SOIL CARBON DYNAMICS IN A RICE BASED CROPPING SYSTEM

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DECLARATION

I, hereby declare that this thesis entitled **"Soil carbon dynamics in a rice based cropping system"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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DEDICATED

TO

MY MOTHER

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LIST OF ABBREVIATIONS

%	Per cent
^{0}C	Degree Celsius
B	Boron
C	Carbon
Ca	Calcium
CD	Critical difference
CFU	Calony forming unit
cm	centimetre
CS	Cropping systems
Cu	Copper
DAS	Days after sowing
dS m^{-1}	deci Siemens per meter
EC	Electrical Conductivity
et al.	and other co workers
Fe	Iron
Fig.	Figure
FYM	Farmyard manure
g	gram
g kg^{-1}	gram per kilogram
K	Potassium
KAU	Kerala agricultural university
kg	kilogram
kg ha^{-1}	kilogram per hectare
LC	Labile carbon
m	Metre
MBC	Microbial biomass carbon
Mg	Magnesium
mg	milligram
Mg ha^{-1}	Megagram per hectare
mg kg^{-1}	milligram per kilogram

Mg m^{-3}	Megagram per cubic metre
mg g^{-1}	Milligram per gram
mM	milimolar
µm	Micro metre
µg g^{-1}	Microgram per gram
Mn	Manganese
MSL	Mean sea level
N	Nitrogen
No.	Number
NS	Non-significant
P	Phosphorus
Pg	Peta gram
pH	Negative logarithm of hydrogen ions
POC	Particulate organic carbon
PoP	Package of practice
S	Sulphur
SEm (±)	Standard error
sp.	species
SOC	Soil organic carbon
t	tonnes
t ha^{-1}	tonnes per hectare
TOC	Total organic carbon
TPF	Triphenylfarmazan
viz.	namely
Zn	Zinc

Introduction

1. INTRODUCTION

Soil organic matter encompasses non-mineral fractions of soil obtained primarily from residual plant and animal materials, produced by microbial action and decomposed under the impact of temperature, rainfall, humidity and other related soil environmental conditions. A favorable soil physical structure is maintained by soil organic matter (SOM), which in turn influences the retention and availability of nutrients and microbial activities. Thus, it plays a pivotal role in maintaining the soil quality and ecosystem sustainability.

Soil organic carbon (SOC) in the upper one metre soil depth is approximately 1200–1600 Pg C and 2376–2456 Pg C, in the 2 m soil layer (Batjes and Sombroek, 1997). The SOC is approximately 2.5 and 2 times as high as that in the vegetation (650 Pg C) and environment (750 Pg C), respectively (Batjes, 1998). SOC pool is in dynamic equilibrium with climate, especially precipitation and temperature (Jenny, 1941). Long-term studies had reported that practices such as manure and compost application, crop rotation, green manure and residue incorporation, reduced tillage and adjustment of irrigation methods enhanced the C dynamics and storage (Yadav *et al.,* 2000;Chatterjee *et al.,* 2018). Improvement in organic carbon status by one per cent could improve the yield by 10 per cent (Nawaz *et al.,* 2016).

Total SOC is composed of labile and recalcitrant pools. Labile organic carbon (LOC) fraction consists of physical (particulate organic matter), chemical ($KMnO_4$-C) and biological (microbial biomass carbon) fractions while, the recalcitrant pool (humus) is decomposition resistant (Mandal *et al.,* 2008). The relative percentage of carbon fractions determine soil quality and is, therefore, a key factor in determining soil carbon dynamics. Labile carbon has a higher impact on soil physical stability and is a more delicate indicator of carbon dynamics in soil. This fraction can react quickly to modifications in the supply of carbon and has been suggested as early indicators of land use impact on soil quality. Inclusion of legumes in cropping system encourages particulate organic matter (Barrios *et al.,* 1996), more through the addition of organic matter and root biomass. Left over root biomass and debris act as a significant source of POC (Puget and Drinkwater, 2001).

Non-labile soil carbon fractions have longer turnover time and thus, retain potential for long-term SOC sequestration (Paul *et al.,* 2001). However, the vertical distribution of soil organic carbon (SOC) is uncertain within the soil profile depth. The subsoil with lower carbon concentration has the ability for long-term storage of SOC, as the time for organic matter (OM) decomposition increases with soil depth. Therefore, OM in the subsoil has the capacity to contribute to mitigation of increasing atmospheric carbon dioxide (CO_2) through SOC sequestration (Lorenz and Lal, 2016).

Balanced application of nutrients with a high intensity cropping system enhances the production of root biomass, which in turn improves the storage of total SOC and organic carbon fractions (Purakayastha *et al.*, 2008). The cropping systems or land-use management practices that could store more carbon than the critical levels are likely to sustain SOC levels and retain good soil health (Mandal *et al.,* 2008). Analysis of long-term experiments stated that reducing the fallow period and increasing the intensity of cropping systems could improve carbon sequestration in soil due to greater production of biomass and inclusion of residues (Bandyopadhyay and Lal, 2015).

In India, rice-based cropping systems predominate and spreads over 43.1 million hectares (AIREA, 2019). The particular land-use system determines whether the soil is a net sink or a source of CO_2. Due to the slow pace of decomposition of organic matter owing to standing water conditions, wetlands are the efficient carbon sinks. The role of cropping system in increasing carbon sink capacity of soils and stabilizing CO_2 levels has become attention of scientific research. Since the allocation of biomass and its decomposition determine the relative distribution of C input to soil with depth (Jackson *et al.,* 1996), the nature of plants included in the sequence, *ie*., the presence of more biomass-generating plants, is a significant control factor in determining the addition of soil organic matter (SOM), which plays a significant part in determining carbon status.

There are many regional and global soil carbon budgets accessible for certain biomes, such as temperate grasslands (Parton *et al*., 1987), but carbon pools in vertical soil profile distribution and associated interactions with climate change and cropping systems have been less studied (Jobbagy and Jackson, 2000; Mazumdar *et al.*, 2015). In India, only very few works have been attempted to study the carbon fractions or dynamics in different depths of soil.

Hence, the present study entitled "Soil carbon dynamics in a rice based cropping system" was carried out with the following objectives:

1. Study and compare the soil carbon dynamics in different rice based cropping systems *viz.,* rice-rice-maize, rice-rice-vegetable and rice-rice-daincha in a riverine alluvium
2. Characterize the soil carbon dynamics at varying depths up to 105cm in a rice based cropping systems of riverine alluvium
3. Correlation of soil carbon dynamics with major weather parameters

Review of Literature

2. REVIEW OF LITERATURE

For the last few years, our country has been suffering from the serious consequences of global warming and hence every effort must be made to reduce the emissions of greenhouse gases (GHG). Soil can act as a major sink of atmospheric CO_2. Management practices that can enhance the soil carbon storage capacity are really helpful in mitigating climate change. Maintenance of carbon in soil depends on the dominant carbon fractions present *viz.*, labile or non- labile, which varies with the particular cropping system. The research information related to carbon dynamics under different cropping systems with particular reference to rice based cropping system are reviewed in this chapter.

2.1 GLOBAL WARMING AND CARBON SEQUESTRATION

Agricultural soils had lost approximately 30 to 40 t SOC ha^{-1} due to over exploitation of land, extensive erosion and other degrading processes resulting in drastic decline in soil quality and productivity (Lal, 2007). Since industrial revolution, fossil fuel combustion and land use changes had drastically increased atmospheric temperature, causing global warming. Restoration of degraded soils, converting marginal lands to suitable land use systems and adoption of recommended management practices had significant potential in carbon sequestration and mitigation of GHG emissions, in turn, reducing global warming effect (Lal *et al.,* 2015).

2.2 SOIL CARBON POOLS AND DYNAMICS

The soil carbon pool consists of both organic and inorganic components. Decomposed plant and animal residues constitute the soil organic carbon (SOC). Elemental carbon and that associated with primary minerals like dolomite, gypsum and calcite form the soil inorganic carbon (SIC). Organic and inorganic soil carbon pool had been estimated to be 1550 and 950 Pg, respectively (Batjes, 1996; Bhattacharyya *et al.,* 2013).

About 1200–1600 Pg carbon was present in the upper one metre layer of soil (Batjes and Sombroek, 1997), which comes to 56 per cent of total soil carbon (Jobbágy and Jackson, 2000). Average soil carbon content in two metre depth of soil layer was about 2416 Pg. SOC content was about 2.5 times higher than that in the vegetation and about twice as high as that in the atmosphere (Bhattacharyya *et al.,* 2012; Batjes, 1998). Around 20 to 30 per cent of earth's soil pool was stored in wetlands. In undisturbed wetlands, the average SOC sequestration rate could reach 1.18 Mg C ha^{-1} y^{-1} (Mitsch *et al.,* 2012).

The SOC is composed of both labile (active) and recalcitrant (resistant) fractions. Labile pool was more sensitive to management practices (Campbell *et al.,* 1997) and recalcitrant fraction, more resistant to microbial activities. Thus recalcitrant portions function as potential indicator of soil carbon retention (Mandal *et al.*, 2003; Culman *et al.*, 2012).

Labile pool and total organic carbon (TOC) play an important role in soil carbon dynamics and nutrient cycling (Batjes, 1996). About 60 Pg C could be sequestered in the soil in the next 50 to 100 years following sustainable land use management practices (Bell and Lawrence, 2009). Soil C pools like POC, aggregate associate C, labile and recalcitrant carbon were affected by management practices like organic farming, conservation agriculture, integrated nutrient management, crop diversity and agroforestry (Bhattacharyya *et al*., 2010). The LC fractions are more sensitive to land management practices and also positively correlated to soil microbial activity in surface layer (Pabst *et al.,* 2013). Soil labile pool consists of physical, chemical and biological fractions which contain particulate organic carbon (POC), potassium permanganate oxidizable C and microbial biomass C, respectively (Ghosh *et al.,* 2016).

About 45 per cent C present in crop residues and 15 per cent of residue-derived C was stored as passive C in the soil. Thus, crop residues had high potential for C storage and their removal adversely affected soil C pool (Lal, 1997). Crop residues are straight source of soil C pool, and thus had great impact on soil carbon dynamics (Follett, 2001). Fields grown with zero tillage recorded 17 and 14 per cent higher total SOC and particulate organic C contents, respectively, compared to that with conventional tillage in the upper soil layer after 9 years of continuous cropping (Bhattacharyya *et al.*, 2013).

More sequestration of SOC was noticed in paddy fields compared to coconut plantations. This might be due to organic amendments and crop residue addition under rice cultivation (Chacko *et al.,* 2014). According to Nawaz *et al.* (2016), wheat residue mulching enhanced the total C, C: N ratio, SOC and soil microbial biomass carbon (MBC) by 18.2, 38.6, 71.7 and 8.3 percent, respectively, than those under non-mulched treatments.

2.3 CROPPING SYSTEMS AND SOIL PHYSICAL PROPERTIES

According to McFarland *et al.* (1990), soil strength and bulk density were influenced by cropping sequences and tillage methods. They observed lower bulk density (BD) in the surface soil under sorghum-wheat-soybean crop rotation than wheat-soybean-fallow.Wetlands had lower bulk density at the surface and it increases with soil depth (Gilbert *et al.*, 2005). In general, surface soil had lower bulk density and it increased with depth (Mazumdar *et al.,* 2015). Restoration of wetlands by pugging drainage and scrapping soil resulted in increased BD up to 30 cm depth (Fenstermacher *et al.,* 2016).

In rice-wheat cropping system, reduction in BD was noticed due to organic manure addition (Mandal *et al.*, 2003). Similar decrease in BD was reported by Singh *et al.* (2005), in fields where rice straw incorporation was practised in place of crop residue burning.

In a long term experiment practiced at Punjab Agricultural University, Ludhiana, incorporation of green manure (*Sesbania aculeate*) during summer season in wheat – rice/ maize sequences reduced soil BD (Boparai *et al.*, 1992).

2.4 CROPPING SYSTEMS AND SOIL CHEMICAL PROPERTIES

Cropping systems can significantly influence soil chemical properties like soil pH and EC, major nutrients (primary and secondary) and micronutrients. Better physico-chemical characteristics were noticed in integrated rice based cropping systems compared to monocropping owing to plant rotation, green manure incorporation and organic residue recycling (Channabasavanna *et al.*, 2002; Rajput *et al.*, 2015). Chemical properties under different cropping systems are reviewed in this section.

2.4.1 Soil carbon fractions

Influence of cropping systems on different soil carbon fractions like total organic carbon, particulate organic carbon, microbial biomass carbon and labile carbon are reviewed here.

2.4.1.1 Total organic carbon

SOC is a key indicator of soil quality which influenced physical, chemical, and biological properties of soil and thus, crop productivity (Baver and Black, 1994). Inclusion of pulses in rice-based cropping systems along with integrated nutrient management practices had significant effect on soil C dynamics (Newaj and Yadav, 1994). Cropping system being practiced had significant influence on SOC content, which in turn affects biomass production (Romkens, 1999).

According to Majumder *et al.* (2008), TOC was 26.7, 24.1, and 22.0 per cent higher with FYM, paddy straw and green manure, respectively, over control in rice – wheat cropping system following INM practices. Intensive cropping without fertilizer application had resulted in 30 per cent decrease in SOC under rice – wheat cropping system in Indo- gangetic plains (Nayak *et al.*, 2012). Inclusion of FYM along with full NPK increased SOC stock from 9.19 to 9.99 Mg ha^{-1} C; while in control the stock was merely 7.84 Mg ha^{-1} C (Brar *et al.*, 2013).

