic soils, a large portion of the Ca exists in soluble form, yet both soluble and exchangeable Ca diminishes with diminishing soil pH. Besides at low soil pH, the availability of Ca is decreased by higher concentrations of Al (Haynes and Ludecke, 1981). The availability of Mg is greatly influenced by the availability of other cations such as NH_4, Ca and K (Fageria, 2001; Romheld and Kirkby, 2007). Ca, Mg, and K content interact antagonistically with one another and the addition of any of them will lessen the availability of the other two (Malvi, 2011).

High sulphur content could leads to the generation of sulphides and organic acids in submerged soils of rice field that might cause toxicity as substantiated by Yoshida (1981) and Sahrawat (2005).

Soil acidity makes most of the nutrients unavailable, for example, Nitrogen (N), Phosphorus (P), Potassium (K), Magnesium (Mg), Sulphur (S), Copper (Cu) and Boron (B) is advanced between pH 5.5 and 7 (Rajput, 2012).

2.4.4 Available micronutrients

Ottow (1981) reported that ferrous ion acumulation will increases with increase in organic matter.

The availability of micronutrients generally decreases as soil pH increases (Wilson and Slaton, 2002). Takeda *et al.* (2005) reported that the increase in soil pH effected the degree of complexation of Cu in the soil solution and the soluble complexes of Cu increased the total copper solubility in soil, even though, the free Cu^{2+} solubility was remarkably low under high soil pH.

According to Han *et al.* (2007) the available Mn, Fe and Zn in catfish pond soils were higher than paddy and forest soils.

Some of the nutrients, for example, Al, Fe, Manganese (Mn) and Zinc (Zn) are progressively accessible at a lower pH and when the pH goes underneath 5.0, these nutients become increasingly soluble and collect in the toxic concentrations in the rhizosphere (Rajput, 2012).

Sharma *et al.* (2008) reported that the application of FYM improved apparent availability of added and native boron from soil to sunflower crops.

Dey *et al.* (2015) explained that the significance of boron (B) under intensive cropping systems particularly in acid soils. His study revealed that use of lime or FYM helped in modifying the distribution of soil B in different fractions by way of changing soil pH and organic C content, resulting in enrichment of plant available pool.

2.4.5 Exchangeable aluminium

Since the kari soils possesses extreme acidity, the iron and aluminium toxicity are predominant and which are the major concerns for low rice productivity in lowland acid sulphate soils (Fageria and Carvalho, 1982). Phosphorus deficiency is another problem in acid sulphate soils as the P gets fixed due to high concentrations of Fe and Al (Suswanto *et al.,* 2007).

2.4.6 Silicon

Usually the silicon concentration is quite high in grasses (Epstein, 1999). It has a prominent role in plant growth. Silicon helps to improve plant growth and yield and provide resistance against lodging. It also helps to enhance photosynthesis, has a good effect on surface properties. It offers resistance to disease causing organisms, herbivores, salinity stress, metal toxicity, drought stress and protection against temperature extemes (Epstein, 2001; Ma and Takahashi, 2002).

Materials and methods

3. MATERIALS AND METHODS

Kari soils are a major type of soil in Kuttanad which is high in organic matter content with fossils of wood in the sub surface. In these soils the major rice based cropping system is rice-water fallow or rice-fish. After rearing fish no tillage operations are usually done by farmers as the soil gets well puddled by the movement of fish. Study on influence of rice cultivation, fish rearing and keeping land as water fallow and tillage, on organic C stock of soils of these two systems can bring light into the effective management of these lands as a C sink. The present study entitled "Dynamics of carbon stock in rice based farming systems of *Kari* soils" was undertaken with the objective of studying the influence of rice-fish and rice-water fallow systems on C stock and C dynamics in *Kari* soil.

The experiment was carried out in paddy field coming under of KVK, Kumarakom *Kari* soils of Kuttanad. The details of the field experiment from which the soil samples were collected, the laboratory analytical methods followed and statistical techniques adopted are discussed in this chapter.

3.1 DETAILS OF FIELD EXPERIMENT AT KVK, KUMARAKOM

Design : CRD

Replication : 10 (number of soil samples)

Treatments : 4

Season : Dec 2017 to Dec 2018

Location : Rice field of KVK, Kumarakom

T_1- rice-fish system; soil samples from soil depth 0-20 cm
T_2- rice-fish system; soil samples from soil depth 20-40 cm
T_3- rice-water fallow system; soil samples from soil depth 0-20 cm
T_4- rice-water fallow system; soil samples from soil depth 20-40 cm

Rice-fish system

Field size: 25 cents

One crop of rice from August to November (four months) followed by fish rearing from December to July (eight months)

One sample from every 2.5 cents at two depths, 0 to 20 cm and 20 to 40 cm at two stages.

a. Before rice

b. After rice

Rice-water fallow system

Field size : 25 cents

One crop of rice from August to November (four months) followed by water fallow from December to July (eight months)

One sample from every 2.5 cents at two depths, 0 to 20 cm and 20 to 40 cm at two stages.

a. Before rice

b. After rice

3.2 COLLECTION OF SOIL SAMPLES

Initial soil samples were collected before fish or before water fallow from both rice-fish and rice-water fallow system. During the field experiment soil samples were collected at two different stages *viz*. Before and after rice cultivation in both rice-fish and rice-water fallow system. Samples were collected from two depths *viz*. 0-20 and 20-40 cm using soil tube, soil from soil tube is collected, packed in a polythene bag and labelled.

3.3 PREPARATION OF SOIL SAMPLES FOR ANALYSIS

The samples were air dried, ground and passed through 2 mm sieve and used for analysing C fractions and other physico-chemical properties of soil.

3.4 SOIL CARBON POOLS

3.4.1 Soil organic carbon

Soil organic C was determined by Walkley and Black's (1934) rapid titration method.

3.4.2 Labile carbon

Three grams of air-dried soil (<2 mm) sample was taken in a 50 ml centrifuge tube and to that 30 ml of 20 mM $KMnO_4$ was added. Run a blank without taking soil. The content was shaken for 15 minutes and it was centrifuged for 5 minutes at 2000 rpm and 2 ml aliquot of supernatant solution was transfered into 50 ml volumetric flask and read the absorbance at 560-565 nm and concentration of $KMnO_4$ was determined from standard calibration curve and the labile C calculated (Blair *et al.*, 1995).

3.4.3 Particulate organic carbon

Particulate organic C (POC) was determined by sodium hexa meta phosphate dissolution method as described by Camberdella and Elliott (1992) and Hassink (1995). Ten gram of soil sample was taken in a conical flask and 30 ml of 0.5 percent sodium hexa meta phosphate solution was added and shaken for 15 h on a reciprocal shaker. The dispersed soil sample was passed through 53 µm sieve. After rinsing several times with water, the material which was retained on sieve and the fine fraction that was collected in the beaker were dried at 50°C overnight. The POC fraction of >53 µm (coarse fraction) and <53 µm (fine fraction) were analysed for carbon content by Walkley and Black's (1934) rapid titration method.

3.5 OTHER SOIL PARAMETERS

The standard procedure followed for the other soil parameters are given in Table 1 and the analytical values of initial samples collected are given in Table 2.

3.6 STATISTICAL ANALYSIS

All the data were analysed statistically for analysis of variance applicable to completely randomized design (CRD) by standard procedures using statistical analysis software WASP package.

Table 1. Standard procedures followed in analysis of soil samples

SL. No.	Parameters	Method	Reference
1.	pH	pH meter	Jackson (1958)
2.	EC	Conductivity meter	Jackson (1958)
3.	Organic C	Chromic acid wet digestion method	Walkley and Black (1934)
4.	Bulk density	Undisturbed core sampler	Black *et al.* (1965)
5.	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
6.	Available P	Bray extraction and photoelectric colorimetry	Bray and Kurtz (1945)
7.	Available K	Flame photometry	Jackson (1958)
8.	Available Ca	Atomic absorption spectroscopy	Jackson (1958)
9.	Available Mg	Atomic absorption spectroscopy	Jackson (1958)
10.	Available S	Photoelectric colorimetry	Williams and Steinbergs (1959)
11.	Available Zn	Atomic absorption spectroscopy	Sims and Johnson (1991)

12.	Available Fe	Atomic absorption spectroscopy	Sims and Johnson (1991)
13.	Available Cu	Atomic absorption spectroscopy	Sims and Johnson (1991)
14.	Available Mn	Atomic absorption spectroscopy	Sims and Johnson (1991)
15.	Available B	Photoelectric colorimetry	Berger and Truog (1939)
16.	Exchangeable Al	Atomic absorption spectroscopy	Willis (1965)
17.	Available Si	Photoelectric colorimetry	Korndorfer *et al.* (2001)

Table 2. Properties of initial soil sample

PARAMETER	T_1	T_2	T_3	T_4
Bulk density (g cm^{-3})	0.86	1.06	0.88	1.10
pH	3.87	3.62	3.51	3.33
EC (dS m^{-1})	3.07	3.25	2.85	3.00
Available N (kg ha^{-1})	365.97	263.42	324.13	251.23
Available P (kg ha^{-1})	10.12	9.98	9.69	9.18
Available K (kg ha^{-1})	385.36	313.41	314.32	285.46
Available Ca (mg kg^{-1})	330	355	306	322
Available Mg (mg kg^{-1})	155	140	150	155
Available S (mg kg^{-1})	92.46	110.57	92.77	108.21
Available Fe (mg kg^{-1})	759	794	777	784
Available Cu (mg kg^{-1})	5.79	5.92	6.32	6.89
Available Mn (mg kg^{-1})	5.86	5.65	6.59	6.48
Available Zn (mg kg^{-1})	7.82	8.59	8.20	9.16
Available B (mg kg^{-1})	0.23	0.21	0.24	0.22
Exchangeable Al (mg kg^{-1})	346	333	358	335
Available Si (mg kg^{-1})	55.09	50.74	60.42	49.08

Organic C (g kg^{-1})	49.61		42.03		46.52		40.56	
Labile C (mg kg^{-1})	6158.034		6047.631		6023.097		5891.227	
Particulate organic carbon (g kg^{-1})	**<53 µm**	**>53 µm**	**<53 µm**	**>53 µm**	**<53 µm**	**>53 µm**	**<53 µm**	**>53 µm**
	13.09	5.62	11.55	4.74	12.94	5.2	10.78	4

T_1- rice-fish system; soil samples from soil depth 0-20 cm

T_2- rice-fish system; soil samples from soil depth 20-40 cm

T_3- rice-water fallow system; soil samples from soil depth 0-20 cm

T_4- rice-water fallow system; soil samples from soil depth 20-40 cm

Plate 1a. Rice-fish system

Plate 1b. Rice-water fallow system

Plate 1. Field view of rice-fish and rice-water fallow system before rice cultivation

Plate 2a. Rice-fish system

Plate 2b. Rice-water fallow system

Plate 2. Field view of rice-fish and rice-water fallow system after rice cultivation

Results

4. RESULTS

The results of the investigation entitled "Dynamics of carbon stock in rice based farming systems of *Kari* soils" are presented in this chapter.