Rice– wheat– mung bean cropping system had 6 per cent higher SOC than rice–wheat system due to increased cropping intensity Ghosh *et al.* (2012). Venkatesh *et al.* (2013) reported that, inclusion of pulses in maize-wheat-mungbean and pigeon pea-wheat cropping systems showed increased TOC than conventional maize-wheat system. According to Dubey *et al.* (2014), highest SOC was obtained in green manure-rice-durum wheat cropping system followed by rice-vegetable pea-sorghum sequence. Multiple cropping with crop rotation resulted in more biomass carbon and total carbon stocks, both in plant and soil, as compared to sole cropping (Tariyal, 2014).

The SOC stock decreased with depth due to continuous cultivation in rice-rice cropping system. On an average, 50, 26 and 24 per cent of the SOC stock depleted at 0-20, 20-40 and 40-60 cm, respectively (Mandal *et al.,* 2008).

According to Ardo *et al.* (2004), intensive cropping over a long period decreased SOC and keeping field fallow intermittently during cropping sequence could improve organic carbon content in soil. Practising proper cropping sequence, conversion of degraded lands to restorative land uses, conservation tillage, cover crops and crop residue mulch, nutrient recycling through addition of compost and organic manure and sustainable management of water resources helped in restoration of depleted SOC pool (Lal, 2004).

In acid hill soils of Nagaland, more SOC was noticed in kitchen garden (26.1 g kg^{-1}) than natural forest (23.6 g kg^{-1}) and lowland paddy systems (9.1 g kg^{-1}) due to continuous addition of organic matter (Singh and Bordoloi, 2011). Jha *et al.*, (2012) could observe 3 to 6 fold higher SOC in forest systems compared to agricultural cropping system. According to Venkanna *et al.* (2014), TOC stock in Vertisols followed the order forest soils > fodder system > cropping systems with paddy, maize, cotton and red gram > permanent fallow > castor system.

2.4.1.2 Particulate organic carbon

Particulate organic matter (POM) fraction is a sensitive indicator of changes in SOM content, associated with particles of sand size and act as easily decomposable substrate for soil microbes and reservoir for plant nutrients for a short period (Gregorich and Carter, 1997; Das *et al.,* 2018). Soil organic C fractions like Particulate organic matter (POM), microbial biomass C (MBC) and hot water soluble C (HWSC) contents were all significantly lower under conventional tillage than under either minimum or no tillage (Chen *et al.*, 2009).

Change in land use system to poplar based agroforestry system, increased POC and MBC after 4 years and magnitude of increase was comparatively higher in sandy clay loam than in sandy loam soil (Mao *et al.*, 2010). The relative proportion of active carbon pool including LC, POC and MBC in surface to subsurface soil was found to be highest in rice–wheat–rice–chickpea cropping system (1.14:1) than in rice–wheat–mung bean system (1.07:1), and rice–wheat cropping system (0.69:1) (Ghosh *et al.*, 2012).

As per the findings of Manna *et al.* (2006), addition of full NPK and FYM increased POC, MBC and hot water soluble C rice-based multiple cropping systems in Indo-Gangetic Plains of India.

2.4.1.3 Labile carbon

Labile carbon content was higher in the surface layer due to biomass addition and more intense microbial activities. In rice –wheat cropping system, combined application of FYM along with 100 per cent NPK, enhanced the labile carbon content by 14.5 per cent in the surface layer (Singh *et al.,* 2003; Brar *et al.,* 2013). Light fraction carbon (LFC) was increased by 55.5, 53.2 and 29.6 per cent, respectively, under FYM alone, integrated fertilization (with 50 per cent NPK and 50 per cent FYM) and full inorganic fertilizers (with 100 per cent NPK) in rice – wheat system (Banger *et al*, 2009).

Total organic carbon, labile fractions of carbon and total nitrogen content were 31 to 43, 84 to 85, and 15 to 34 per cent higher in grassland as compared to agricultural system and also legumes in grass land had more C sequestration potential than in cultivated area (Malhi *et al.*, 2003). In rice based cropping systems, yield was decided by the labile fractions or active pools of soil carbon *viz.*, LOC and MBC (Nath *et al.*, 2016).

2.4.1.4 Microbial biomass carbon

Microbial biomass carbon (MBC) comprises 2-3 per cent of SOC and 3-5 per cent soil organic N and acts as a catalyst for the conversion of stable organic forms of nutrients to plant available form for a long period (Coleman *et al.*, 1983). It was regarded as one of the active fractions of SOM due to its fast turnover and influence in nutrient cycling and developing soil structure (Franzluebbers *et al.,* 2000). The inclusion of organic sources either as amendment or though biomass residue into the soil increased MBC in the soil even though SOC was unaffected (Doran, 2002). Long-term use of organic and inorganic fertilizers under maize-wheat cropping system significantly improved active fractions of SOC *viz.,* WSC (water soluble carbon), MBC (microbial biomass carbon), MBN (microbial biomass nitrogen) (Kaur *et al.,* 2008; Das *et al.,* 2017).

The MBC content was higher in plots applied with FYM either solo or in combination with chemical fertilizers (NPK) over control plot and also decreased with soil depth (Banger *et al*, 2009). Benbi *et al.* (2012) reported that maize-wheat and poplar based agroforestry systems had higher microbial biomass carbon and mineralizable carbon content over rice- wheat cropping system.

Kaur *et al.* (2000) observed that MBC content in the soil was 42 per cent higher in tree based system as compared to monocropping systems. They also reported that MBC was low in rice-berseem cropping system as compared to agroforestry systems in the alkaline soils of North India. MBC was higher in alfalfa crop rotation system than alfalfa monoculture due to improved biochemical properties and microbial activities in the soil (Wang *et al.,* 2009).

2.4.2 Electrochemical properties

In rice-rice soil systems, the pH increased with long-term submergence due to proton consumption during the reduction process as compared to rice-soya, rice-onion and rice-tobacco sequences (Ratnayake *et al.,* 2017).

According to Thakur and Sharma (1988), soil pH was not affected by different cropping systems *viz.*, maize-green gram-wheat, maize-wheat-green gram and maize-wheat. Dubey *et al.* (2014) conducted a long-term rice-based cropping system experiment at Jabalpur and found that the highest pH was observed with green manure-rice-durum wheat system followed by pea-sorghum rice-vegetable system.

Electrical conductivity of the soil was significantly influenced by crop rotation and fertilization (Bharadwaj and Omanwar, 1994). Haggar *et al.* (2011)

reported that, mixed shade coffee systems had higher soil EC due to lower impact of rainfall on the soil and reduced leaching loss of salt.The reduction of electrical conductivity with soil depth might be due to less availability of soluble salts as the depth progresses (Sarwar *et al.,* 2017).

2.4.3 Major nutrients

Increased aeration through crop rotation enhanced aerobic breakdown of crop residues and acts as a promising management technique to improve major soil nutrients like N, P, K, Ca and Mg supply in lowland rice crop systems (Gu *et al.,* 2009). Inclusion of green manure or leguminous crops in rice based cropping system could improve soil chemical properties like primary nutrients (N, P and K) (Ali *et al.,* 2012).

Combined application of fertilizers with biochar significantly increased the soil nutrients (N, P, K) and crop yield in legume- rice cropping system over control (Party *et al.,* 2016). According to Zhao *et al.* (2016), there was a significantly positive correlation between SOM and available N, P, and K soil content in rice-based crop systems that indicated that SOM was a potential contributor to crop yield by supplying nutrients through mineralization.

According to Das *et al.* (2018), soil physico-chemical properties were influenced by different cropping systems in Eastern Himalayas of India. Available N was higher for soybean-based cropping sequence due to biological N fixation. Increased microbial activity and reduced fixation of water-soluble P increased the available P content compared to rice bean sequences. Biomass recycling resulted in more soil available K in rice-rapeseed system.

Crop residue incorporation before the start of the experiment reduced approximately 30 kg ha^{-1} N for both wheat and rice in wheat – rice cropping system (Singh and Kumar, 2008). Soil primary nutrients *viz.*, N, P, K and S were higher in legume based cropping systems which added nutrients to soil in organic form compared to non-leguminous cropping system (Vidyavathi *et al.*, 2012).

Setia and Sharma (2005) reported that S in soil decreased with depth and became unavailable below 60 cm depth, in a maize-wheat cropping sequence. Soil chemical properties varied with the cropping systems. Highest available N and P contents were obtained under rice-vegetable pea-sorghum system and K, under rice-potato-bhindi cropping system (Dubey *et al*., 2014).

2.4.4 Micro nutrients

Jaggi *et al*. (2001) reported that, long-term application of chemical fertilizers had a deleterious effect on soil fertility and integration of organic manures with chemical fertilizers improved soil health along with build-up of secondary nutrients like S and B in the soil.

Micronutrients *viz*., Zn, Fe, Cu and Mn in a wheat – rice cropping system were increased significantly by long-term application of fertilizers along with organic manure and crop residues (Prasad and Sinha, 2000). El-fouly *et al.* (2015) reported that continuous monocropping and sole addition of chemical fertilizers (NPK) without any organic matter into the soil significantly reduced micronutrients (Fe, Zn, Mn and Cu) in the soil. Micronutrients like Zn and Cu were higher in tomato-cauliflower-radish/pea system while Zn and Cu in capsicum/cabbage-coriander-spinach/pea cropping system (Parmar *et al.,* 2016).

2.5 CROPPING SYSTEMS AND SOIL BIOLOGICAL PROPERTIES

Microorganisms are involved in nutrient cycling in the soil through processes like decomposition, immobilization and mineralization and determination of microbial biomass C, N, P and S are necessary for developing suitable nutrient management practices (Wu *et al.,* 1994; Zhu *et al.,* 2018). Influence of cropping systems on soil biological properties including enzyme activities and microbial count are reviewed here.

2.5.1 Enzyme activities

Addition of organic manure, residual incorporation and adoption of practices which improved organic matter content in the soil enhanced activity of enzymes like urease, dehydrogenase and acid and alkaline phosphatase (Bandick and Dick, 1999; Roy *et al.,* 2011). In a long term experiment under rice-wheat cropping sequence, addition of organic manure along with chemical nutrients had increased enzyme activity and microbial population (Basak *et al.,* 2016). This might be due to the positive correlation between enzymes and organic C and N in the soil (Kunito *et al.,* 2018).

2.5.2 Microbial population

Pankhurst *et al.* (1995) observed significant effect of N-fertilization on enhancement of fungi and protozoan population and cellulose decomposition. Integrated nutrient management in sorghum-wheat cropping system produced higher microbial count (Malewar *et al.,* 1999).Similar results obtained by Sharma *et al.* (2014) under pomegranate based cropping system. Fungi were abundant in less pH or acidic soils while, bacteria and actinomycetes under neutral or alkaline soils (Grosso *et al.,* 2016). With organic matter (FYM) addition, bacteria and actinomycetes counts were enhanced, resulting in increased crop yield and soil nutrient status (Kataoka *et al.,* 2017).

2.6 CROPPING SYSTEMS AND CARBON MANGEMENT INDICES

The carbon management index (CMI) derived from the TOC pool and labile pool, evaluate the capacity of management systems to improve soil quality (Blair *et al*., 1995). The CMI below or above 100 indicate either a negative or positive impact on TOC content and soil quality (De Bona *et al.,* 2008). In rice–wheat cropping system amended with *Lantana spp*. the CMI values decreased from surface soil to lower depths irrespective of nutrient management practices (Sharma *et al*., 2003). Similar result was obtained by Moharana *et al.* (2012) under pearl millet–wheat system with integrated use of FYM and NPK. Increase in CMI due to intensive cropping systems could be attributed to enhanced soil organic carbon through root biomass addition (Moharana *et al*., 2017).

Materials and Methods

3. MATERIALS AND METHODS

The project entitled “Soil carbon dynamics in rice based cropping systems of Kerala” was carried out at College of Agriculture, Vellayani and Integrated Farming System Research Station, Karamana (IFSRS) during 2017-19. The prime objective of the experiment was to study and compare the soil carbon dynamics under diverse rice based cropping systems.

3.1 LOCATION OF STUDY

The experiment was laid out at IFSRS, Karamana during *Virippu* (first crop), *Mundakan* (second crop) and summer (third crop) seasons of 2018-19. The site is located at 8^0 28’ 25” N latitude and 76^0 57’ 32” E longitude, at an altitude of 5 m above mean sea level. Different rice based cropping sequences, including cereal, vegetable and green manure crops during the summer season have been in practice in this area for the last seven years.

3.1.1 Climate

Data on weather parameters *viz*., maximum and minimum temperature, rainfall and relative humidity were collected from Agro Meteorology Observatory, IFSRS, Karamana, during the study period and is illustrated in Fig. 1. Total rainfall of 1775.3mm was recorded during the crop period (May, 2018-19), with highest monthly rainfall during August-2018 (310.8 mm). Minimum and maximum temperature ranged from 21.35 to 26.3 ^{0}C and 30.15 to 33.65 ^{0}C.