The experiment includes two different farming systems *viz*. Rice-fish and rice-water fallow systems, which were divided into four treatments *viz*. T_1- rice-fish system; soil samples from 0-20 cm depth, T_2- rice-fish system; soil samples from 20-40 cm depth, T_3- rice-water fallow system; soil samples from 0-20 cm depth, T_4- rice-water fallow system; soil samples from 20-40 cm depth to make the statistical analysis simple. The values between these treatments were compared separately at different stages such as before rice and after rice cultivation.

4.1 SOIL CARBON POOLS

4.1.1 Soil organic carbon

The data pertaining to the effect of treatments on organic C in soil at different stages are given in Table 3. Before raising rice crop, the SOC was highest in treatment T_1 (rice-fish system; soil samples from soil depth 0-20 cm) (57.014 g kg^{-1}), followed by T_2 (rice-fish system; soil samples from soil depth 20-40 cm) (53.611 g kg^{-1}) and lowest in T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm) (50.089 g kg^{-1}) and treatment T_2 was on par with T_3. Among the treatments, the treatments with surface soil (0-20 cm) was found to have highest SOC compared to sub surface soil (20-40 cm) and the SOC was higher in rice-fish system at both the depths compared to rice water fallow system.

After rice cultivation, the SOC was analysed and found that the content ranged from 40.134 to 48.5 g kg^{-1} with highest value in treatment T_1 (rice-fish system; soil samples from soil depth 0-20 cm) and lowest value in T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm). The treatment T_1 was on par with T_3 and T_3

was on par with T_2. Soil sample collected from 0-20 cm depth (surface depth) recorded higher SOC under rice-fish and rice-water fallow system.

Table 3. Effect of treatments on soil organic C at different stages (g kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	57.01	48.50
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	53.61	43.84
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	52.82	45.40
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	50.08	40.13
SE(m)±	**0.490**	**0.544**
CD(0.05)	**3.148**	**3.499**

4.1.2 Labile carbon

The data related to effect of treatments on labile C in soil at differnt stages are presented in Table 4. There was no significant difference observed between the treatments during both before rice and after rice cultivation. However higher labile C was observed in T_1 (rice-fish system; soil samples from soil depth 0-20 cm) at both the stages.

Table 4. Effect of treatments on labile C in soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	6249.11	5996.29
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	6117.55	5930.92
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	6076.45	5988.74
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	6057.13	5903.24
SE(m)±	**25.857**	**17.756**
CD(0.05)	**NS**	**NS**

4.1.3 Particulate organic carbon

The effect of treatments on particulate organic C (POC) concentration in soil at different stages are presented in Table 5.

The particulate organic C was fractioned into fine (<53 μm) and coarse (>53 μm) fractions. Before raising rice crop, the fine (<53 μm) POC fractions ranged from 11.58 to 15.10 g kg^{-1} with highest value in T_1 (rice-fish system; soil samples from soil depth 0-20 cm) and lowest in T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm). The treatments T_1, T_2 and T_3 were on par and T_2 was on par with T_4. The higher fine (<53 μm) POC fractions were recorded in surface soil depth with 15.10 and 14.03 g kg^{-1} in rice-fish and rice-water fallow system respectively and were on par. The values of sub surface soil depth showed no significant difference.

For coarse (>53 μm) POC fractions, the treatments were found to be significantly different with T_1 (6.25 g kg^{-1}) being the highest recorded treatment

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followed by T_3 (5.4 g kg^{-1}) and T_2 (5.29 g kg^{-1}) and T_4 (4.61 g kg^{-1}) recorded the lowest value. The rice-fish system contained more coarse (>53 µm) POC fractions at both surface and sub surface soil depths than rice-water fallow system.

After rice cultivation, the T_1 (rice-fish system; soil samples from soil depth 0-20 cm) found to have high fine (<53 µm) POC fractions (14.27 g kg^{-1}) followed by T_3 (13.69 g kg^{-1}) and and they were on par. Treatment T_2 and T_4 were also on par with each other. Both surface and sub surface soil depth did not show any significant difference with respect to fine POC under rice-fish and rice-water fallow system, however higher values were observed in rice-fish system.

Table 5. Effect of different treatments on particulate organic C in soil at different stages (g kg^{-1})

Treatments	Before rice		After rice	
	<53 µm	>53 µm	<53 µm	>53 µm
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	15.10	6.25	14.27	5.97
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	13.10	5.29	12.64	5.10
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	14.03	5.40	13.69	5.45
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	11.58	4.61	12.33	4.70
SE(m)±	**0.322**	**0.064**	**0.128**	**0.071**
CD(0.05)	**2.062**	**0.417**	**0.827**	**0.456**

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The coarse (>53 μm) POC fractions were found higher in surface soil depths than sub surface soil depths in both the systems with highest being in the rice-fish system (5.97 g kg^{-1}) (T_1), followed by 5.45 g kg^{-1} in rice water fallow system (T_3). It was also found that T_2 (rice-fish system; soil samples from soil depth 20-40 cm) was on par with T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm) and T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm) was on par with T_2 (rice-fish system; soil samples from soil depth 20-40 cm).

4.2 SOIL PROPERTIES

4.2.1 Bulk density

The data pertaining to the effect of treatments on bulk density of soil at different stages are given in Table 6. The treatments found to be significantly different during both the stages, however the bulk density between surface soils (T_1 and T_3) was found to be on par during both before rice and after rice cultivation and also the bulk density between sub surface soils (T_2 and T_4) was found non significant during both the stages. The significant difference was only observed between surface (0-20 cm depth) and sub surface soil (20-40 cm depth). BD was higher in subsurface soil in both the systems.

4.2.2 Soil pH

Effect of treatments on soil pH at different stages are presented in Table 7. Before raising rice crop, among the treatments the highest pH was recorded in treatment T_1 (4.21) followed by T_3 (3.89), T_2 (3.61) and T_4 (3.42). The surface soils (T_1 and T_3) recorded higher pH than sub surface soils (T_2 and T_4). High pH was observed in rice-fish system compared to rice-water fallow system. The pH between treatment T_2 and T_4 was on par with each other.

After rice cultivation, the highest pH was recorded in treatment T_1 followed by T_3, T_2 and T_4 which were on par with each other. The higher pH was observed in rice-fish system than rice-water fallow system.

4.2.3 Soil EC

The data related to the effect of treatments on electrical conductivity of soil at different stages are given in Table 8. Before raising rice crop, the mean values ranged between 1.81 and 2.80 dS m^{-1}. Treatment T_2 (rice-fish system; soil samples from soil depth 20-40 cm) resulted in significantly higher EC (2.80 dS m^{-1}) than all other treatments and it was on par with T_4 (2.61 dS m^{-1}). Treatment T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm) recorded significantly lower EC (1.81) than all other treatments and which was on par with T_1 (1.90 dS m^{-1}). The sub surface soil (T_2 and T_4) had significantly higher EC than surface soil (T_1 and T_3) in both systems.

After rice cultivation, the treatment T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm) recorded the higher EC (3.26 dS m^{-1}) and it was on par with T_2 and T_1. The treatment T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm) recorded lower EC (2.48 dS m^{-1}) among the treatments and which was on par with T_1. The surface soils of treatments showed no significant difference between rice-fish and rice-water fallow system and the same was observed with respect to sub surface soils of treatments.

There was no significant difference observed between rice-fish and rice-water fallow system at both the depths (0-20 cm and 20-40 cm). The significant difference was observed only between surface (0-20 cm) and sub surface soils (20-40 cm) in both the systems during before rice and after rice stages.

Table 6. Effect of treatments on bulk density of soil at different stages (g cm^{-3})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	0.86	0.88
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	1.04	1.06
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	0.87	0.87
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	1.04	1.05
SE(m)±	**0.01**	**0.006**
CD(0.05)	**0.029**	**0.015**

Table 7. Effect of treatments on soil pH at different stages

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	4.21	3.88
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	3.61	3.42
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	3.89	3.56
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	3.42	3.33
SE(m)±	**0.041**	**0.036**
CD(0.05)	**0.263**	**0.235**

Table 8. Effect of treatments on electrical conductivity of soil at different stages (dS m^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	1.90	2.90
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	2.80	3.22
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	1.81	2.48
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	2.61	3.26
SE(m)±	**0.063**	**0.068**
CD(0.05)	**0.406**	**0.447**

4.2.4 Available N

The data regarding the effect of treatments on available nitrogen in soil at different stages are given in Table 9. During before rice cultivation, the higher available N was recorded in treatment T_1 (449.07 kg ha^{-1}) which was on par with T_3 (413.95 kg ha^{-1}). The treatment T_4 (289.76 kg ha^{-1}) recorded the lower available N among the treatments and the same was on par with T_2.