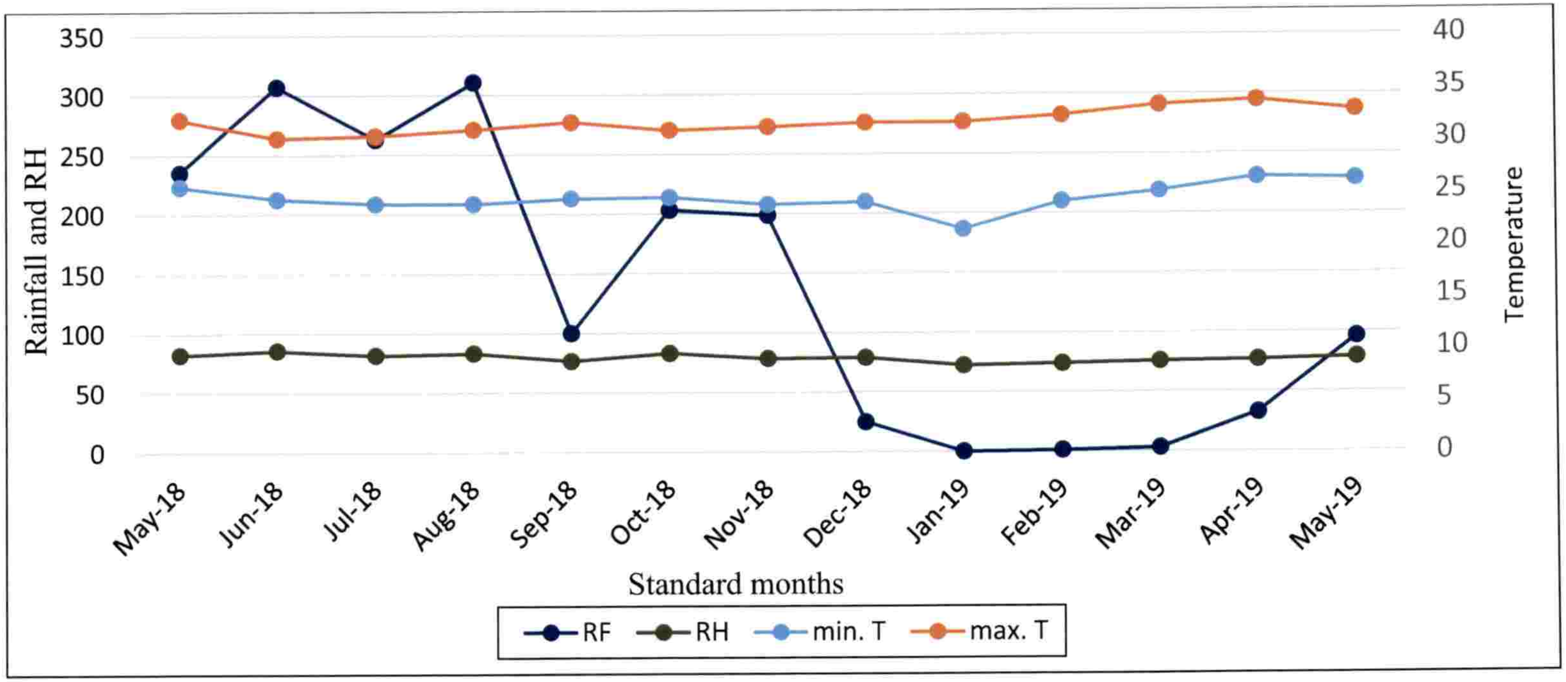
3.1.2 Crop history

Rice based cropping sequences *viz*., rice-rice-maize (R-R-M), rice-rice-bhindi (R-R-B) and rice-rice-daincha (R-R-D) have been followed at IFSRS, Karamana in the selected field. Rice crop was taken during *Virippu* (first crop) and *Mundakan* (second crop) seasons. During the summer (third crop) season, field was divided into three equal parts and maize, bhindi and daincha were taken, respectively, in each part.

Design of experiment: Randomized Block Design (RBD)

Treatments: 4 (R-R-B, R-R-M, R-R-D, R-R-F)

Replications: 5



Min.T – minimum temperature (^{0}C); Max. T – Maximum temperature (^{0}C)
RH – relative humidity (%); RF – rainfall (mm)

Fig 1. Weather data during the cropping period (May, 2018 – 19)

3.2 MATERIALS

3.2.1 Crop variety

During the first two crop seasons, medium duration (115-120 days), dwarf, medium tillering, non- lodging and brown plant hopper (BPH) resistant rice variety, Uma (Mo-16) was grown (Table 1). Bhindi (hybrid: Manjima), which is resistant to mosaic virus, maize (variety: Co 6) with semi dent type kernel and big sized cob and green manure crop daincha (variety: TN local) were grown during the third crop season. Rice seeds were obtained from IFSRS, Karamana, Kerala Agricultural University (KAU); bhindi seeds from College of Agriculture, Vellayani, KAU; maize and daincha seeds from Tamil Nadu Agricultural University, Coimbatore.

3.2.2 Manures and fertilizers

Farm yard manure was incorporated in the field at the time of initial ploughing. NPK fertilizers (Urea, Rajphos and Muriate of potash, respectively) were applied for all the crops except daincha after transplanting as per KAU (2016).

Table 1. Fertilizers and manures given to the crops

Crop	FYM	N	P_2O_5	K_2O
	(t ha^{-1})	(kg ha^{-1})		
Rice	5	100	45	45
Maize	25	135	65	15
Bhindi	25	75	25	25

3.3. METHODS

3.3.1 Crop duration

After *Virippu* and *Mundakan*, the entire field was divided into three equal parts and maize (cereal), bhindi (vegetable) and daincha (green manure) were raised in each part. Daincha was incorporated into the field at 50 per cent flowering stage, *i.e.*, 45 days after sowing (DAS). Harvest of bhindi fruits was completed in 75 DAS and biomass uprooted from the field. Maize leaves were incorporated into the field 80 DAS, after complete cob harvest (Table 2).

Table 2. Crops grown, variety and period of planting

Season	Crop	Variety	Duration
Virippu	Rice	Uma	4.6.2018 to 25.9.2018
Mundakan	Rice	Uma	4.10.2018 to 16.1.2019
Summer	Bhindi	Manjima	1.2.2019 to 18.5.2019
	Maize	Co 6	1.2.2019 to 20.5.2019
	Daincha	TN local	1.2.2019 to 16.3.2019

3.3.2 Harvest

The crops were harvested separately from each plot. After threshing and winnowing, paddy grain and straw yield were taken separately. Biomass yield of daincha was noted. Economic and biomass yield of maize and bhindi were recorded.

3.3.3 Soil sample collection

After each crop season, surface samples (0-15 cm) were collected and analysed for physical, chemical and biological parameters following the procedure depicted in section 3.4. In order to study the soil carbon dynamics, samples were drawn up to 105 cm depth at 15 cm intervals before and after the experiment (one year crop cycle) using soil tube. Soil samples were also drawn up to 105 cm depth from adjacent fallow and undisturbed fields. Sampling was replicated five times. Fresh samples were collected for the estimation of soil microbial biomass carbon and microbial count. The samples drawn were shade dried, passed through 2mm sieve and used for analysis of major physical, chemical and biological properties.

3.3.4 Preparation of plant samples

After each harvest, the main produce and by product were collected separately, air dried in shade and later in hot air oven at 65 ˚C. The dried biomass was powdered and stored for further analysis.

a. Daincha

b. Maize

c. Bhindi

Plate 2. View of summer crops *viz*., daincha, maize and bhindi,

a. *Virippu*

b. ***Mundakan***

Plate 1. Rice crop during *Virippu* and *Mundakan*

Daincha **Maize leaves**

Plate 3. Incorporation of crop residues (summer season)

Plate 4: Soil sampling at varied depths using soil tube

3.4 CHEMICAL ANALYSIS

3.4.1 Soil analysis

The procedures followed for the physical, chemical and biological analyses of soil samples are abridged in Table 3.

Table 3. Basic procedure for the analysis of soil samples

Parameter	Method	Reference
A. Physical		
Bulk density	Core sampler method	Veihmeyer and Hendrickson, 1948
B. Chemical		
pH (1:2.5)	Potentiometric method - pH meter	Jackson (1967)
EC (1:2.5)	Conductometric method - Conductivity meter	Jackson (1973)
Available N	Alkaline potassium permanganate method	Subbiah and Asija (1956)
Available P	Bray No. 1 extraction - spectrophotometer	Jackson (1973)
Available K	Neutral normal ammonium acetate extraction - flame photometer	Jackson (1973)
Exchangeable Ca and Mg	Versanate titration method	Hesse (1971).
Available S	0.15% $CaCl_2$ extraction - turbidimeter	Massoumi and Cornfield (1963)
Available Fe, Mn, Zn and Cu	0.1 M HCl extraction -atomic absorption spectrophotometer	Osiname *et al.* (1973)
Available B	Hot water extraction - spectrophotometer	Gupta (1967)
C. Biological		

1. Microbial count		
Bacteria	Serial dilution and plate count method - Nutrient Agar medium	Timonin, 1940
Fungi	Serial dilution and plate count method - Rose Bengal Agar medium	Timonin, 1940
Actinomycetes	Serial dilution and plate count method - Kenknight‘s medium	Timonin, 1940
2. Enzyme activities		
Dehydrogenase	Incubation - TPF released - spectrophotometer	(Thalmann, 1966)
Urease	Incubation - urea hydrolysed - spectrophotometer	(Tabatabai and Bremner, 1972)
Acid phosphatase	Incubation - p- nitrophenol released - spectrophotometer	(Tabatabai and Bremner, 1969)

3.4.2. Soil carbon pools

The major soil carbon pools studied include total organic carbon, particulate organic carbon, labile carbon and microbial biomass carbon.

3.4.2.1 Total organic carbon (TOC)

Soil total organic carbon content was assessed by wet oxidation followed by titration with ferrous ammonium sulphate as described by Walkley and Black’s (1934).

3.4.2.2 Particulate organic carbon (POC)

Particulate organic matter (POM) was separated from soil following the method as described by Camberdella and Elliott (1992). Soil sample (10g) was dispersed in 30ml 0.5% sodium hexa-metaphosphate solution by shaking for 15 hours on a reciprocating shaker. The dispersed soil suspension was passed through

53μm size sieve mesh. The materials retained on the sieve (>53μm size fraction) and moved through sieve (<53μm size fraction) were transferred to glass beakers and oven-dried at 50 ^{0} C for 24 h. The dried materials were ground and POC of coarse fraction (> 53μm) and finer fraction (<53μm) were analyzed by fallowing the method of Walkley and Black's (1934).

3.4.2.3 Labile carbon (LC)

Air dried soil sample (3g) was mixed with 30 ml of 20 mM potassium permanganate ($KMnO_4$) and kept in reciprocating shaker for 15 minutes. The soil suspension was then transferred to 50 ml centrifuge tube and centrifuged at 2000 rpm for 5 minutes. 2 ml aliquot from the supernatant solution was taken in 50 ml volumetric flask and absorbance was determined using spectrophotometer at 560-565 nm. By determining the KMnO4 concentration from the standard calibration curve, labile carbon was calculated (Blair *et al.*, 1995).

3.4.2.4 Microbial biomass carbon (MBC)

Microbial biomass carbon was determined adopting chloroform ($CHCl_3$) fumigation extraction method by estimating the amount of CO_2– C evolved from the soil samples as described by Voroney and Paul (1984). Ten gram soil sample was taken in 250 ml conical flask and fumigated with 10ml chloroform. Both fumigated and non-fumigated (without chloroform) samples were kept for incubation for 24h. Vials containing 5 mL of 0.1N sodium hydroxide (NaOH) were kept hanging inside the conical flask and left undisturbed for seven days. The evolved CO_2 got entrapped in NaOH vials and later titrated against 0.1N HCl, and MBC was content estimated.

3.4.3 Plant analysis

The prepared plant samples collected after crop harvest were analyzed for major (N, P, K, Ca and Mg) and micro (Fe, Mn, Zn and Cu) nutrients based on standard procedures as furnished in Table 4.

Table 4. Basic procedures for chemical analysis of plant samples

Parameter	Method	Reference
N	Microkjeldhal distillation after digestion using concentrated sulphuric acid	Jackson (1973)
P	Nitric-perchloric (9:4) acid digestion and spectrophotometry using vanado-molybdo yellow colour method	Jackson (1973)
K	Nitric-perchloric (9:4) acid digestion and flame photometry	Jackson (1973)
Ca and Mg	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrophotometry	Piper (1966)
Fe, Cu, Zn and Mn	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrophotometry	Lindsay and Norvel (1978)

3.5 YIELD ATTRIBUTES

3.5.1. Economic yield

Paddy grain yield obtained during *Virippu* and *Mundakan* seasons were recorded. During summer season, bhindi pod yield and maize cob yield were recorded and expressed in tonnes per hectare (t ha^{-1}).

3.5.2. Biomass yield

By product (dry weight) obtained after each crop harvest was represented as biomass yield and expressed in t ha^{-1}. Biomass yield of paddy straw, daincha, and crop residues of bhindi and maize were recorded.

3.6 COMPUTED INDICES

Three indices *viz*., carbon lability index (CLI), carbon pool index (CPI) and carbon management index (CMI) were computed (Blair *et al*., 1995).

3.6.1. Carbon lability index (CLI)

Labile C loss is more significant than non-labile C loss. To take this into consideration, C lability index was calculated by dividing soil labile C of the crop field by LC of undisturbed soil, which was taken as the reference soil.

CLI = LC of sample soil / LC of reference soil

3.6.2 Carbon pool index (CPI)

The loss of C from a soil with a large carbon pool is less consequential than the loss of the same quantity of C from a soil that has already been depleted or began with a smaller total C pool. To account for this, C pool index was calculated by dividing TOC of the crop field by TOC of undisturbed soil, which was taken as the reference soil.

CPI= TOC of sample soil / TOC of reference soil

3.6.3 Carbon management index (CMI)

Calculated by multiplying CPI and CLI and expressed in percentage.

CMI = CPI*LI*100

CMI offers a sensitive measure rate of change of the soil C dynamics the structures relative to a more stable reference soil.

3.7 STATISTICAL ANALYSIS

Data generated from the analyses of surface soil and plant samples were statistically analyzed using Analysis of Variance Technique. Soil carbon dynamics at differential depths were analyzed using factorial RBD (Randomized block design) (Cochran and Cox, 1965). Correlation of soil carbon fractions with weather parameters and enzyme activities was determined.

Results

4. RESULTS

An investigation on the different carbon fractions in a wetland soil at varied depths, entitled "Soil carbon dynamics in a rice based cropping system" was conducted at Integrated Farming System Research Station, Karamana during the period 2017-19. Major results of the investigation are detailed in this chapter.

4.1 SOIL ANALYSIS

Soil samples were collected from surface depth (0-15 cm) after each crop season and up to 105cm depth at 15cm intervals before and after the experiment and analysed for major soil physical, chemical and biological parameters.

4.1.1 Physical parameters

Soil bulk density under different cropping sequences and at varied depth are presented in Tables 5 and 6.

4.1.1.1 Bulk density

The cropping sequences showed significant influence on soil bulk density (BD) in the surface layer (0-15 cm) only after summer season (Table 5). A slight decrease in bulk density was noticed over the seasons. R-R-D (1.29), R-R-B (1.29) and R-R-F (1.23 Mg m^{-3}) cropping sequences recorded the highest values after *Virippu*, *Mundakan* and summer seasons, respectively. Except R-R-D sequence, BD of all the other three cropping sequences were found to be on par after summer season.

An increase in soil bulk density with depth was observed (Table 6) and the highest BD was noticed at 90-105 cm. BD at varied depths was significantly influenced by the different cropping sequences. R-R-F sequence recorded the highest BD at 0-15 (1.23 Mg m^{-3}), 15-30 (1.29 Mg m^{-3}), 30-45 (1.40 Mg m^{-3}) and 45-60 (1.47 Mg m^{-3}) cm depth and R-R-D sequence at 60-75 (1.59 Mg m^{-3}) and 75-90 (1.68 Mg m^{-3}) cm. The highest BD at 90-105 cm was observed for R-R-M sequence (1.73 Mg m^{-3}). Invariably, a decrease in BD was observed at all the depths under four different cropping sequences, at the end of the cropping cycle.

Table 5.Influence of cropping sequence on bulk density after each season, Mg m^{-3}

Cropping sequence	Bulk density(0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	1.27	1.29	1.19
R-R-M	1.28	1.27	1.21
R-R-D	1.29	1.28	1.17
R-R-F	1.25	1.28	1.23
SE m(±)	0.01	0.02	0.01
CD(0.05)	NS	NS	0.04

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 6.Influence of cropping sequence on soil bulk density at varied depths, Mg m-^{3}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	1.26	1.19	1.21	1.17	1.23
15-30	1.52	1.27	1.28	1.24	1.29
30-45	1.67	1.39	1.30	1.28	1.40
45-60	1.89	1.45	1.41	1.40	1.47
60-75	1.94	1.50	1.56	1.59	1.56
75-90	1.97	1.57	1.64	1.68	1.61
90-105	2.01	1.62	1.73	1.72	1.65
SE m(±)		0.02			
CD(0.05)-Depth		0.04			
CD(0.05)-CS		0.02			
CD(0.05)-Interaction		0.05			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2 Chemical parameters

Soil chemical properties *viz.,* different carbon fractions, pH, EC, major and micro nutrients were determined from the surface layer at the end of each crop season and at varied depths before and after the cropping cycle.

4.1.2.1 Carbon dynamics

Different soil carbon fractions like total organic carbon, particulate organic carbon (<53 and >53 µm), labile carbon and microbial biomass carbon under different cropping sequences at surface layer after each crop season and up to 105 cm depths before and after the experiment were analysed.

4.1.2.1.1 Total organic carbon (TOC)

Except *Mundakan* season, TOC was significantly influenced by the cropping sequences both after *Virippu* and summer seasons (Table 7). Both after *Virippu* and *Mundakan* seasons, R-R-F sequence recorded the highest soil TOC (18.39 and 19.41 g kg^{-1}, respectively) and R-R-M sequence, the lowest (17.07 and 18.21 g kg^{-1}, respectively). The TOC obtained in R-R-F sequence was found to be on par with R-R-B after *Virippu.* After summer season, R-R-D sequence produced significantly higher soil TOC (22.2 g kg^{-1}). An increase in TOC content was noticed for all the cropping sequences except R-R-F sequence. After *Mundakan* season, a slight increase in TOC was noticed in R-R-F sequence but after summer season, it declined.

Table 8 indicates soil TOC content up to 105 cm depth at 15 cm intervals under different cropping sequences. A drastic decline in TOC was noticed with depth. At the end of the cropping system, a slight improvement in TOC was obtained especially in the surface layer (0 – 15 cm) for all the cropping sequences. In all the layers, the highest TOC resulted with R-R-D sequence (22.2, 15.5, 13.4, 10.85, 8.35 and 3.35 g kg^{-1} at 0-15, 15-30, 30-45, 45-60, 60-75, 75-90 and 90-105 cm, respectively). R-R-B sequence produced the lowest TOC in all the layers except

0-15 and 75-90 cm depth. In the surface layer and 75-90 cm depth, R-R-F sequence produced the lowest TOC (18.8 and 2.85 g kg^{-1}) content.

Table 7. Influence of cropping sequence on TOC after each season, g kg^{-1}

Cropping sequence	TOC(0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	18.02	18.72	19.85
R-R-M	17.07	18.21	20
R-R-D	17.58	18.87	22.2
R-R-F	18.39	19.41	18.8
SE m(±)	0.14	0.14	0.03
CD(0.05)	0.42	NS	1.12

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 8. Influence of cropping sequence on TOC at varied depths, g kg-^{1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	15.00	19.85	20.00	22.20	18.80
15-30	14.15	13.65	14.70	15.50	14.65
30-45	12.60	11.60	13.10	13.40	12.65
45-60	10.35	9.00	10.50	10.85	10.60
60-75	6.65	6.30	7.40	8.35	7.50
75-90	2.40	3.05	3.45	3.35	2.85
90-105	1.60	1.30	2.00	2.15	1.85
SE m(±)		1.17			
CD(0.05)-Depth		2.76			
CD(0.05)-CS		0.87			
CD(0.05)-Interaction		3.30			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.1.2 Particulate organic carbon (POC)

POC in > 53μm and < 53 μm size fractions at the surface layer and at different depths were studied. In general, < 53 μm fractions contained more organic carbon than > 53μm fractions under all cropping sequences (Table 9). POC fraction (both

> 53µm and < 53 µm size) after summer season alone was significantly influenced by the different cropping sequences. R-R-B sequence had reported the highest > 53µm size fraction POC after *Virippu* (1351.56 mg kg^{-1}) and R-R-D sequence, after *Mundakan* (1452.46 mg kg^{-1}) and summer (1901.77 mg kg^{-1}) seasons. Soil after summer season from R-R-D sequence was found to be significantly superior to all others in POC (> 53µm). Lowest POC for all the three seasons (1288.87, 1374.36 and 1405.46 mg kg^{-1} for *Virippu*, *Mundakan* and summer seasons, respectively was reported in R-R-F system.

On analysing POC in <53µm size fractions, it was noticed that R-R-F, R-R-B and R-R-D sequence resulted in the highest POC after *Virippu* (2742.08 mg kg^{-1}), *Mundakan* (2828.63 mg kg^{-1}) and summer (3295.13 mg kg^{-1}) seasons, respectively. R-R-M cropping sequence (2631.32 mg kg^{-1}) recorded the lowest POC after *Virippu*, R-R-D (2787.64 mg kg^{-1}) after *Mundakan* and R-R-F (2894.89 mg kg^{-1}) after summer seasons. At the end of each cropping sequence, an improvement in POC in both size fractions (>53µm and <53µm) was noticed. POC under R-R-D cropping sequence was found to be significantly superior to all other sequences.

From surface soil (0-15cm) to deeper depth (90-105cm), POC of >53µm size fraction ranged from 965.23 to 25.24 mg kg^{-1} and < 53µm size fraction from 2395.32 to 541.65 mg kg^{-1}, before the experiment (Table 10). After the completion of the cropping sequence, POC of > 53µm fraction in R-R-B sequence ranged from 1470.33 to 80.07 mg kg^{-1}, R-R-M from 1636.26 to 25.12 mg kg^{-1} , R-R-D from 1901.77 to 15.33 mg kg^{-1} and R-R-F from 1405.46 to 20.43 mg kg^{-1} from the surface to 105 cm depth. A similar increase in POC content of < 53µm fraction was noticed at different depths in all the other cropping sequences.

Table 9. Influence of cropping sequence on POC after each season, mg kg^{-1}

Cropping sequence	POC(0-15cm)					
	> 53µm size			< 53µm size		
	Virippu	*Mundakan*	Summer	*Virippu*	*Mundakan*	Summer
R-R-B	1351.56	1407.94	1470.33	2703.36	2828.63	2905.12
R-R-M	1305.75	1428.64	1636.26	2631.32	2790.74	3098.78
R-R-D	1312.43	1452.46	1901.77	2676.44	2787.64	3295.13
R-R-F	1288.87	1374.36	1405.46	2742.08	2802.35	2894.89
SE m(±)	1.12	2.57	28.1	0.26	0.19	21.5
CD(0.05)	NS	NS	86.4	NS	NS	65.43

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.1.3 Labile carbon (LC)

Results in Table 11 revealed that LC decreased during first two seasons and then increased after summer season in all the cropping sequences. After *Virippu* and *Mundakan* season, R-R-B (1673.43 mg kg^{-1}) and R-R-M (1527.45 mg kg^{-1}) sequences had higher LC content, respectively. Among the cropping sequences, no significant difference in LC content was noted after both the seasons. After summer season, LC content was highest in R-R-D sequence (2283.97 kg^{-1}) and lowest in R-R-F sequence (1746.62 kg^{-1}) at surface layer.

LC content was significantly higher up to 30cm depth and decreased with depth. Initially, it ranged from 1963.64 to 280.72 mg kg^{-1} from 0 to 105 cm depth (Table 12). After the completion of the experiment, LC content in R-R-B sequence ranged from 1958.23 to 122.27 mg kg^{-1}, 2023.24 to 171.34 mg kg^{-1} in R-R-M sequence, 2283.97 to 216.32 mg kg^{-1} in R-R-D sequence and 1746.62 to 124.31 mg kg^{-1} in R-R-F sequence.

Table 10. Influence of cropping sequence on POC at varied depths, mg kg^{-1}

Cropping sequence	Initial		At the end of the trial POC (> 53µm size)				At the end of the trial (< 53µm size)			
	POC (> 53µm size)	POC (< 53µm size)	R-R-B	R-R-M	R-R-D	R-R-F	R-R-B	R-R-M	R-R-D	R-R-F
0-15	965.23	2395.32	1470.33	1636.26	1901.77	1405.46	2905.12	3098.78	3295.13	2894.89
15-30	560.43	2240.25	745.24	831.34	972.35	654.86	2565.05	2705.32	2855.07	2555.56
30-45	525.67	2090.54	462.15	575.37	634.33	483.53	2271.63	2370.12	2520.21	2365.32
45-60	430.43	1845.76	284.53	353.63	377.95	300.63	1729.82	1885.08	2034.94	1850.21
60-75	245.54	1502.43	201.35	226.44	232.43	215.35	1220.24	1270.23	1371.32	1368.32
75-90	55.08	562.67	94.42	70.72	74.74	65.53	605.12	690.32	727.45	812.32
90-105	25.34	541.65	80.07	25.12	15.33	20.43	490.23	580.08	623.94	553.43
SE m(±)			40.04				77.01			
CD(0.05)-Depth			123.21				241.30			
CD(0.05)-CS			67.92				178.38			
CD(0.05)-Interaction			115.21				218.10			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 11. Influence of cropping sequence on soil LC after each season, mg kg^{-1}

Cropping sequence	LC(0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	1673.43	1505.37	1958.23
R-R-M	1613.32	1527.45	2023.24
R-R-D	1648.90	1513.96	2283.97
R-R-F	1576.52	1422.57	1746.62
SE m(±)	0.08	0.08	32.71
CD(0.05)	NS	NS	98.42

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 12. Influence of cropping sequence on soil LC at varied depths, mg kg^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	1963.34	1958.23	2023.24	2283.97	1746.62
15-30	1785.47	1421.55	1377.59	1482.88	1451.19
30-45	940.07	832.73	624.19	869.53	808.20
45-60	579.22	666.11	532.19	661.00	609.88
60-75	490.28	412.59	314.45	348.19	392.14
75-90	366.59	248.01	249.03	281.74	253.12
90-105	280.72	122.27	171.34	216.32	124.31
SE m(±)		55.222			
CD(0.05)-Depth		186.29			
CD(0.05)-CS		165.26			
CD(0.05)-Interaction		170.07			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.1.4 Microbial biomass carbon (MBC)

Different cropping sequences had significantly influenced soil MBC content during all the three seasons (Table 13). R-R-B sequence recorded the highest MBC after *Virippu* (466.67 mg kg^{-1}) and *Mundakan* (462.22 mg kg^{-1}) while R-R-D sequence, after summer season (629.62 mg kg^{-1}). The lowest MBC was noticed in R-R-M sequence after *Virippu* and R-R-F sequence after both *Mundakan* (408.89 mg kg^{-1}) and summer (481.48 mg kg^{-1}) seasons, respectively. A significant improvement in MBC was noticed at the end of each cropping cycle.