After rice cultivation, higher available N was observed in treatment T_1 (357.50 kg ha^{-1}) which was on par with T_3 (353.74 kg ha^{-1}) and T_2 and T_4 were also on par with each other.

The treatments with surface soil were found to be having significantly higher available N than sub surface soil at both the stages and no significant difference was observed between rice-fish and rice-water fallow system at same depths during before and after rice stages. There was a reduction in soil available N values after rice.

Table 9. Effect of treatments on available nitrogen in soil at different stages (kg ha^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	449.07	357.50
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	311.09	253.38
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	413.95	353.74
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	289.76	247.11
SE(m)±	**6.202**	**5.639**
CD(0.05)	**39.770**	**36.168**

4.2.5 Available P

Though available phosphorus concentration in soil ranged from 16.78 to 19.31 and 9.13 to 9.97 kg ha^{-1} during before rice and after rice respectively, the data presented in Table 10 revealed that there was no significant difference between the treatments. However there was a reduction in available soil P after rice in all the treatments.

Table 10. Effect of treatments on available phosphorus in soil at different stages (kg ha^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	19.31	9.97
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	16.78	9.26
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	17.25	9.50
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	16.97	9.13
SE(m)±	**0.398**	**0.340**
CD(0.05)	**NS**	**NS**

4.2.6 Available K

Various treatments differed significantly with respect to available K concentration in soil at different stages (Table 11). Available K concentration ranged from 380.88 to 445.55 kg ha^{-1} before rice cultivation. The highest mean value of 445.55 kg ha^{-1} was recorded by T_1 (rice-fish system; soil samples from soil depth 0-20 cm) followed by T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm) which was on par with T_2. The treatment T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm) recorded the lowest mean value of 380.88 kg ha^{-1}.

The T_1 (rice-fish system; soil samples from soil depth 0-20 cm) recorded the highest mean value of 376.31 kg ha^{-1} among all the treatments after rice cultivation followed by treatment T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm) which was on par with treatment T_2 and T_4.

The rice-fish system recorded the higher available K than rice-water fallow systems at 0-20 cm and 20-40cm during both the stages (before and after rice). The soil available K values were found to decline after rice.

Table 11. Effect of treatments on available potassium in soil at different stages (kg ha^{-1})

Treatments	**Before rice**	**After rice**
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	445.55	376.31
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	419.60	286.01
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	424.04	309.10
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	380.88	282.00
SE(m)±	**2.359**	**5.549**
CD(0.05)	**15.130**	**35.584**

4.2.7 Available Ca

Effect of treatments on available calcium is shown in Table 12. Average values of Ca content ranged from 322 to 384 mg kg^{-1} before rice stage. The treatment T_2 (rice-fish system; soil samples from soil depth 20-40 cm) registered maximum value of 384 mg kg^{-1} followed by T_1 (rice-fish system; soil samples from soil depth 0-20 cm) (352 mg kg^{-1}) which was statistically on par with T_4 and T_3. After rice stage, the values ranged from 302 to 368 mg kg^{-1} with maximum value (368 mg kg^{-1}) in T_2 (rice-fish system; soil samples from soil depth 20-40 cm) which was on par with T_1 (rice-fish system; soil samples from soil depth 0-20 cm). T_1 was on par with T_4 and T_4 was on par with T_3.

The available calcium content was higher in sub surface soil (T_2 and T_4) than in surface soil (T_1 and T_3) in both the systems (Rice-fish and rice-water fallow) and at both the stages (before and after rice) and it was higher in rice-fish system than rice-water fallow system at 0-20 cm and 20-40 cm depth during both the stages.

Table 12. Effect of treatments on available calcium content of soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	352	338
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	384	368
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	322	302
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	338	320
SE(m)±	**4.848**	**5.430**
CD(0.05)	**31.096**	**34.824**

4.2.8 Available Mg

The data given in the Table 13 with respect to the effect of treatments on available magnesium content of soil at different stages showed no significant difference among the treatments during before and after rice stages. However higher Mg content was recorded in rice-fish system (T_1 and T_2) compared to rice water-fallow system (T_3 and T_4) at both the stages.

Table 13. Effect of treatments on available magnesium content of soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T$_1$ (rice-fish system; soil samples from soil depth 0-20 cm)	192.00	161.50
T$_2$ (rice-fish system; soil samples from soil depth 20-40 cm)	192.00	160.00
T$_3$ (rice-water fallow system; soil samples from soil depth 0-20 cm)	161.00	150.00
T$_4$ (rice-water fallow system; soil samples from soil depth 20-40 cm)	166.50	147.00
SE(m)±	**5.124**	**4.839**
CD(0.05)	**NS**	**NS**

4.2.9 Available S

Effect of treatments on available sulphur in soil is depicted in Table 14. T$_2$ (rice-fish system; soil samples from soil depth 20-40 cm) recorded highest mean value than all other treatments during before rice cultivation (149.17 mg kg^{-1}) followed by T$_1$ (rice-fish system; soil samples from soil depth 0-20 cm) which was on par with T$_4$ and T$_3$.

In sub surface soil the available sulphur content was significantly high (149.17 mg kg^{-1}) in rice-fish system than in rice-water fallow system and in surface soil there was no significant difference between both the systems.

The highest available sulphur was found in treatment T$_2$ (122.51 mg kg^{-1}) after rice cultivation, which was on par with treatment T$_4$ and treatment T$_1$ was on par with

T_3. The sub surface soil was found to be having high available sulphur content than surface soil.

Table 14. Effect of treatments on available sulphur content of soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	122.96	113.20
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	149.17	122.51
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	110.73	112.96
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	119.03	121.02
SE(m)±	**2.250**	**1.020**
CD(0.05)	**14.432**	**6.547**

4.2.10 Available Fe

The data depicted in Table 15 shows no significant difference between the treatments during before and after rice, however the sub surface soils (T_2 and T_4) were found to be having higher available iron concentration than surface soils (T_1 and T_3) and also rice-water fallow system had higher mean values than rice-fish system.

4.2.11 Available Mn

The data revealed that there was no significant difference in available Mn (Table 16) between the treatments before and after paddy cultivation. The mean values ranged from 5.86 to 7.22 mg kg^{-1} and 5.10 to 6.64 mg kg^{-1} before and after rice respectively.

Table 15. Effect of treatments on available iron concentration in soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	761.30	759.10
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	797.80	781.40
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	813.80	797.40
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	831.10	816.90
SE(m)±	**10.457**	**7.138**
CD(0.05)	**NS**	**NS**

Table 16. Effect of treatments on available manganese concentration in soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	6.64	5.51
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	6.31	5.10
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	7.22	6.64
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	5.86	6.28
SE(m)±	**0.153**	**0.185**
CD(0.05)	**NS**	**NS**

4.2.12 Available Zn

The data pertaining to the effect of treatments on available Zinc (Zn) concentration in soil at different stages are presented in Table 17. The mean values before rice varied from 4.69 to 6.55 mg kg^{-1} with highest being treatment T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm) which was on par with T_3 and lowest being treatment T_1 (rice-fish system; soil samples from soil depth 0-20 cm) which was on par with T_2. Rice-fish system had significantly lower available Zn than rice-water fallow system. However no significant difference was observed between surface (0-20 cm) and sub surface soils (20-40 cm) of both the systems. The treatments showed no significant difference with respect to after rice samples.

Table 17. Effect of treatments on available Zinc concentration in soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	4.69	7.83
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	5.05	8.61
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	6.01	8.45
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	6.55	9.15
SE(m)±	**0.184**	**0.152**
CD(0.05)	**1.173**	**NS**

4.2.13 Available Cu

The data of available Cu concentration in soil is given in Table 18. Before rice cultivation, treatment T_2 (rice-fish system; soil samples from soil depth 20-40 cm) had higher available copper (8.68 mg kg^{-1}) which was on par with treatment T_4 (8.63 mg kg^{-1}) and treatment T_1 and T_3 were on par with each other. There was no significant difference recorded between rice-fish and rice-water fallow systems.

No significant difference was observed between the various treatments after rice

Table 18. Effect of treatments on available copper concentration in soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	6.79	5.70
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	8.68	6.09
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	6.72	6.14
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	8.63	6.23
SE(m)±	**0.151**	**0.073**
CD(0.05)	**0.966**	**NS**

4.2.14 Available B

The statistical analysis of the data on available boron (Table 19) indicated no significant effect between various treatments before and after rice cultivation.

Table 19. Effect of treatments on available boron concentration in soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	0.21	0.22
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	0.20	0.19
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	0.20	0.22
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	0.19	0.20
SE(m)±	**0.007**	**0.004**
CD(0.05)	**NS**	**NS**

4.2.15 Exchangeable Al

The data related to effect of treatments on available aluminium concentration in soil at different stages are presented in Table 20. The available Al varied from 339 to 359.10 mg kg^{-1} during before rice and 318.20 to 340.40 mg kg^{-1} after rice. However there was no significant difference observed between the treatments.

4.2.16 Available Si

The data summarized in Table 21 express the significant effect of treatments on available silicon concentration in soil. The mean values ranged from 58.09 to 78.61 mg kg^{-1} during before rice and 51.44 to 73.98 mg kg^{-1} during after rice stage. The treatment T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm) recorded the highest mean value of 78.61 mg kg^{-1} and 73.98 mg kg^{-1} before and after rice respectively, followed by treatment T_4 which was on par with T_1 at both stages. The treatment T_2 (rice-fish system; soil samples from soil depth 20-40 cm) registered the lowest mean of 58.09 mg kg^{-1} before rice cultivation and 51.44 mg kg^{-1} after rice cultivation.

The treatments with surface soils (0-20 cm; T_1 and T_3) recorded higher available silicon than treatments with sub surface soils (20-40 cm; T_2 and T_4) and rice-water fallow system (T_3 and T_4) recorded higher available silicon than rice-fish system (T_1 and T_2) at both stages.