Table 13. Influence of cropping sequence on MBC after each season, mg kg^{-1}

Cropping sequence	MBC(0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	466.67	462.22	518.51
R-R-M	426.67	423.67	585.18
R-R-D	457.78	440.00	629.62
R-R-F	431.11	408.89	481.48
SE m(±)	6.06	5.30	9.04
CD(0.05)	18.12	16.32	28.12

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

A drastic decline in MBC was noticed with depth and was almost negligible after 75 cm depth (Table 14). R-R-D sequence recorded the highest content at 0-15 (629.62 mg kg^{-1}), 15-30 (377.77 mg kg^{-1}) and 45-60 cm (103.7 mg kg^{-1}) depths. At 30-45 cm depth, R-R-B, R-R-M and R-R-D sequences obtained the same MBC (214.81 mg kg^{-1}). R-R-M and R-R-D recorded the same values (44.44 mg kg^{-1}) at 60-75 cm depth. In all the layers except 45-60 cm depth, R-R-F recorded the lowest value. At 45-60 cm depth, R-R-B obtained the lowest (81.48 mg kg^{-1}).

Table 14. Influence of cropping sequence on MBC at varied depths, mg kg^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	355.6	518.51	585.18	629.62	481.48
15-30	281.3	348.14	362.96	377.77	340.74
30-45	118.3	214.81	214.81	214.81	177.77
45-60	89	81.48	96.29	103.70	88.88
60-75	29.3	37.03	44.44	44.44	37.03
75-90	-	-	-	-	-
90-105	-	-	-	-	-
SE m(±)		20.8			
CD(0.05)-Depth		54.3			
CD(0.05)-CS		48.38			
CD(0.05)-Interaction		59.10			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.2 pH

It is evident form Table 15 that, different cropping systems had significantly influenced soil pH after *Virippu, Mundakan* and summer seasons. A slight increase in soil pH was observed at the end of cropping sequence in all the four systems except R-R-F. The highest pH was recorded by R-R-F (5.27), R-R-B (5.25) and R-R-M (5.53) after Virippu, Mundakan and summer seasons, respectively. The pH of R-R-F after *Virippu* and R-R-M after summer were significantly superior to all other sequences. R-R-D recorded the lowest pH after *Virippu* (5.05) and R-R-F, the lowest after *Mundakan* (5.13) and summer (5.01) seasons.

Much variation in pH was noticed with depth under different cropping sequences (Table 16). R-R-B (5.35) and R-R-M (5.53) sequences recorded the highest pH at surface layer. The highest pH with R-R-D sequence was noticed at 15-30 depth. But for R-R-F sequence, 75-90 cm depth (5.38) registered the highest pH and 15-30 cm, the lowest. With R-R-D, the lowest value was obtained at 30-45 cm depth. R-R-B (5.12) and R-R-M (4.99) sequences recorded the lowest pH at 90-105 cm depth.

Table 15. Influence of cropping sequence on soil pH after each season

Cropping sequence	pH (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	5.11	5.25	5.35
R-R-M	5.07	5.21	5.53
R-R-D	5.05	5.19	5.37
R-R-F	5.27	5.13	5.01
SE m(±)	0.03	0.01	0.03
CD(0.05)	0.09	0.04	0.12

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 16. Influence of cropping sequence on soil pH at varied depths

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	5.00	5.35	5.53	5.37	5.01
15-30	5.21	5.33	5.43	5.47	4.96
30-45	5.23	5.23	5.35	5.02	5.21
45-60	5.12	5.27	5.31	5.04	5.13
60-75	5.09	5.18	5.32	5.12	5.34
75-90	4.92	5.24	5.07	5.41	5.38
90-105	5.09	5.12	4.99	5.29	5.27
SE m(±)		0.05			
CD(0.05)-Depth		0.18			
CD(0.05)-CS		0.17			
CD(0.05)-Interaction		0.14			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.3 Electrical Conductivity (EC)

Only after *Virippu* and *Mundakan*, soil EC was significantly influenced by the different cropping sequences. Except R-R-M, all other cropping sequences showed a decrease in EC at the end of summer season. R-R-M sequence recorded the highest EC both after *Mundakan* (0.35 dS m^{-1}) and summer (0.36 dS m^{-1}) seasons. Both R-R-B and R-R-M recorded the highest value of 0.31 dS m^{-1} after *Virippu.* R-R-F sequence obtained the lowest value of 0.29, 0.30 and 0.20 dS m^{-1} respectively, after *Virippu, Mundakan*, and summer seasons.

Table 17. Influence of cropping sequence on soil EC after each season, dS m^{-1}

Cropping sequence	EC (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	0.31	0.32	0.23
R-R-M	0.31	0.35	0.36
R-R-D	0.30	0.33	0.24
R-R-F	0.29	0.30	0.20
SE m(±)	0.014	0.01	0.02
CD(0.05)	NS	0.04	0.07

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

A drastic reduction in EC of soil with depth was observed (Table 18). In general, a decline in EC was noticed at all depths at the end of each cropping sequence, compared to initial level. The highest EC was obtained in the surface layer with all cropping sequences- 0.23, 0.36, 0.24, 0.20 dS m^{-1} , respectively for R-R-B, R-R-M, R-R-D and R-R-F systems. In all the soil layers except 75-90 cm depth, the highest EC was observed in R-R-M sequence.

Table 18. Influence of cropping sequence on soil EC at varied depths, dS m^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	0.32	0.23	0.36	0.24	0.20
15-30	0.31	0.19	0.33	0.17	0.19
30-45	0.17	0.14	0.31	0.14	0.16
45-60	0.11	0.11	0.29	0.09	0.10
60-75	0.08	0.08	0.16	0.08	0.07
75-90	0.05	0.10	0.09	0.06	0.03
90-105	0.04	0.04	0.06	0.03	0.02
SE m(±)		0.01			
CD(0.05)-Depth		0.03			
CD(0.05)-CS		0.04			
CD(0.05)-Interaction		0.04			

4.1.2.4 Available major nutrients

Results on soil available primary nutrients (N, P and K) and secondary nutrients (Ca, Mg and S) are presented in Tables 19 to Table 30.

4.1.2.4.1 Available N

Cropping sequences had no significant influence on available N during any of the seasons (Table 19). However, R- R- F sequence recorded the highest available N after both *Virippu* (341.20 kg ha^{-1}) and *Mundakan* (336.17 kg ha^{-1}) seasons and the lowest (326.06 kg ha^{-1}) after summer season. The trend was reverse for R-R-D sequence. It recorded the lowest N content after *Virippu* (326.14 kg ha⁻

^{1}) and *Mundakan* (321.12 kg ha^{-1}) and the highest (38.69 kg ha^{-1}) after summer season.

Table 19. Influence of cropping sequence on available N after each season, kg ha^{-1}

Cropping sequence	Available N (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	331.16	328.65	330.33
R-R-M	338.68	326.14	334.51
R-R-D	326.14	321.12	338.69
R-R-F	341.197	336.17	326.06
SE m(±)	18.97	12.07	13.09
CD(0.05)	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 20. Influence of cropping sequence on available N at varied depths, kg ha^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	342.87	330.33	334.51	338.69	326.06
15-30	309.42	267.61	275.97	280.15	282.52
30-45	301.06	242.52	221.61	246.70	253.98
45-60	259.24	209.07	196.52	217.43	200.70
60-75	229.97	204.89	171.43	209.07	178.89
75-90	200.70	183.98	171.43	179.80	160.53
90-105	192.34	154.71	154.71	161.43	157.98
SE m(±)		10.01			
CD(0.05)-Depth		32.27			
CD(0.05)-CS		26.32			
CD(0.05)-Interaction		26.95			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 20 represents the available soil N in varied soil layers upto 105 cm depth under different cropping sequences. The interaction between cropping systems and depth of sampling significantly influenced available N. A reduction in available N was noticed in all the depths under the different cropping systems. In all soil layers, except, 15-30, 30-45 and 75-90 cm, R- R- D sequence recorded the highest soil available nitrogen. R- R- F sequence registered the highest value at 15-30 (282.52 kg ha^{-1}) and 30-45 (253.98 kg ha^{-1}) cm depths. At 75-90 cm depth, R- R- B sequence recorded the highest (183.98 kg ha^{-1}) available soil N. R- R- F sequence registered the lowest N content at 0-15 (326.06 kg ha^{-1}) and 75-90 (160.53 kg ha^{-1}) cm; R- R- B at 15-30 (267.61 kg ha^{-1}) and 90-105 (154.1 kg ha^{-1}) cm and R- R- M at 30-45 (221.61 kg ha^{-1}) , 45-60 (196.52 kg ha^{-1}) and 60-75 (171.43 kg ha^{-1}) cm.

4.1.2.4.2 Available Phosphorus

Soil available P was not significantly influenced by the different cropping sequences (Table 21). Only in R-R-B sequence, decrease in available P was noticed at the end of crop cycle. R- R- F sequence recorded the highest available P status after *Virippu* (45.43 kg ha^{-1}) and *Mundakan* (43.22 kg ha^{-1}). It was highest in R- R- D sequence (46.60 kg ha^{-1}) after summer season. R- R- B sequence obtained the lowest available P content after *Virippu* (42.48 kg ha^{-1}) and summer (39.16 kg ha^{-1}) seasons. After *Mundakan*, it was the lowest in R- R- D (40.24 kg ha^{-1}).

Table 22 indicates the interaction effect of cropping sequence and soil depth on available P content. Available P decreased with depth and the highest status was observed in the surface 0-15 cm layer. R-R-D sequence recorded the highest P content only in the surface layer (46.60 kg ha^{-1}). At 15 – 30 (35.63 kg ha^{-1}), 60 – 75 (18.40 kg ha^{-1}), 75-90 (17.03 kg ha^{-1}) and 90-105 (13.90 kg ha^{-1}) cm depths, R-R-M sequence recorded the highest soil P content. R-R-F system obtained the highest values at 30-45 (29.17 kg ha^{-1}) and 45-60 (21.73 kg ha^{-1}) cm depths. The lowest soil available P at all layers was noticed with R- R- B sequence.

Table 21. Influence of cropping sequence on available P after each season, kg ha^{-1}

Cropping sequence	Available P (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	42.48	41.63	39.16
R-R-M	43.58	42.00	44.64
R-R-D	43.09	40.24	46.6
R-R-F	45.43	43.22	45.23
SE m(±)	3.29	3.44	3.54
CD(0.05)	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 22. Influence of cropping sequence on available P at varied depths, kg ha^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	44.60	39.16	44.64	46.60	45.23
15-30	34.50	27.60	35.63	35.44	35.44
30-45	24.30	19.77	23.69	23.89	29.17
45-60	21.90	16.84	20.17	18.79	21.73
60-75	15.20	13.31	18.40	17.03	17.03
75-90	10.90	10.38	17.03	15.86	13.90
90-105	9.10	10.18	13.90	12.14	10.38
SE m(±)		1.68			
CD(0.05)-Depth		4.14			
CD(0.05)-CS		5.48			
CD(0.05)-Interaction		4.84			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.4.3 Available Potassium

Based on Table 23, cropping sequences had significant influence on soil available K content only after summer season. A decrease in soil available K was observed in all cropping sequences after summer compared to that in *Virippu*, except R-R-D system. Soil available K after summer was found to on par with all the cropping sequences except R- R- B system. R-R-M, R-R-B and R-R-D system recorded the highest K status after *Virippu* (150.11 kg ha^{-1}), *Mundakan* (146.22 kg ha^{-1}) and summer (154.31 kg ha^{-1}) seasons, respectively. The lowest K status was noticed in R-R-F after *Virippu* (147.87 kg ha^{-1}) and *Mundakan* (143.29) and in R-R-B (141.10 kg ha^{-1}) after summer.

Table 23. Influence of cropping sequence on available K after each season, kg ha^{-1}

Cropping sequence	Available K (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	149.51	146.22	141.1
R-R-M	150.11	145.69	148.35
R-R-D	149.29	145.16	154.31
R-R-F	147.87	143.29	145.72
SE m(±)	2.95	3.26	3.08
CD(0.05)	NS	NS	9.13

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

A reduction in soil available K content at all depths was observed at the end of copping cycle compared to that at initial level (Table 24). Like other primary nutrients, K status also decreased with depth. In the surface layers (0 – 30 cm), R-R-D sequence recorded the highest K content. But towards the deeper depth (90 – 105 cm), R- R- F cropping sequence obtained the highest K. R-R-B system resulted in the lowest K content in the surface layer and R-R-M system, in the deepest layer.

Table 24. Influence of cropping sequence on available K at varied depths, kg ha^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	156.60	141.10	148.35	154.31	145.72
15-30	142.13	129.69	132.32	132.90	121.94
30-45	138.55	122.74	108.55	122.10	118.28
45-60	125.15	102.40	99.27	115.15	110.95
60-75	116.29	111.56	111.75	101.75	103.70
75-90	102.25	94.12	82.91	90.73	93.63
90-105	97.74	86.56	78.39	85.17	92.83
SE m(±)		8.63			
CD(0.05)-Depth		21.29			
CD(0.05)-CS		23.38			
CD(0.05)-Interaction		26.59			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.4.4 Exchangeable Calcium

Table 25 represents the soil exchangeable Ca at surface layer at the end of each crop season. No significant influence of cropping systems on soil exchangeable Ca was noticed. Except R-R-B sequence, all others recorded a slight increase in Ca content at the end of third crop season. R-R-B (252.90 mg kg^{-1}), R-R-M (251.2 mg kg^{-1}) and R-R-D (257.33 mg kg^{-1}) obtained the highest value after *Virippu, Mundakan* and summer seasons, respectively. R- R- F recorded the lowest value after *Virippu* and *Mundakan* and R-R-B, after summer season.

In all the layers except surface layer (0 – 15 cm), a slight reduction in soil exchangeable Ca was noticed compared to the initial levels (Table 26). R- R- D sequence recorded the highest Ca content in all soil depths. R-R-F system obtained the lowest Ca content in all layers except 0-15 and 90-105 cm depths. R-R-B (246.67 mg kg^{-1}) and R-R- M (144 mg kg^{-1}) sequences recorded the lowest Ca in 0-15 cm and 90-105 cm, respectively.

Table 25. Influence of cropping sequence on Ca after each season, mg kg^{-1}

Cropping sequence	Exchangeable Ca (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	252.90	250.40	246.67
R-R-M	252.80	251.20	254.67
R-R-D	251.20	250.30	257.33
R-R-F	249.60	247.93	248.21
SE m(±)	2.85	3.19	3.87
CD(0.05)	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 26. Influence of cropping sequence on Ca at varied depths, mg kg^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	253.33	246.67	254.67	257.33	256.00
15-30	242.67	237.33	240.00	241.33	226.67
30-45	218.67	209.33	213.33	216.00	197.33
45-60	205.33	190.67	200.00	201.33	188.00
60-75	184.00	184.00	188.00	184.00	172.00
75-90	173.33	173.33	166.67	168.00	164.00
90-105	155.33	148.00	144.00	145.33	146.67
SE m(±)		10.39			
CD(0.05)-Depth		28.48			
CD(0.05)-CS		21.27			
CD(0.05)-Interaction		24.48			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.4.5 Exchangeable Magnesium

According to Table 27, cropping sequences had no significant influence on exchangeable Mg content of soil. At the end of summer season, Mg content was enhanced only in R-R-D sequence. Highest Mg content was noticed in R-R-B after *Virippu* and *Mundakan*. It was highest in R-R-D after summer crop. R-R-F sequence recorded the lowest after *Virippu, Mundakan* and summer seasons.

Table 27. Influence of cropping sequence on Mg after each season, mg kg^{-1}

Cropping sequence	Exchangeable Mg (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	36.80	34.40	33.33
R-R-M	36.00	34.40	34.67
R-R-D	35.20	32.80	37.33
R-R-F	34.40	32.80	33.33
SE m(±)	2.55	3.33	1.98
CD(0.05)	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Much variation in Mg content was observed with depth (Table 28) and the cropping sequence – depth interaction had significantly influenced soil exchangeable Mg. A decline in exchangeable Mg content was noticed in all the layers except 90-105 cm depth, at the end of crop cycle. However, R-R-D sequence recorded the highest Mg content in all the soil layers.

Table 28. Influence of cropping sequence on Mg at varied depths, mg kg^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	37.33	33.33	34.67	37.33	33.33
15-30	33.33	32.00	33.33	33.33	30.67
30-45	28.00	26.67	28.00	29.33	26.67
45-60	22.67	21.33	21.33	24.00	22.67
60-75	21.33	14.67	16.00	18.67	16.00
75-90	12.00	13.33	14.67	16.00	13.33
90-105	6.67	8.00	6.67	8.00	6.67
SE m(±)		1.69			
CD(0.05)-Depth		4.34			
CD(0.05)-CS		5.3			
CD(0.05)-Interaction		4.8			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.4.6 Available Sulphur

Soil available S after the summer crop alone was significantly influenced by the different cropping sequences (Table 29). R-R-D recorded the highest available S after *Virippu* and summer seasons and R-R-M, after *Mundakan* crop. Available S content in R-R-D (74.13 mg kg^{-1}) after summer crop was significantly superior to all other cropping sequences. Lowest S content was detected in R-R-F sequence at the end of each crop season.

Table 29. Influence of cropping sequence on available S after each season, mg kg^{-1}

Cropping sequence	Available S (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	30.54	28.92	42.32
R-R-M	30.47	29.88	48.83
R-R-D	31.13	29.59	74.13
R-R-F	29.44	28.70	29.37
SE m(±)	1.10	1.58	1.87
CD(0.05)	NS	NS	4.93

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 30. Influence of cropping sequence on available S at varied depths, mg kg^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	33.44	42.32	48.83	74.13	31.37
15-30	30.63	31.22	32.85	40.39	26.78
30-45	26.19	23.53	24.71	25.30	24.12
45-60	22.05	22.34	19.23	20.27	21.01
60-75	19.97	17.76	17.02	16.72	17.31
75-90	18.05	16.28	15.68	15.24	15.24
90-105	16.28	13.46	12.28	13.02	12.13
SE m(±)		1.99			
CD(0.05)-Depth		6.23			
CD(0.05)-CS		4.89			
CD(0.05)-Interaction		5.67			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Throughout the entire depth, a reduction in available S content was noticed in R-R-F sequence alone (Table 30). R-R-D sequence recorded the highest S content up to 45 cm depth (74.13, 40.39 and 25.30 mg kg^{-1} at 0-15, 15-30 and 30-

45 cm, respectively). From 45 to 105 cm depth, R-R-B obtained the highest S content (22.34, 17.76, 16.28 and 13.46 mg kg^{-1} at 45-60, 60-75, 75-90 and 90-105 cm depth). R-R-F system recorded the lowest S content at 0-30 and 75-105 cm depths.

4.1.2.5 Available micro nutrients

Tables 31 to 40 represent the soil available micronutrients *viz*., Fe, Mn, Zn, Cu and B at surface layer after each crop season and at deeper layers at the end of the experiment.

4.1.2.5.1 Available Fe

As per Table 31, soil available Fe was not significantly influenced by the cropping sequences. At the end of crop cycle, a decrease in available Fe was noticed in all the cropping sequences. After *Virippu* (397.4 mg kg^{-1}) and *Mundakan* (391.2 mg kg^{-1}), R-R-D recorded the highest Fe content while R-R-F system (349.87 mg kg^{-1}), after summer season. A reverse trend was noticed in the lowest Fe content.

As indicated in Table 32, significant influence was noticed in the available Fe content due to interaction between cropping sequence and soil depths. R-R-F sequence obtained the highest Fe content at 0- 60 cm depth, R-R-D at 60-75, R-R-M at 75-90 and R-R-B at 90-105 cm. The lowest Fe content was observed in R-R-D system at 0-30, 45-60, 75-105 cm depths, R-R-M at 30-45 cm and R-R-B at 60-75 cm.

Table 31. Influence of cropping sequence on available Fe after each season, mg kg^{-1}

Cropping sequence	Available Fe (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	395.15	390.35	304.47
R-R-M	391.85	390.90	318.63
R-R-D	397.40	391.20	359.87
R-R-F	389.75	386.05	349.87
SE m(±)	24.37	23.44	22.30
CD(0.05)	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 32. Influence of cropping sequence on available Fe at varied depths, mg kg^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	400.17	304.47	318.63	359.87	349.87
15-30	579.42	330.13	380.10	376.40	386.40
30-45	385.58	209.20	143.13	290.77	307.43
45-60	340.75	169.73	164.57	146.30	209.63
60-75	170.08	130.92	155.10	183.77	177.10
75-90	106.25	106.35	164.03	106.32	114.97
90-105	96.42	121.53	94.87	88.94	93.67
SE m(±)		28.47			
CD(0.05)-Depth		72.96			
CD(0.05)-CS		67.28			
CD(0.05)-Interaction		80.96			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.5.2 Available Manganese

No significant influence was noticed in the soil available Mn due to different cropping sequences during any crop season (Table 33). A decrease in available Mn content was observed at the end of cropping sequence. Highest Mn was obtained in R-R-D (36.52 mg kg^{-1}) after *Virippu*, R-R-M (33.76 mg kg^{-1}) after *Mundakan* and R-R-F (30.51 mg kg^{-1}) after summer season. R-R-B recorded the lowest Mn content after *Virippu* and Mundakan and summer seasons.

Interaction influence of cropping sequence and depth on available Mn is given in Table 34. The cropping sequences had resulted in decrease in available Mn content of soil at all layers. Upto 60 cm depth, R-R-F sequence resulted in the highest available Mn content. R-R-B recorded the highest value at 60-75 cm, R-R-M at 75-90 and R-R-D at 90-105 cm depth.

Table 33. Influence of cropping sequence on available Mn after each season,mg kg^{-1}

Cropping sequence	Mn (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	34.04	32.72	28.73
R-R-M	35.50	33.76	29.07
R-R-D	36.52	32.98	29.2
R-R-F	35.82	34.62	30.51
SE m(±)	1.40	1.11	1.27
CD(0.05)	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 34. Influence of cropping sequence on available Mn at varied depths, mg kg^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	35.13	28.73	29.07	27.20	30.51
15-30	36.90	29.27	27.93	28.77	32.26
30-45	39.00	29.13	25.53	26.00	32.03
45-60	34.93	20.61	18.30	19.27	25.28
60-75	33.63	17.57	14.33	14.61	14.07
75-90	30.90	13.67	15.13	14.53	11.81
90-105	29.73	10.73	10.97	11.27	10.23
SE m(±)		1.91			
CD(0.05)-Depth		4.75			
CD(0.05)-CS		3.57			
CD(0.05)-Interaction		5.43			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.2.5.3 Available Zn

Available Zn content of soil was significantly influenced by cropping sequences only during *Virippu* season (Table 35). R-R-B recorded the highest Zn content both during *Virippu* (21.02 mg kg^{-1}) and *Mundakan* (19.25 mg kg^{-1}) and R-R-D (20.51 mg kg^{-1}) after summer season. During all the three seasons, R-R-F obtained the lowest Zn content.

Table 35. Influence of cropping sequence on available Zn after each season, mg kg^{-1}

Cropping sequence	Zn (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	21.02	19.25	20.34
R-R-M	19.67	18.59	19.96
R-R-D	19.38	18.54	20.51
R-R-F	18.47	17.49	19.57
SE m(±)	0.30	0.79	0.83
CD(0.05)	0.94	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 36. Influence of cropping sequence on available Zn at varied depths, mg kg^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	21.48	20.34	19.96	20.51	19.57
15-30	19.32	15.77	14.26	14.53	13.78
30-45	18.55	13.59	11.53	13.36	12.97
45-60	16.04	10.59	6.56	11.20	11.75
60-75	15.53	10.17	5.97	9.98	9.06
75-90	5.45	8.30	4.72	8.51	7.05
90-105	4.66	4.31	3.78	4.65	4.25
SE m(±)		0.87			
CD(0.05)-Depth		3.32			
CD(0.05)-CS		2.56			
CD(0.05)-Interaction		2.46			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Gradual reduction in Zn content was noticed in all the soil layers under all cropping sequences compared to initial levels (Table 36). Much variation was observed in the Zn content in the different soil layers. R-R-D system recorded the highest value at 0-15 (20.51 mg kg^{-1}), 60-75 (9.98 mg kg^{-1}) and 90-105 (4.65 mg kg^{-1}) cm depths. At 15-30, 30-45 and 60-75 cm, R-R-B obtained the highest Zn content and R-R-F at 45-60 cm. upto 45 cm depth R-R-F recorded the lowest value.

4.1.2.5.4 Available Cu

Soil available Cu content was significantly influenced by the cropping sequences throughout the cropping period (Table 37). R-R-B sequence recorded the highest value in all the three seasons, except *Virippu*. After summer season, R-R-B sequence obtained the highest Cu content (7.71 mg kg^{-1}) and was found to be significantly superior to all the others. R-R-M recorded the lowest Cu content during all the three seasons.

Table 37. Influence of cropping sequence on available Cu after each season, mg kg^{-1}

Cropping sequence	Cu (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	9.82	9.32	7.71
R-R-M	9.56	8.54	6.62
R-R-D	10.24	8.96	6.76
R-R-F	9.72	9.16	7.49
SE m(±)	0.13	0.14	0.16
CD(0.05)	0.31	0.44	0.51

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 38. Influence of cropping sequence on available Cu at varied depths, mg kg^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	10.50	7.71	6.62	6.76	7.49
15-30	10.00	6.50	3.60	5.48	5.25
30-45	11.20	5.18	3.45	3.89	3.32
45-60	7.80	3.84	2.93	3.46	3.29
60-75	4.83	3.20	2.75	3.33	3.01
75-90	3.13	3.02	2.82	2.87	2.68
90-105	2.47	2.85	2.58	2.64	2.84
SE m(±)		0.22			
CD(0.05)-Depth		0.57			
CD(0.05)-CS		0.54			
CD(0.05)-Interaction		0.63			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

As indicated in Table 38, R-R-B system obtained the highest soil Cu content in all the layers, except 60-75 cm depth. A decreasing trend in available Cu compared to the initial level was noticed in all the layers, except 90-105 cm depth.

The lowest Cu status was obtained in R-R-M sequence at 0-15, 15-30, 45-60, 60-75, and 90-105 cm depths

4.1.2.5.5 Boron

Tables 39 and 40 indicate the influence of cropping sequences on available B content of soil at varied depths. B content was significantly influenced by the cropping sequences only after *Mundakan*. R-R-M sequence had the highest B (0.65 mg kg^{-1}) content and was found to be on par with R-R-B (0.63 mg kg^{-1}) and R-R-D (0.61 mg kg^{-1}) sequences. After *Virippu*, R-R-B sequence obtained the highest B content (0.64 mg kg^{-1}). Available soil B content increased after summer in all the cropping sequences and R-R-D obtained the highest (0.79 mg kg^{-1}) content.

Table 39. Influence of cropping sequence on available B after each season, mg kg^{-1}

Cropping sequence	B (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	0.64	0.63	0.75
R-R-M	0.65	0.64	0.74
R-R-D	0.62	0.61	0.79
R-R-F	0.57	0.53	0.65
SE m(±)	0.01	0.01	0.01
CD(0.05)	NS	0.05	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Up to 0-45 cm depth, R-R-D sequence recorded the highest B content (Table 40). Beyond this depth there was not much variation in B content with cropping sequences. In general, R-R-F sequence recorded the lowest value for B content in soil at different depths.