Table 20. Effect of treatments on exchangeable aluminium concentration in soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	343.10	325.20
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	339.00	318.20
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	353.70	335.40
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	359.10	340.40
SE(m)±	**3.814**	**4.146**
CD(0.05)	**NS**	**NS**

Table 21. Effect of treatments on available silicon concentration in soil at different stages (mg kg^{-1})

Treatments	Before rice	After rice
T_1 (rice-fish system; soil samples from soil depth 0-20 cm)	67.13	59.10
T_2 (rice-fish system; soil samples from soil depth 20-40 cm)	58.09	51.44
T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm)	78.61	73.98
T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm)	67.25	61.85
SE(m)±	**0.704**	**1.023**
CD(0.05)	**4.525**	**6.569**

Discussion

5. DISCUSSION

To assess the Dynamics of carbon stock in rice based farming systems of *Kari* soils, studies were carried out on soil properties and soil C pools of two kinds of farming systems namely rice-fish and rice-water fallow system and the result obtained are discussed in this chapter.

5.1 SOIL CARBON POOLS

5.1.1 Soil organic carbon

The soil organic C (SOC) content in two different farming systems varied from 50.09 to 57.01 g kg^{-1} and 40.13 to 48.5 g kg^{-1} before rice and after rice respectively (Table 3). The *Kari* soils are high in organic C. Thampatti (1997) recorded higher OC content of 10 to 30% in kari soil.

The rice- fish system was found to be having higher SOC than rice- water fallow system which might be due to the additional C input from decomposing dead fish and fish feaces (Cagauan, 1995) along with the contribution from rice residues.

The surface soils (0-20 cm) recorded significantly higher SOC than the sub surface soils (20-40 cm) (Fig. 1). Zhang (2004) found greater SOC in surface soils and it was found to decrease with increase in depth, this might be due to input of C through crop residues, stubbles and stalks of rice in surface soil. Every year there is addition of crop residue on the surface soil in the kari soil which makes the organic matter into a easily available form. Though there is large deposits of partially decomposed or undecomposed wooden materials in the sub surface of kari soils these are not in the immediately available form. Also under flooded condition the organic matter in the surface soil are more exposed to the atmospheric air making it more available than that under the subsurface soil condition.

The initial samples (Table 2) which were collected before fish rearing or before water fallow were low in SOC but after fish culture (before rice stage) or after water fallow it increased. This may be because of the addition of organic matter in both the systems *i. e.,* by the residues of fish and rice crop in rice-fish system and residues of rice crop alone in rice-water fallow system.

The soil organic C was found to be positively correlated with soil C pools like labile C and particulate organic C whereas SOC and bulk density were negatively correlated (Table 22).

5.1.2 Labile carbon

There was no significant difference in labile C (LC) between the treatments at before and after rice (Table 4).

Labile C represents the easily decomposable part of soil organic matter that gets decomposed within few weeks or months. Greater turnover of soil organic matter and greater availability of other soil nutrients are associated with higher level of labile C. Labile C fractions are more sensitive indicators of the effect of land use than soil organic C due to their significant effect on soil quality as reported by He *et al.* (2008).

As reported by Mc Lauchlan and Hobbie (2004), the labile fractions of C were heavily dependent on the amount of soil organic C. There exists a positive correlation between LC and SOC and POC (Table 22) and same was reported by Naik (2016)

5.1.3 Particulate organic carbon

Before rice cultivation, higher fine (<53 μm) POC fractions were recorded in surface soil depth with 15.1 and 14.03 g kg^{-1} in rice-fish and rice-water fallow system respectively (Fig. 2) and they were on par with each other. The POC values of sub surface soil showed no significant difference. The rice-fish system contained more coarse (>53 μm) POC fractions at both surface and sub surface soil depths than rice water-fallow system (Fig. 2).

After rice, the values of fine (<53 μm) POC fractions for surface soil depths of both farming systems were not significantly different, however higher value was observed in rice-fish system. The fine fraction POC values for sub surface soil depths of both the systems were found to be not significantly different. The coarse (>53 μm) POC fractions were found to be higher in surface soil depths than sub surface soil depths in both the systems with the highest being in the rice fish system (5.97 g kg^{-1}) (Fig. 2).

In general, the particulate organic C (POC) was found to be higher in rice-fish system compared to rice-water fallow system (Fig. 2) and surface soil (0-20 cm) contained higher POC than sub surface soil (20-40 cm). Among the fractions, POC in fine (<53 μm) fraction was found to be higher than coarse (>53 μm) fraction (Fig. 2).

The initial samples (Table 2) which were collected before fish rearing or before water fallow were low in POC but after fish culture (before rice stage) or after water fallow it increased.

POC represents the non-complexed organic matter that mainly contains partially decomposed residues of plants and animals, root fragments *etc*. Particulate organic C is the highly active pool of soil organic C and is the most sensitive indicator of management effects on SOC (Elliott *et al.,* 1994). Coarse fraction of POC represents the unprotected pool of soil organic matter, which is said to be labile fraction consisting of plant residues at various stages of decomposition (Cambardella and Elliott, 1992). Particulate organic C is known to be an effective measure of active SOM pool and is positively correlated with SOC and labile C (Table 22). It was in consonance with the findings of Naik (2016).

Table 22. Correlation analysis of soil organic C versus other soil parameters

Variables correlated with SOC	Before rice	After rice
Labile C	0.187	0.259
Particulate OC	0.450*	0.480*
Bulk density	-0.452*	-0.373*
Soil pH	0.303	0.292
Soil EC	-0.247	-0.120
Available N	0.353*	0.121
Available P	0.210	0.069
Available K	0.441*	0.579*
Available Ca	0.107	0.141
Available Mg	-0.005	0.140
Available S	0.004	-0.150
Available Fe	-0.354*	-0.198
Available Cu	-0.135	-0.069
Available Zn	-0.389*	-0.244
Available Mn	-0.016	-0.180
Available B	0.017	0.025
Available Al	0.002	0.104
Available Si	-0.144	-0.245

***significant at 0.05 level**

5.2 SOIL PROPERTIES

5.2.1 Bulk density

There was no significant difference observed between rice-fish and rice-water fallow systems with respect to bulk density. However significant difference in bulk density was recorded between surface and sub surface soils (Fig. 3). Sub surface soils had higher bulk density than surface soils. This was in agreement with the findings of Ahukaemere and Akpan (2012). There was a strong negative correlation between SOC and BD (Table 22) and the same was also reported by Naik (2016).

5.2.2 Soil pH

Higher pH was observed in rice-fish system compared to rice-water fallow system (Fig. 4). As reported by Han *et al.* (2007) soil pH changed in the following orders among various land use practices: catfish pond soils > paddy soils > forest soils. Omofunmi *et al.* (2016) investigated the impact of fish pond effluents on soils, the results shown that pH of effluent discharged soils were relatively higher or alkaline than that of non-effluent discharged soils.

The soil pH decreased with increase in depth (Fig. 4). This might be due to high organic matter in sub soil which is a peculiarity of kari soils, which might result in increase or decrease in the soil pH as reported by Tan *et al.* (2007). The presence of weakly acidic chemical functional groups of soil organic molecules makes soil organic matter an effective buffer. The subsoil showed higher potential acidity compared to surface soils (Indira, 2013).

The initial samples (Table 2) which were collected before fish rearing or before water fallow were low in soil pH but after fish culture (before rice stage) or after water fallow it increased. The water submergence of paddy fields always help in improving the soil pH to neutrality because of the decrease in redox potential. In these redox reactions, ferric iron (from amorphous ferric hydroxides) serves as an electron acceptor and OM (CH_2O) as the electron donor. This reaction results in the consumption of acidity and raising the soil pH (Sahrawat, 2012).

A considerable reduction in soil pH (Fig. 4) was recorded after rice which might be due to drying of field at harvest as reported by Devi (2018). This maybe be due to the S present in the soil being converted to oxides of S and H_2SO_4 upon exposure to air.

5.2.3 Soil EC

There was no significant difference observed between rice-fish and rice-water fallow system at both the depths (0-20 cm and 20- 40 cm) with respect to soil EC values. The significant difference was only observed between surface (0-20 cm) and sub surface soils (20- 40 cm) in both the systems at before and after rice stages (Fig. 5). Significantly higher EC recorded in subsurface soil might be due to the presence of salt content (especially Na salt) and also leaching of salts from surface to subsurface soil during saline water inundation. Considerable increase in soil EC was observed after rice which might be due to increased salt concentration upon drying of soil (Devi, 2018) resulting in rising up of salt from the subsurface into the surface soil by evaporation. The initial samples (Table 2) which were collected before fish rearing or before water fallow were high in EC but after fish culture (before rice stage) or after water fallow it was decreased. This was also the effect of drying of the field after the previous crop resulting in higher initial EC values.

5.2.4 Available primary nutrients

Although the kari soil has higher OC content, available N status is generally low due to poor microbial activity (Koruth *et al.* 2013). The treatments with surface soil was found to be having significantly higher available N than sub surface soil at both the stages (Fig. 6) as reported by Zhang (2004). However, no significant difference was observed between rice- fish and rice-water fallow system at both the stages though available N was found to be higher in rice-fish system (Table 8). Rice-fish systems are often related with recycling of nutrients, improvements in resource utilization and increase in soil fertility due to accumulation of nitrogen (Li, 1988; Lightfoot *et al.*, 1992; Sastradiwirja, 1992; Frei and Becker, 2005).

Generally available P in kari soil is in low ranges due to the presence of Fe and Al sesquioxides that could be a subsequent of utmost soil acidity which was also evident from the present study. The P fixation by Fe and Al sesquioxides which is a consequent of extreme soil acidity was also reported by Tisdale *et al.* (1995), Audebert and Sahrawat (2000) and Dixit (2006). Though available phosphorus concentration in soil ranged from 16.786 to 19.318 and 9.130 to 9.979 kg ha^{-1} before rice and after rice respectively, the data presented in Table 10 revealed that there was no significant difference between the treatments. However available P was observed to be higher in rice-fish system than in rice water fallow system. After rice the P values generally showed a decrease owing to the reduction in pH due to drying of soil at harvest.