Table 40. Influence of cropping sequence on available B at varied depths, mg kg^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	0.65	0.75	0.74	0.79	0.65
15-30	0.57	0.67	0.66	0.70	0.58
30-45	0.52	0.51	0.52	0.54	0.52
45-60	0.50	0.49	0.49	0.49	0.49
60-75	0.39	0.41	0.42	0.40	0.39
75-90	0.25	0.25	0.24	0.25	0.25
90-105	0.19	0.19	0.19	0.19	0.18
SE m(±)		0.02			
CD(0.05)-Depth		0.04			
CD(0.05)-CS		0.03			
CD(0.05)-Interaction		0.05			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.3 Biological parameters

Variation in soil enzyme activities and microbial count with cropping sequences and soil depth are presented in Tables 41 to 52.

4.1.3.1 Enzyme activities

Tables 41 to 46 represent the influence of cropping sequences on soil enzyme activities *viz.*, dehydrogenase, urease and acid phosphatase and their variation with depth.

4.1.3.1.1 Dehydrogenase

Soil dehydrogenase activity was not significantly influenced by the different cropping sequences (Table 41). However, R-R-D sequence obtained the highest activity both under *Virippu* (25.3 µg g^{-1}) and *Mundakan* (24.07 µg g^{-1}) and R-R-F (26.17 µg g^{-1}), after summer season. Lowest activity was observed in R-R-F after *Virippu* (24.45) and summer seasons (24.25) and R-R-B after *Mundakan* (23.13).

Table 41. Influence of cropping sequence on dehydrogenase activity after each season, µg of TPF released g^{-1} soil 24 h^{-1}

Cropping sequence	Dehydrogenase(0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	24.91	23.13	24.82
R-R-M	25.07	23.84	25.91
R-R-D	25.30	24.07	26.17
R-R-F	24.45	23.49	24.25
SE m(±)	1.04	1.12	1.24
CD(0.05)	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

A drastic reduction in dehydrogenase activity was noticed with depth and was almost negligible beyond 75 cm depth (Table 42). R-R-D sequence recorded the highest dehydrogenase activity at 0-15 (26.17 µg g^{-1}), 45-60 (11 µg g^{-1}) and 60-75 cm (6.27 µg g^{-1}) depths and R-R-B sequence (18.3 C) at15 to 45 cm. The lowest activity was noticed with R-R-F sequence at 0-15 (24.25 µg g^{-1}) and 30- 45 cm (12.35 µg g^{-1}), R-R-M at 15-30 (15.93 µg g^{-1}) and R-R-B at 45 – 75 (9.92 µg g^{-1}) cm depth.

Table 42. Influence of cropping sequence on dehydrogenase activity at varied depths, µg of TPF released g^{-1} soil 24 h^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	24.56	24.82	25.91	26.17	24.25
15-30	18.04	18.30	15.93	17.40	16.38
30-45	14.65	14.52	13.24	13.05	12.35
45-60	10.88	9.92	10.75	11.00	10.43
60-75	3.97	5.31	6.14	6.27	6.14
75-90	-	-	-	-	-
90-105	-	-	-	-	-
SE m(±)		1.08			
CD(0.05)-Depth		3.13			
CD(0.05)-CS		2.09			
CD(0.05)-Interaction		3.07			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.3.1.2 Urease

An increase in urease activity was noticed at the end of crop cycle in all the cropping sequences, except R-R-B (Table 43). Initially, there was a slight decline after *Mundakan* season and increased after summer crop. No significant difference was noticed in urease activity among the cropping sequences after each seasons. R-R-B sequence recorded the highest activity after *Virippu* (86.67 mg g^{-1}) and *Mundakan* (83.57 mg g^{-1}) seasons and R-R-D sequence (91.3 mg g^{-1}), after summer. The lowest activity was observed in R-R-F after *Virippu* (83.83 mg g^{-1}) and *Mundakan* (82.43 mg g^{-1}) and in R-R-B (84.80 mg g^{-1}), after summer.

Here also, urease activity drastically declined with depth and was negligible beyond 75 cm. (Table 44). R-R-D recorded the highest activity upto 45 cm depth (91.3, 85.74, 78.47 mg g^{-1} at 0-15, 15-30, 30-45cm); R-R-B (74.14 mg g^{-1}) and R-R-F (39.48 mg g^{-1}) at 45-60 and 60-75 cm depth, respectively. At 0-15, 15-60 and 60-75 cm depths, R-R-B (84.8 mg g^{-1}), R-R-F (80.75, 76.25, 71.19 mg g^{-1} at 15-30,30-45,40-60cm depth) and R-R-M (37.37 mg g^{-1}) obtained the lowest value, respectively.

Table 43. Influence of cropping sequence on soil urease activity after each season, mg of urea hydrolysed g^{-1} soil h^{-1}

Cropping sequence	Urease (0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	86.87	83.57	84.80
R-R-M	85.23	82.93	88.19
R-R-D	85.17	83.37	91.30
R-R-F	83.83	82.43	85.19
SE **m**(±)	1.84	1.14	2.34
CD(0.05)	NS	NS	6.85

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 44. Influence of cropping sequence on urease activity at varied depths, mg of urea hydrolysed g^{-1} soil h^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	85.58	84.80	88.19	91.30	85.19
15-30	80.30	83.41	84.08	85.74	80.75
30-45	74.14	76.97	76.25	78.47	76.25
45-60	60.64	74.14	71.69	71.69	71.19
60-75	37.87	39.04	37.37	38.10	39.48
75-90	-	-	-	-	-
90-105	-	-	-	-	-
SE m(±)		1.65			
CD(0.05)-Depth		4.12			
CD(0.05)-CS		3.89			
CD(0.05)-Interaction		4.67			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.3.1.3 Acid phosphatase

As per Table 45, acid phosphatase activity after summer season alone was significantly influenced by the cropping systems. An improvement in enzyme activity was noticed at the end of summer crop. R-R-D sequence (37.81 µg g^{-1}) recorded the highest value after summer crop and was found to be on par with R-R-M sequence (35.39 µg g^{-1}). The lowest activity was observed in R-R-F during all the three seasons.

Table 45. Influence of cropping sequence on soil acid phosphatase activity after each season, µg of p- nitro phenol released g^{-1} soil h^{-1}

Cropping sequence	Acid phosphatase(0-15cm)		
	Virippu	*Mundakan*	Summer
R-R-B	27.47	26.38	30.82
R-R-M	27.27	26.76	35.39
R-R-D	26.90	25.98	37.81
R-R-F	26.14	25.62	28.72
SE m(±)	0.85	1.01	1.21
CD(0.05)	NS	NS	3.72

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 46. Influence of cropping sequence on acid phosphatase activity at varied depths, µg of p- nitro phenol released g^{-1} soil h^{-1}

Depth (cm)	Initial	At the end of the trial			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	25.09	30.82	35.39	37.81	28.72
15-30	22.97	27.21	28.88	29.94	24.24
30-45	20.27	23.06	22.69	23.51	22.69
45-60	16.36	19.70	20.30	21.03	20.60
60-75	10.09	10.82	11.12	10.24	11.15
75-90	-	-	-	-	-
90-105	-	-	-	-	-
SE m(±)		2.60			
CD(0.05)-Depth		5.78			
CD(0.05)-CS		6.54			
CD(0.05)-Interaction		7.39			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

The cropping sequence- depth interaction on soil acid phosphatase activity is given in Table 46. The highest activity was observed in R-R-D sequence at all depths, except 60-75 cm. R-R-F system obtained the lowest enzyme activity upto 45 cm depth ; R-R-M at 45-60 and R-R-D at 60-75 cm. A uniform increase in enzyme activity was noticed at all the depths.

4.1.3.2 Microbial count

The influence of cropping systems on microbial count *viz.,* bacteria, fungi and actinomycetes and their variation with depth are given in Tables 46 to 51.

4.1.3.2.1 Bacteria

Bacterial count after summer season alone was significantly influenced by the cropping sequences (Table 47). After *Virippu*, R-R-B recorded the highest bacterial count (8.71 log cfu g^{-1}). R-R-B and R-R-F sequences obtained the highest value after *Mundakan.* The highest bacterial count observed with R-R-D after summer season was found to be significantly superior to all the others. Except summer season, R-R-D recorded the highest value after *Virippu* and *Mundakan.* .

Table 47. Influence of cropping sequence on bacterial count after each season,

Cropping sequence	Bacterial count (log cfu g^{-1}) at 0-15cm		
	Virippu	*Mundakan*	Summer
R-R-B	8.71	8.68	8.69
R-R-M	8.68	8.63	8.76
R-R-D	8.60	8.62	8.85
R-R-F	8.65	8.68	8.73
SE m(±)	0.017	0.014	0.02
CD(0.05)	NS	NS	0.06

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

There was a decline in soil bacterial growth with depth and was almost negligible after 75 cm depth (Table 48). R-R-D sequence recorded the highest bacterial count at 0-45 (8.85, 8.74, 8.63 log cfu g^{-1} at 0-15, 15-30, 30-45cm) and R-R-B at 45-60 cm depth. An overall increase in bacterial count was noticed in all the soil layers. The lowest count at 0-15 and 60-75 cm depth was observed in R-R-B, R-R-F at 15-30 and R-R-M at 30-60 cm.

Table 48. Influence of cropping sequence on soil bacterial count at varied depths

Depth (cm)	Initial	At the end of the trial (log cfu g^{-1})			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	8.67	8.69	8.76	8.85	8.73
15-30	8.37	8.64	8.63	8.74	8.62
30-45	8.02	8.57	8.48	8.63	8.53
45-60	7.41	8.41	8.14	8.29	8.29
60-75	7.12	7.57	7.76	7.76	7.74
75-90	-	-	-	-	-
90-105	-	-	-	-	-
SE m(±)		0.06			
CD(0.05)-Depth		0.15			
CD(0.05)-CS		0.13			
CD(0.05)-Interaction		0.19			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.1.3.2.2 Fungi

Table 49 indicates the influence of cropping systems on soil fungal count. Not much variation in count was observed after each season. R-R-F obtained the highest count after *Virippu* (5.81 log cfu g^{-1}) and *Mundakan* (5.79 log cfu g^{-1}) and R-R-D (5.82 log cfu g^{-1}) after summer. R-R-B system recorded the lowest fungal count during all the three crop seasons.

Table 49. Influence of cropping sequence on soil fungal count after each season

Cropping sequence	Fungal count (log cfu g^{-1}) at 0-15cm		
	Virippu	*Mundakan*	Summer
R-R-B	5.71	5.70	5.73
R-R-M	5.78	5.73	5.76
R-R-D	5.79	5.76	5.82
R-R-F	5.81	5.79	5.76
SE m(±)	0.01	0.01	0.02
CD(0.05)	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 50. Influence of cropping sequence on soil fungal count at varied depths

Depth (cm)	Initial	At the end of the trial(log cfu g^{-1})			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	5.70	5.73	5.76	5.82	5.76
15-30	5.38	5.61	5.65	5.69	5.60
30-45	5.23	5.52	5.52	5.59	5.50
45-60	4.76	5.12	5.14	5.28	5.15
60-75	4.27	4.60	4.73	4.79	4.73
75-90	-	-	-	-	-
90-105	-	-	-	-	-
SE m(±)		0.03			
CD(0.05)-Depth		0.12			
CD(0.05)-CS		0.09			
CD(0.05)-Interaction		0.10			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

According to Table 50, a slight increase in soil fungal count was observed in soil layers at the end of experiment. The cropping sequence – depth interaction had significant influence on fungal count. R-R-D system recorded the highest count in all the soil layers. The lowest count was obtained for R-R-B in 0-15, and 45-75 cm layers and R-R-F in 15-45 cm depths. The count was negligible after 75 cm depth.

4.1.3.2.3 Actinomycetes

In general, a reduction in actinomycete population was noticed at the end of crop period (Table 51) and was not significantly influenced by the different cropping sequences. R-R-M, R-R-F and R-R-D recorded the highest values after *Virippu* (6.12 log cfu g^{-1}), *Mundakan* (6.06 log cfu g^{-1}) and summer (6.1 log cfu g^{-1}) seasons, respectively. R-R-F obtained the lowest count after *Virippu* and summer seasons and R-R-B, after *Mundakan.*

Table 51. Influence of cropping sequence on soil actinomycetes count

Cropping sequence	Actinomycetes count (log cfu g^{-1}) at 0-15cm		
	Virippu	*Mundakan*	Summer
R-R-B	6.09	6.03	5.99
R-R-M	6.12	6.04	6.04
R-R-D	6.06	6.04	6.10
R-R-F	6.01	6.06	5.91
SE m(±)	0.02	0.01	0.01
CD(0.05)	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

In all the soil layers under R-R-M and R-R-D sequences, a slight increase in actinomycete count was noticed with depth (Table 52). R-R-D sequence obtained the highest actinomycete count in all the soil layers. At 0-15 and 45-75 cm R-R-B recorded the lowest actinomycete count and R-R-F, at 15-45 cm depths.