Available K concentration ranged from 380.882 to 445.554 kg ha^{-1} at before rice and 282.008 to 376.314 kg ha^{-1} at after rice (Table 11). The surface soil had higher available K than subsoil. A significant difference was observed between the systems. The rice-fish system recorded the higher available K than rice-water fallow systems at both the depths (0-20 cm and 20- 40cm) and at both the stages (before and after rice) (Fig 7). A reduction in available K at harvest might be due to toxic levels of available Fe in the soil with an increase in soil acidity. Ottow *et al.* (1983), Yamauchi (1989) and Sahrawat *et al.* (1996) have proved the occurrence of several nutrient disorders and deficiencies in soil including that of K due to Fe toxicity.

Mohanty *et al.* (2009) reported an increased organic C, available N and P in soil, which was likely due to (1) the additional nutrients from the dead fishes and faeces and (2) fish grazing on the photosynthetic aquatic biomass and other components of the system, thereby aiding in nutrient cycling, minimizing N losses (Cagauan, 1995) and facilitating P release from the sediment (Breukelaar *et al.*, 1994). The nitrogen, phosphorous, and potassium contents of the soil and water increased significantly when fish are stocked in rice fields (Oehme *et al.*, 2007).

All the primary nutrients (N, P, K) considerably decreased after rice cultivation irrespective of the treatments. The reason might be due to the reduced pH as well as crop removal. This was in consonance with the findings of Devi (2018). The SOC was positively correlated with available N and K (Table 22).

The initial samples (Table 2) which were collected before fish rearing or before water fallow were low in available N, P, and K content but after fish culture (before rice stage) or after water fallow they increased.

5.2.5 Available secondary nutrients

The available calcium content was higher in sub surface soil (T_2 and T_4) than in surface soil (T_1 and T_3) in both the systems (Rice-fish and rice-water fallow) and at both the stages (before and after rice) (Fig. 8) which might be due to the presence of deposits of $CaCO_3$ shells in these depths in kari soils (GoK, 1999). High acidity in spite of huge accumulation of lime shells could be a peculiar characteristic of the kari soils (Nair and Iyer, 1948; Subramoney, 1958; 1959; Money, 1961; Money and Sukumaran, 1973; Chattopadhyay and Sidharthan, 1985). Available Ca was higher in rice- fish system than rice water fallow system at 0-20 cm and 20-40 cm depth at both the stages (Table 12) which might be due to addition of nutrients by fish faeces and decomposition of dead fishes.

There was decline in the available Ca after rice cultivation which might be due to the removal by the crop and due to reduction in soil pH at harvest. As Ca is very vulnerable to leaching, the reduction in available Ca might be attributed to higher precipitation towards the end of the crop causing nutrient loss and also due to crop removal. Increased soil acidity after the rice harvest might also be a reason for reduction in Ca availability.

The data related to available Mg (Table 13) showed no significant difference between the treatments at before rice and after rice stages. However there was a higher Mg content recorded in rice-fish system (T_1 and T_2) compared to rice-water fallow system (T_3 and T_4) at both the stages which might be due to addition of nutrients by fish faeces and decomposition of dead fishes. There was a reduced Mg availability after rice cultivation which could be due to the crop removal and higher soil acidity similar to that of Ca.

The precipitation and subsequent leaching of Mg and reduction in soil pH similar to that of Ca. As reported by Edmeades *et al.* (1985) and Myers *et al.* (1988), Mg remain in solution form and vulnerable to leaching as it is a poor competitor for exchangeable sites with Al and Ca.

In sub surface soil the available sulphur content was significantly high (149.171 mg kg^{-1}) in rice-fish system than in rice-water fallow system and in surface soil there was no significant difference between both the systems at before rice stage. No significant difference was observed between rice-fish and rice-water fallow system at both the depths. However, the sub surface soil was found to be high in available sulphur content than surface soil (Fig. 9) because of the presence of S salts originating from the partially decomposed organic matter in deeper kari soil.

The initial samples (Table 2) which were collected before fish rearing or before water fallow were low in available Ca, Mg, and S content but after fish culture (before rice stage) or after water fallow they increased.

5.2.6 Available micronutrients

The data depicted in Table 15 shows no significant difference between the treatments at before and after rice, however the sub surface soils (T_2 and T_4) were found to be having higher available Fe concentration than surface soils (T_1 and T_3). The reason might be due to the comparatively lower pH in subsoil making Fe more available.

The data revealed that there was no significant difference in available Mn (Table 16) between the treatments at both the stages (before and after rice). The mean values ranged from 5.87 to 7.23 mg kg^{-1} and 5.10 to 6.64 mg kg^{-1} before and after rice respectively.

Rice-fish system had significantly lower available Zn content than rice-water fallow system (Table 17) which might be due to the higher soil pH in rice-fish systems. However no significant difference was observed between surface (0-20 cm) and sub surface soils (20-40 cm) of both the systems. The treatments showed no significant difference with respect to after rice samples. There was an increase in available Zn after rice cultivation which is again might be due to reduced pH condition in the soil.

With respect to Cu, no significant difference was noticed between rice-fish and rice-water fallow systems at both the depths after rice stage (Table 18). However, there was a significant difference found in the available Cu content between surface and subsurface soil. The sub surface soil contained more available Cu which might be due to the low pH in subsoil. The high organic matter present in surface soil can bind with Cu making it less available. Sanyal and Majumdar (2009) conducted a study in peat soil wherein they observed chelation of Cu with insoluble organic matter that reduces nutrient availability. After rice, no significant difference was recorded among the treatments.

The variation in available B between the treatments was almost negligible at both the stages (before rice and after rice) and statistically not significant (Table 19).

5.2.7 Exchangeable Al

The data related to the effect of treatments on exchangeable aluminium (Al) concentration in soil at different stages are presented in Table 20. The available Al varied from 339.00 to 359.10 mg kg^{-1} before rice and 318.20 to 340.40 mg kg^{-1} after rice. However there was no significant difference observed between the treatments. There was slight decline in Al content after rice.

5.2.8 Available Si

The treatments with surface soils (0-20 cm; T_1 and T_3) recorded higher available silicon than treatments with sub surface soils (20-40 cm ; T_2 and T_4) and the rice-water fallow system (T_3 and T_4) recorded higher available silicon than rice-fish system (T_1 and T_2) at both the stages (Table 21) (Fig. 10).

The rice straw of the previous crop which is the source of Si is mostly being incorporated back into the farming system increasing the Si content. Because of this the surface soil might have more Si content than the sub surface soil.

The rice-water fallow had higher Si values among the treatments. This might be attributed to the higher content of rice straw in the rice-water fallow system retained for decomposition after the previous crop. In the rice-fish system the grass carp included among fish culture might have fed up on the rice straw leading to a decrease in the straw as well as the Si content in the soil.

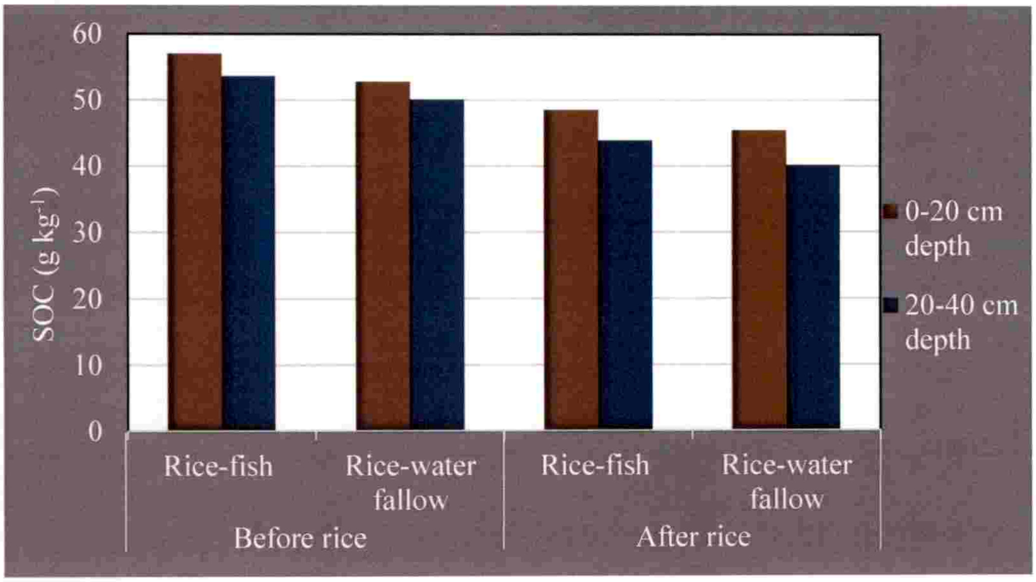

Fig. 1. Effect of rice-fish and rice-water fallow systems on SOC at different stages.

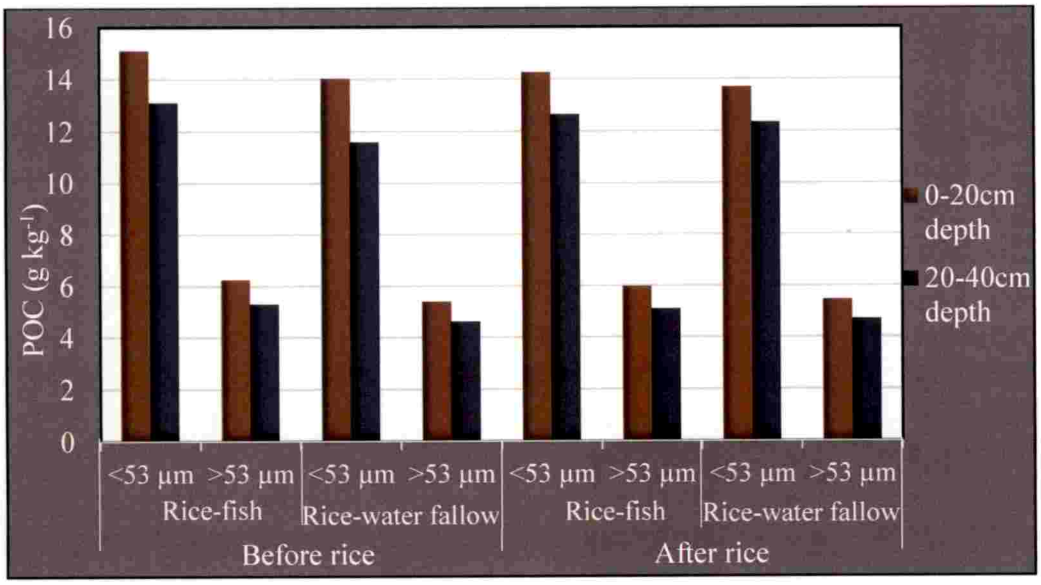

Fig. 2. Effect of rice-fish and rice-water fallow systems on POC at different stages.

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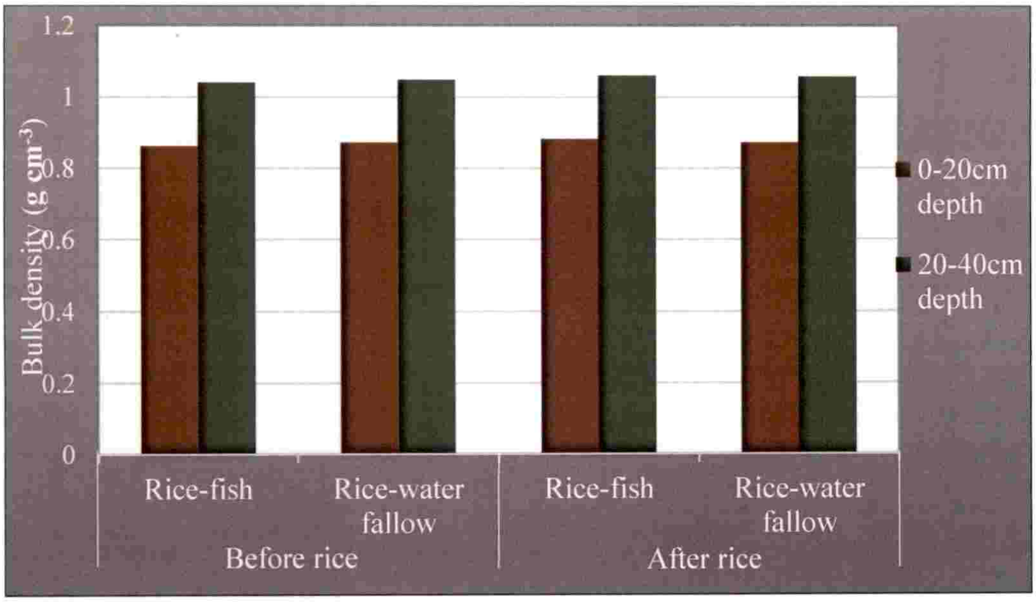

Fig. 3. Effect of rice-fish and rice-water fallow systems on soil bulk density at different stages

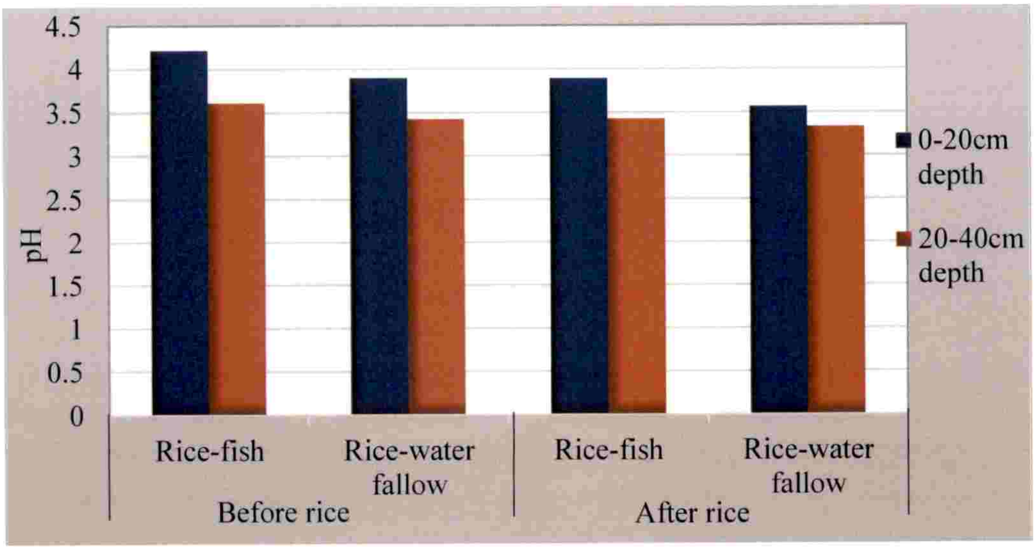

Fig. 4. Effect of rice-fish and rice-water fallow systems on soil pH at different stages

79

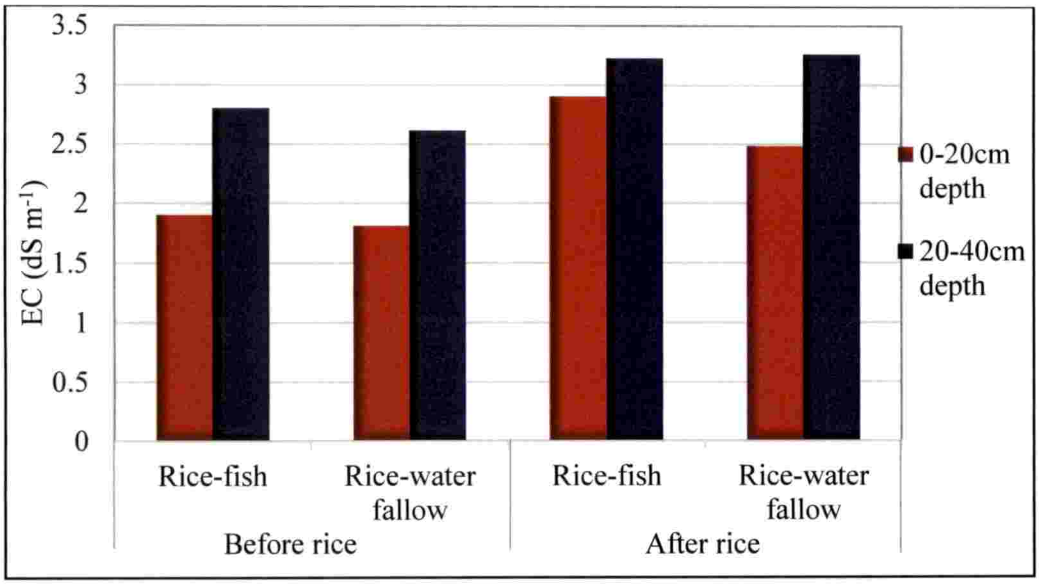

Fig. 5. Effect of rice-fish and rice-water fallow systems on soil EC at different stages

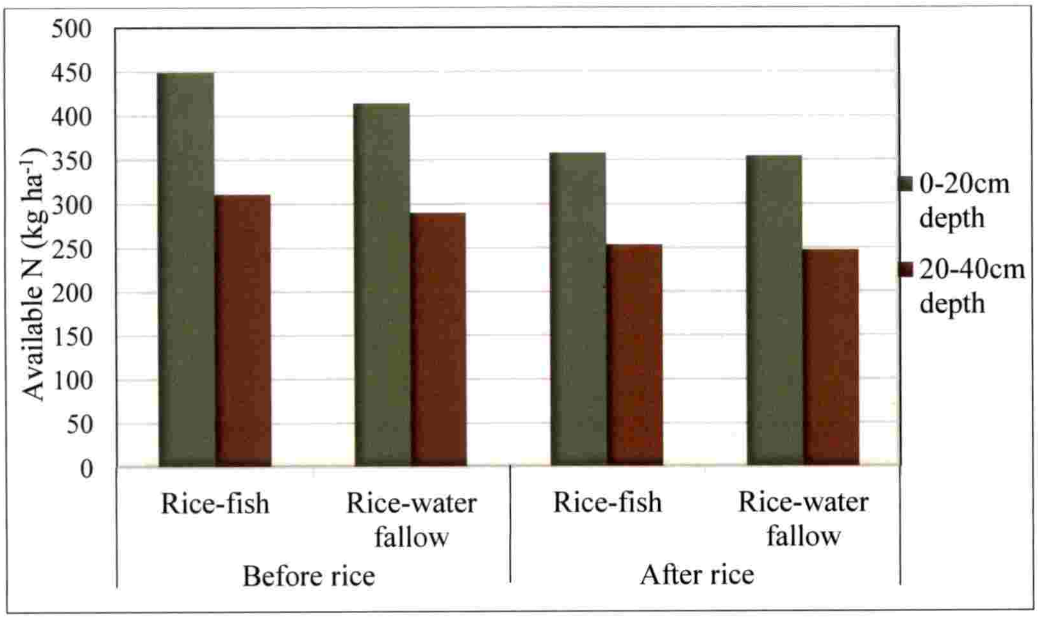

Fig. 6. Effect of rice-fish and rice-water fallow systems on available N at different stages

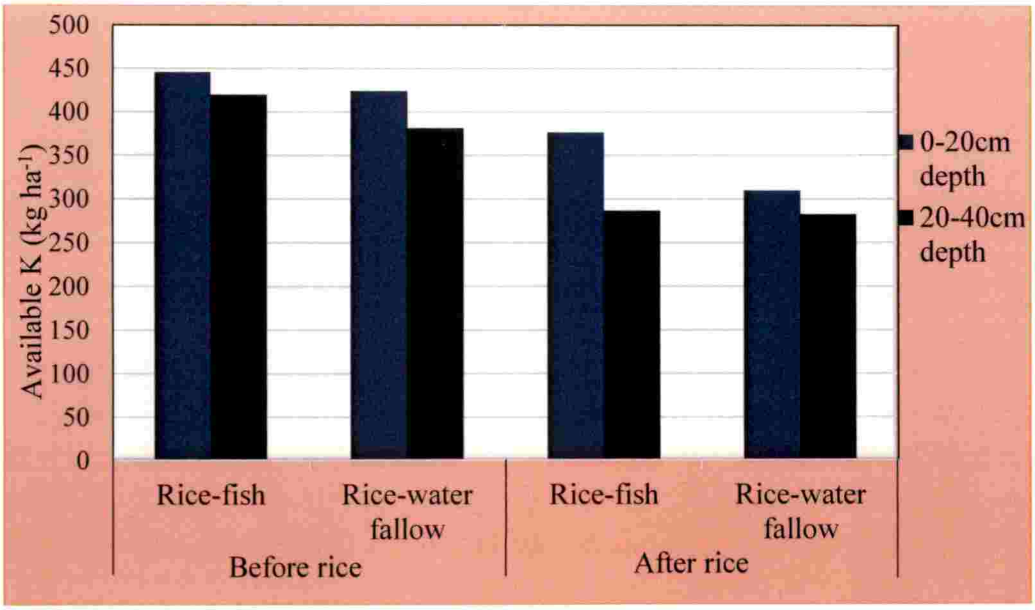

Fig. 7. Effect of rice-fish and rice-water fallow systems on available K at different stages

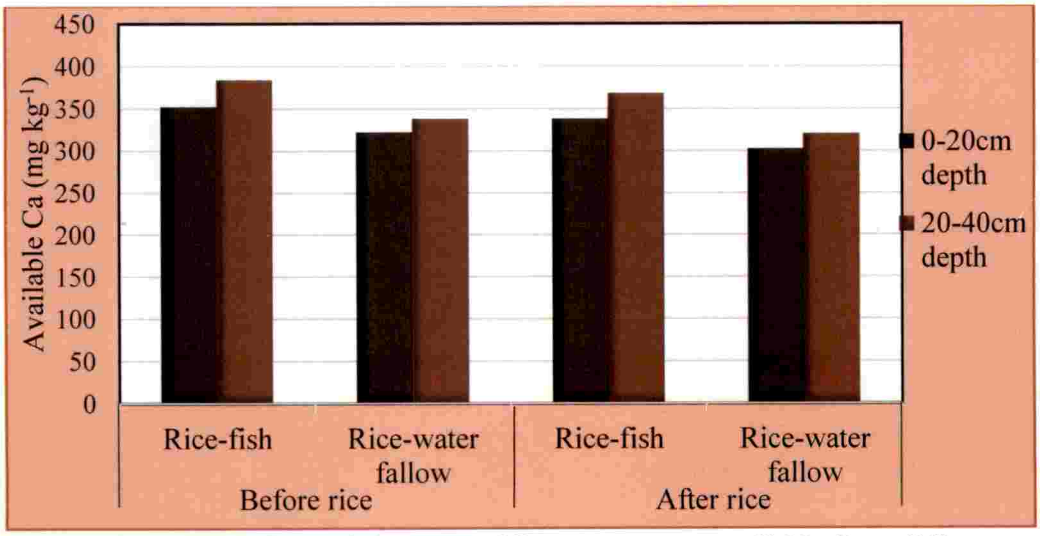

Fig. 8. Effect of rice-fish and rice-water fallow systems on available Ca at different stages

81

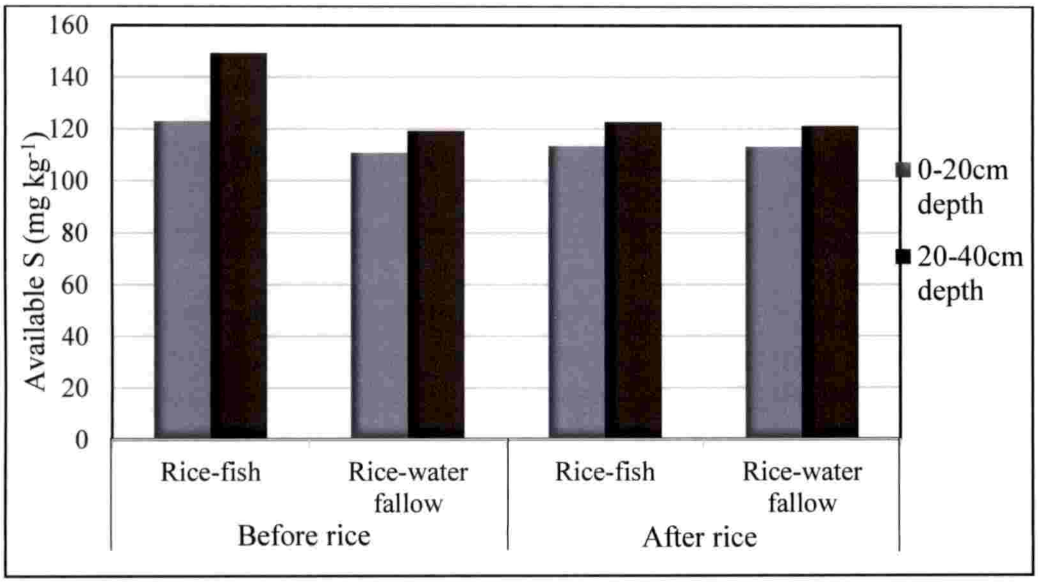

Fig. 9. Effect of rice-fish and rice-water fallow systems on available S at different stages

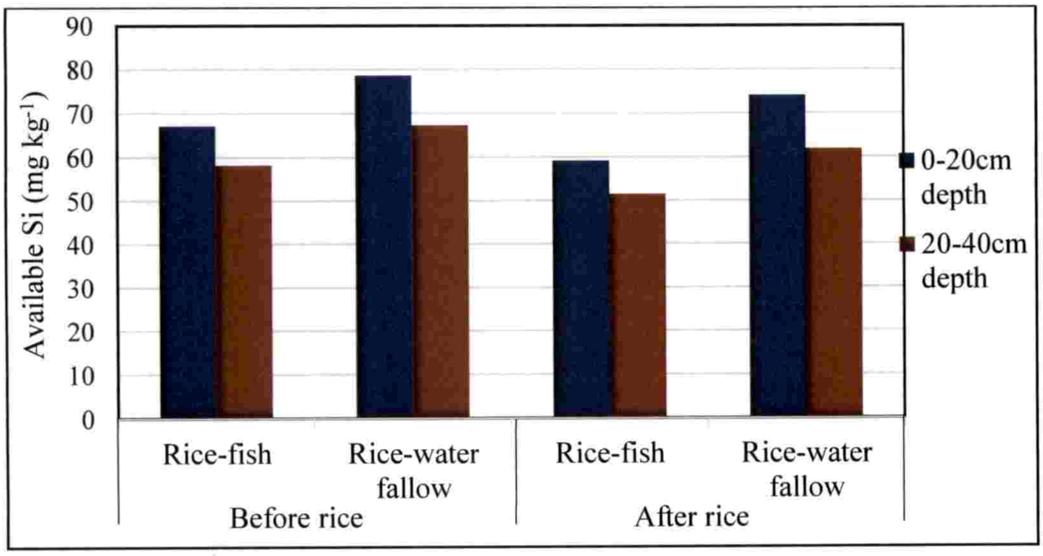

Fig. 10. Effect of rice-fish and rice-water fallow systems on available Si at different stages

Summary

6. SUMMARY

The experiment entitled "Dynamics of carbon stock in rice based farming systems of *Kari* soils" was carried out at rice field of Krishi Vigyan Kendra (KVK), Kumarakom during 2017 to 2018. The major farming systems in kari soils of Kumarakom includes rice - fish and rice - water fallow system. The soil samples were collected from surface (0-20 cm) and subsurface soil depths (20-40 cm) at two different stages like before and after rice cultivation. The experiment was carried out in completely randomized design with 4 treatments and 10 replications (number of soil samples) which included, T_1- rice- fish system; soil samples from soil depth 0-20 cm, T_2- rice-fish system; soil samples from soil depth 20-40 cm, T_3- rice-water fallow system; soil samples from soil depth 0-20 cm, T_4- rice-water fallow system; soil samples from soil depth 20-40 cm. The objective was set out to study the influence of rice - fish and rice - water fallow systems on C stock and C dynamics in *Kari* soil. The samples were analysed for soil C pools such as SOC, labile C, POC and soil properties like BD, soil pH, soil EC, available N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Si and exchangeable Al. The salient findings drawn from the study are summarized in this chapter.

6.1 SOIL CARBON POOLS

The soil organic C (SOC) content in two different farming systems varied from 50.08 to 57.01 g kg^{-1} and 40.13 to 48.50 g kg^{-1} at before rice and after rice respectively (Table 3). The surface soils (0-20 cm) recorded the higher SOC than the sub surface soils (20-40 cm) (Fig. 1). The rice- fish system was found to be having higher SOC than rice- water fallow system. There was no significant difference in labile C (LC) between the treatments before and after rice cultivation. Before rice cultivation, the higher fine (<53 μm) POC fractions were recorded in surface soil depth with 15.10 and 14.03 g kg^{-1} in rice- fish and rice- water fallow systems respectively (Fig. 2) and they were on par with each other and also the values of sub surface soil showed no significant difference. The rice- fish system contained more coarse (>53 μm) POC fractions at both surface and sub surface soil depths than rice water- fallow system (Fig. 2). After rice cultivation, the values of fine (<53 μm) POC fractions for surface soil depths of both farming systems were found to be not significant, however higher value was observed in rice- fish system and also values for sub surface soil depths of both the systems was found to be not significant. The coarse (>53 μm) POC fractions were found to be higher in surface soil depths than sub surface soil depths in both the systems with the highest being in the rice-fish system (5.97 g kg^{-1}) (Fig. 2). Overall the particulate organic C (POC) was found to be higher in rice fish system compared to rice-water fallow system (Fig. 2) and surface soil (0-20 cm) contained higher POC than sub surface soil (20-40 cm). Among the fractions, POC in fine (<53 μm) fraction was found to be higher than coarse (>53 μm) fraction (Fig. 2).

6.2 OTHER SOIL PROPERTIES

With regard to bulk density the treatments were found to be significantly different during both the stages. The bulk density between surface soils (T_1 and T_3) was found to be on par during both before rice and after rice cultivation. The bulk density between sub surface soils (T_2 and T_4) was also found to be not significant during both the stages. The significant difference was only observed between surface (0-20 cm depth) and sub surface soil (20-40 cm depth) where the bulk density was higher in subsurface soil in both the systems. Higher pH was observed in rice-fish system compared to rice-water fallow system during both the stages and surface soils showed higher pH than sub surface soils.

There was no significant difference observed between rice- fish and rice- water fallow system at both the depths (0-20 cm and 20- 40 cm) with respect to soil EC values. The significant difference was only observed between surface (0-20 cm) and sub surface soils (20- 40 cm) in both the systems at before and after rice stages (Fig. 5). Significantly higher EC was recorded in subsurface soil.

With regard to primary nutrients, the treatments with surface soil was found to be having significantly higher available N than sub surface soil at both the stages (Fig. 6). However, no significant difference was observed between rice- fish and rice- water fallow system at both the stages though available N was found to be higher in rice-fish system. No significant difference was observed among the treatments during both the stages with respect to available P content. Available K concentration ranged from 380.882 to 445.554 kg ha^{-1} at before rice and 282.008 to 376.314 kg ha^{-1} at after rice. The surface soil had higher available K than subsoil and the rice-fish system recorded higher available K than rice-water fallow systems at both the depths (0-20 cm and 20-40 cm) during before and after rice cultivation stage.

Among the secondary nutrients, the available calcium content was higher in sub surface soil (T_2 and T_4) than in surface soil (T_1 and T_3) in both the systems (Rice- fish and rice- water fallow) and at both the stages (Before and after rice). The available Ca was higher in rice- fish system than rice- water fallow system at 0-20 cm and 20-40 cm depth during both the stages. Available magnesium content of soil at different stages (before and after rice) showed no significant difference among the treatments. In sub surface soil the available sulphur content was significantly high (149.17 mg kg^{-1}) in rice-fish system than in rice-water fallow system. In surface soil no significant difference was observed in available S content between both the systems at before rice stage. The highest available sulphur (122.51 mg kg^{-1}) was found in treatment T_2 (rice-fish system; soil samples from soil depth 20-40 cm) after rice cultivation, which was on par with treatment T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm). The surface soil of both the systems (T_1 and T_3) were on par with regard to available S content.

With respect to micro nutrients the treatments were not significant for available Fe, Mn, B and exchangeable Al.

With respect to available Zn the mean values before rice varied from 4.69 to 6.55 mg kg^{-1} with the highest being treatment T_4 which was on par with T_3. Rice-fish system had significantly lower available Zn than rice-water fallow system. However no significant difference was observed between surface (0-20 cm) and sub surface soils (20-40 cm) of both the systems. The treatments showed no significant difference with respect to after rice samples. Before rice cultivation, treatment T_2 (rice-fish system; soil samples from soil depth 20-40 cm) had higher available copper (8.68 mg kg^{-1}) which was on par (8.63 mg kg^{-1}) with treatment T_4 (rice-water fallow system; soil samples from soil depth 20-40 cm). The treatments T_1 (rice-fish system; soil samples from soil depth 0-20 cm) and T_3 (rice-water fallow system; soil samples from soil depth 0-20 cm) were on par with each other for available Cu content. There was no significant difference recorded between rice-fish and rice-water fallow systems and also no significant difference was observed between the treatments after rice cultivation for available Cu.

The treatments with surface soils (0-20 cm; T_1 and T_3) recorded higher available silicon than treatments with sub surface soils (20-40 cm; T_2 and T_4). Rice-water fallow system (T_3 and T_4) recorded higher available silicon than rice-fish system (T_1 and T_2) at both before and after rice stages.

The study revealed that the rice-fish system significantly increased the different C pools, soil pH and soil nutrients such as available K, Ca, and S content compared to rice-water fallow system.

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Appendices

APPENDIX – I

Rating of nutrient availability in the soil

Nutrients	Deficiency	Sufficiency	Toxicity
Available N (kg ha^{-1})	<280	280-560	-
Available P (kg ha^{-1})	<10	10-25	-
Available K (kg ha^{-1})	<110	110-270	-
Available Ca (mg kg^{-1})	<300	>300	-
Available Mg (mg kg^{-1})	<120	>120	-
Available S (mg kg^{-1})	<5	5-10	-
Available Fe (mg kg^{-1})	<5	>5	>300
Available Mn (mg kg^{-1})	<1	>1	-
Available Zn (mg kg^{-1})	<1	>1	-
Available Cu (mg kg^{-1})	<1	>1	-
Available B (mg kg^{-1})	<0.5	>0.5	-
Exchangeable Al (mg kg^{-1})	-	-	>120

Source: Venugopal *et al.* (2013)

APPENDIX – II

Weather parameters throughout experiment (December 2017 to December 2018)

Standard Meteorological Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative Humidity (%)	Rainfall (mm)
December	32.23	17.72	79.17	57.40
January	32.37	17.88	76.55	235.00
February	33.47	22.54	78.11	267.80
March	34.49	24.51	76.90	260.80
April	35.02	24.98	79.65	248.20
May	34.47	24.23	78.11	210.90
June	30.49	23.49	86.15	71.60
July	29.82	22.95	86.13	63.30
August	29.99	22.54	85.82	108.60
September	32.47	22.83	83.21	195.60
October	32.74	22.91	81.27	153.90
November	32.79	22.81	81.39	213.90
December	32.21	21.06	84.24	201.10

Source: RARS, Kumarakom.

Abstract

DYNAMICS OF CARBON STOCK IN RICE BASED FARMING SYSTEMS OF *KARI* SOILS

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Abstract of the Thesis
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ABSTRACT

The investigation entitled "Dynamics of carbon stock in rice-based farming systems of *Kari* soils" was carried out in rice field of Krishi Vigyan Kendra (KVK), Kumarakom during 2017 to 2018. The objective of the study was to find out the influence of rice-fish and rice-water fallow systems on carbon stock and carbon dynamics in *Kari* soil.

The major farming systems in *kari* soils includes rice-fish and rice-water fallow system. The soil samples were collected from surface (0-20 cm) and subsurface soil depths (20-40 cm) at two different stages such as before and after rice cultivation. The experiment was carried out in completely randomized design with four treatments and ten replications (number of soil samples) which included, T_1- rice-fish system; soil samples from soil depth 0-20 cm, T_2- rice-fish system; soil samples from soil depth 20-40 cm, T_3- rice-water fallow system; soil samples from soil depth 0-20 cm, T_4- rice-water fallow system; soil samples from soil depth 20-40 cm. The samples were analysed for soil C pools and soil properties.

Bulk density (BD) of the soil showed no significant difference between rice-fish (T_1 and T_2) and rice-water fallow systems (T_3 and T_4). However significant difference was recorded between surface (T_1 and T_3) and sub surface soils (T_2 and T_4). Sub surface soils had higher BD than surface soils.

The soil organic C (SOC) content in two different farming systems varied from 50.09 to 57.01 g kg^{-1} and 40.13 to 48.50 g kg^{-1} before rice and after rice cultivation respectively. The surface soils (T_1 and T_3) and rice-fish system (T_1 and T_2) recorded higher SOC than the sub surface soils (T_2 and T_4) and rice-water fallow system (T_3 and T_4) respectively. The treatments found to be non significant with respect to labile C (LC). Particulate organic C (POC) in fine (<53 μm) fraction was found to be higher than coarse (>53 μm) fraction. Overall POC was found to be higher in rice-fish system

(T_1 and T_2) compared to rice-water fallow system (T_3 and T_4). Surface soil (T_1 and T_3) contained higher POC than sub surface soil (T_2 and T_4).

Higher soil pH was observed in rice-fish system (T_1 and T_2) compared to rice-water fallow system (T_3 and T_4) and also it decreased with increase in depth. Soil EC showed no significant difference between rice-fish and rice-water fallow system at both the depths (0-20 cm and 20-40 cm) but subsurface soils showed significantly higher EC than surface soil in both the systems at before rice and after rice stages.

The treatments with surface soil were found to be having significantly higher available N than sub surface soil at both the stages and no significant difference was observed between rice-fish and rice-water fallow system at same depths at before and after rice stages. Available P showed no significant difference. The rice-fish system recorded the higher available K than rice-water fallow systems at both the depths and at both the stages. The available Ca was higher in sub surface soil (T_2 and T_4) and rice-fish system (T_1 and T_2) than in surface soil (T_1 and T_3) and rice-water fallow system (T_3 and T_4) respectively at both the stages (before and after rice). In subsurface soil the available S was significantly high (149.171 mg kg^{-1}) in rice fish system than in rice-water fallow system and in surface soil there was no significant difference between both the systems before rice cultivation. With respect to Cu, no significant difference was noticed between rice-fish and rice-water fallow systems at both depths during before rice stage. However sub surface soils had significantly higher Cu than surface soils. Rice-fish system had significantly lower available Zn than rice-water fallow system at before rice stage. The surface soils (T_1 and T_3) and rice- water fallow system (T_3 and T_4) recorded higher available silicon than subsurface soils (T_2 and T_4) and rice-fish system (T_1 and T_2) respectively at both stages. The treatments were not significant for available Mg, Fe, Mn, B and Al.

The study revealed that the rice-fish system significantly increased the different C pools, soil pH and soil nutrients such as available K, Ca, and S content compared to rice-water fallow system in *Kari* soils.