Table 52. Influence of cropping sequence on soil actinomycetes count at varied depths

Depth (cm)	Initial	At the end of the trial (log cfu g^{-1})			
		R-R-B	R-R-M	R-R-D	R-R-F
0-15	5.99	5.99	6.04	6.10	5.90
15-30	5.85	5.81	5.91	5.96	5.78
30-45	5.67	5.70	5.79	5.82	5.70
45-60	5.53	5.55	5.63	5.67	5.54
60-75	5.14	5.36	5.39	5.42	5.32
75-90	-	-	-	-	-
90-105	-	-	-	-	-
SE m(±)		0.02			
CD(0.05)-Depth		0.03			
CD(0.05)-CS		0.05			
CD(0.05)-Interaction		0.07			

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.2 PLANT ANALYSIS

Tables 53 to 55 represent major (N, P, K, Ca and Mg) and micro (Fe, Mn, Cu and Zn) nutrient content in the main produce and by product of crops planted during the three seasons.

4.2.1 Major nutrients in grain and straw after *Virippu* and *Mundakan* seasons

During *Virippu* season, significant difference was noticed only for N, P, K and Mg contents in paddy straw (Table 53). All the major nutrients, except K, were higher in paddy grains. R-R-D sequence obtained the highest N (1.98 per cent) and K (1.09 per cent) and R-R-M sequence, the highest P (1.06 per cent), Ca (0.49 per cent) and Mg (1.87 per cent) for paddy grains. For straw, R-R-B sequence recorded the highest N (0.96), K (2.23) and Mg (0.76) and R-R-M sequence, the highest P (0.72) and Ca (0.41) contents.

After *Mundakan* season, except, grain N and P, all the other major nutrients were significantly influenced by the cropping sequences. R-R-M sequence obtained the highest P (1.01), Ca (0.45) and Mg (1.77) in grains. N and K were the highest in R-R-B (1.90) and R-R-D (1.42), respectively. A similar trend was noticed for paddy straw also.

4.2.2 Micro nutrients in grain and straw after *Virippu* and *Mundakan* seasons

Table 54 represents the micro nutrients *viz*., Fe, Mn, Zn and Cu content in paddy grain and straw after *Virippu* and *Mundakan* seasons. No significant difference was noticed for both grain and straw nutrient contents, during any of the seasons. R-R-M sequence recorded the highest Fe (both grain and straw), Zn (grain) and Mn and Cu (straw), during both the seasons. Straw Zn content was highest in R- R- D sequence.

4.2.3 Plant major and micro nutrient content after summer season

Summer crops *viz*., bhindi, maize and daincha were analysed for major (N, P, K, Ca and Mg) and micro nutrients (Fe, Zn, Cu and Mn) [Table 55]. Daincha contained significantly higher N (1.47 per cent) and P (1.3 per cent) content. K (1.96) , Ca (0.85) and Mg (0.21) were highest in bhindi. Fe and Cu were highest in bhindi while Mn and Zn in maize.

4.3 ECONOMIC AND BIOMASS YIELD

Economic and biomass yield of crops are presented in Table 56. Main produce obtained after each crop harvest was noted as economic yield and the by-product as biomass yield. Economic yield was the highest for R-R-B and R-R-D sequences, after *Virippu* (5.21 t ha^{-1}) and *Mundakan* (4.09 t ha^{-1}) seasons, respectively. R-R-M and R-R-D recorded the highest biomass yield after *Virippu* (5.73 t ha^{-1}) and *Mundakan* (4.88 t ha^{-1}) seasons, respectively. About 22.5, 9.21 and 3.60 t ha^{-1} yield were obtained for daincha, bhindi and maize, respectively.

Table 53. Major nutrients in grain and straw after *Virippu* and *Mundakan* season, %

Cropping system	*Virippu*										*Mundakan*									
	Grain					Straw					Grain					Straw				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
R-R-B	1.80	0.97	0.9	0.36	1.75	0.96	0.64	2.23	0.31	0.76	1.90	0.86	0.95	0.33	1.66	1.00	0.63	2.61	0.12	1.6
R-R-M	1.32	1.06	0.73	0.49	1.87	0.82	0.72	1.84	0.41	0.65	1.62	1.01	0.55	0.45	1.77	0.72	0.80	1.74	0.44	1.98
R-R-D	1.98	0.91	1.09	0.39	1.47	0.76	0.58	2.18	0.33	0.58	1.46	0.99	1.42	0.36	1.53	0.67	0.74	2.98	0.38	1.53
R-R-F	1.46	0.78	0.87	0.33	1.41	0.59	0.45	1.76	0.38	0.68	1.42	0.78	0.87	0.41	1.47	0.71	0.57	2.23	0.27	1.43
SE m(±)	0.08	0.003	0.1	0.03	0.02	0.03	0.03	0.07	0.01	0.01	0.047	0.008	0.11	0.03	0.02	0.03	0.04	0.15	0.02	0.03
CD(0.05)	NS	NS	NS	NS	NS	0.11	0.13	0.22	NS	0.05	NS	NS	0.34	0.10	0.07	0.10	0.12	0.46	0.06	0.09

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 54. Micro nutrients in grain and straw after *Virippu* and *Mundakan* season, mg kg^{-1}

Cropping system	*Virippu*								*Mundakan*							
	Grain				Straw				Grain				Straw			
	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn	Cu
R-R-B	412	213	278	53	514	687	286	43	434	297	239	53	604	787	212	57
R-R-M	513	243	303	51	558	719	236	49	482	268	275	51	628	807	245	59
R-R-D	476	209	245	32	523	704	304	40	428	302	254	58	587	795	273	49
R-R-F	412	189	283	43	498	676	247	50	403	278	249	50	568	757	255	48
SE m(±)	0.01	0.01	0.02	0.002	0.01	0.18	0.01	0.002	0.01	0.01	0.02	0.002	0.01	0.15	0.01	0.002
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 55. Plant nutrient content after summer season

Cropping system	N %	P %	K %	Ca %	Mg %	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})
R-R-B	1.32	1.21	1.96	0.85	0.21	423	220	178	52
R-R-M	1.16	0.98	0.97	0.72	0.14	212	223	208	43
R-R-D	1.47	1.30	0.89	0.45	0.11	134	182	134	38
SE m(±)	0.09	0.06	0.26	0.06	0.03	0.07	0.02	0.03	0.005
CD(0.05)	0.30	0.19	0.80	0.20	0.11	NS	NS	NS	NS

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Table 56. Economic and biomass yield of after each season, t ha^{-1}

Cropping system	*Virippu*		*Mundakan*		Summer	
	Grain	Straw	Grain	Straw	Economic yield	Biomass yield
R-R-B	5.21	5.63	3.02	3.25	9.21	25.1
R-R-M	5.10	5.73	3.15	3.45	3.60	7.89
R-R-D	5.01	5.23	4.09	4.88	-	22.5
R-R-F	4.96	5.13	3.56	3.64	-	-
SE m(±)	0.31	0. 73	0.65	0.50	0.05	0.85
CD(0.05)	NS	NS	0.21	NS	0.37	3.45

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

4.4 CORRELATION STUDIES

Correlation of carbon fractions with weather parameters and enzyme activities are presented in Table 57. A positive correlation was observed between carbon fractions and atmospheric temperature (both minimum and maximum temperature) while it was negative with rainfall and relative humidity. For dehydrogenase and acid phosphatase activities, a significantly higher positive correlation was obtained for all the carbon fractions *viz.*, TOC, POC, LC and MBC. But for urease activity, the correlation was significantly higher with TOC alone.

Table 57. Correlation of carbon fractions with weather parameters and enzyme activities

	TOC	POC	LC	MBC
Min. T	0.560	0.654	0.962*	0.900
Max. T	0.953*	0.982*	0.922	0.975*
RF	-0.967	-0.931	-0.578	-0.711
RH	-0.966	-0.929	-0.574	-0.707
Dehydrogenase	0.993**	0.997**	0.964**	0.962**
Urease	0.932**	0.916*	0.805*	0.794*
Acid phosphatase	0.985**	0.978**	0.911**	0.901**

TOC: total organic carbon, POC: particulate organic carbon, LC: labile carbon, MBC: microbial biomass carbon, RF: rainfall, RH: relative humidity, Min.T: minimum temperature, Max. T: maximum temperature.

4.5 COMPUTED INDICES

The adjacent field which was kept undisturbed for a long period was taken as the reference soil and samples were drawn from this field up to 105cm depth at 15cm intervals. Different carbon fractions *viz.*, TOC, POC, LC and MBC were estimated of the reference soil (Table 58). Based on these values, three indices *viz.*, CPI, CLI and CMI of the different cropping systems were calculated (Table 59).

Except R-R-B sequence, all the other cropping systems recorded CPI and CLI more than unity. R-R-D sequence obtained the highest CPI (1.1), CLI (1.09) and CMI (120.56). The lowest values were recorded by R-R-B cropping sequence – 0.94, 0.77 and 72.81, respectively for CPI, CLI and CMI, respectively.

Table 58. Soil carbon fractions in undisturbed reference soil

Depth (cm)	TOC ($g\ kg^{-1}$)	POC		LC $mg\ kg^{-1}$	MBC $mg\ kg^{-1}$
		>53 size	<53 size		
0-15	21	945.95	2865.34	3680.67	422.23
15-30	15.3	752.43	2371.23	3130.21	201.33
30-45	6.6	119.67	1437.45	2241.08	133.78
45-60	5.85	105.46	572.53	2040.23	22.23
60-75	12.15	89.56	392.47	2701.02	19.56
75-90	4.2	61.2	239.56	1932.03	-
90-105	3.45	45.34	134.07	1909.89	-

TOC: total organic carbon, POC: particulate organic carbon, LC: labile carbon, MBC: microbial biomass carbon

Table 59. Computed indices in different cropping sequences

Indices	Carbon pool index	Carbon lability index	Carbon management index
R-R-B	0.94	0.77	72.81
R-R-M	1.03	1.05	109.31
R-R-D	1.10	1.09	120.56
R-R-F	1.00	1.06	106.79

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Discussion

5. DISCUSSION

Increase in atmospheric CO_2 concentration to 415 ppm level (GMD, 2019) from the pre- industrial level of 285 ppm and other GHGs like CH_4 and N_2O have resulted in global warming. According to Intergovernmental Panel on Climate Change (IPCC), keeping global warming level within 2° C is possible only by reducing GHG emissions (IPCC, 2007). Removing CO_2 from the atmosphere and storing it in the soil will help to combat the deleterious effect of climate change. Carbon storage potential of soils can be improved through proper agricultural and land management practices (Beach *et al.*, 2016; Lal, 2010). Cropping systems have got a pivotal role in enhancing carbon sequestration by refining land productivity, maintaining crop diversity and favouring diverse crop residue incorporation (Wang *et al.*, 2009). An investigation was carried out at IFSRS, Karamana to compare the soil carbon dynamics under different rice based cropping systems. The results obtained are discussed in this chapter.

5.1 INFLUENCE OF CROPPING SEQUENCES ON SOIL PHYSICAL PROPERTIES

Bulk density, which is an indication of the soil compaction and porosity, was significantly influenced by the different rice based cropping sequences (Fig.2 and 3). Intensive cropping systems could improve the soil physical properties by way of more crop residue incorporation. This will result in reduced bulk density, increased porosity, formation of more macro aggregates and improved mobility of ions, water and gases within the soil layers, ultimately, affecting the overall productivity of the system as such (Peterson *et al.*, 2002). This is quite evident from the bulk density noticed under R-R-D cropping system.

Irrespective of the cropping systems, an increase in bulk density was noticed with depth. It may be due to the compactness of soil in the deeper layers and less addition of organic residues. Among the different systems, R-R-M cropping systems resulted in the highest bulk density. A similar trend in increased bulk density with depth

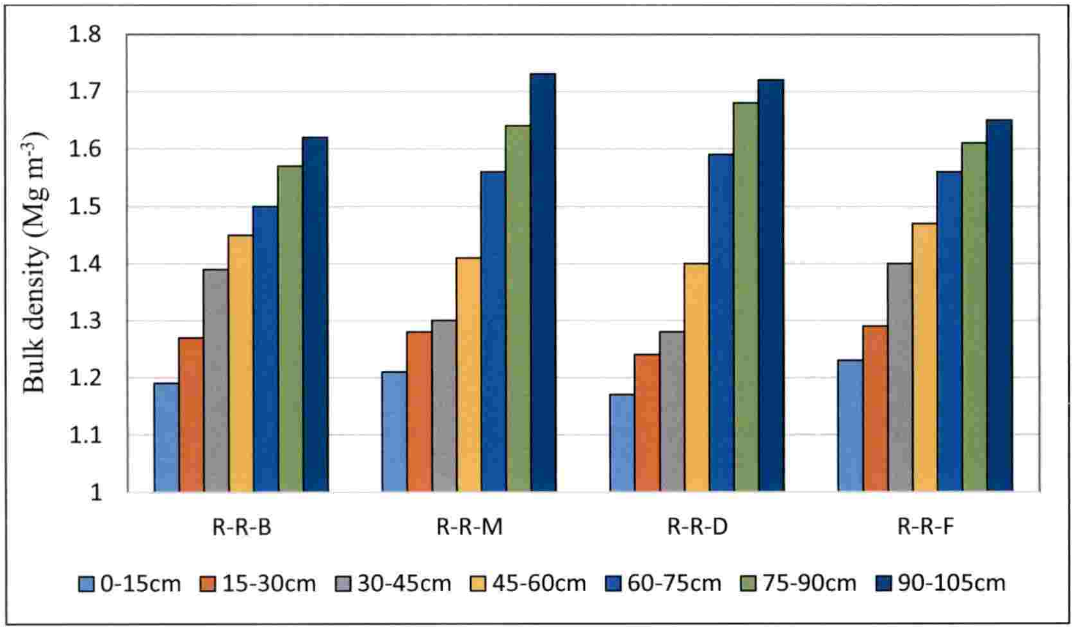


Fig 2. Influence of cropping sequence on soil bulk density at varied depths

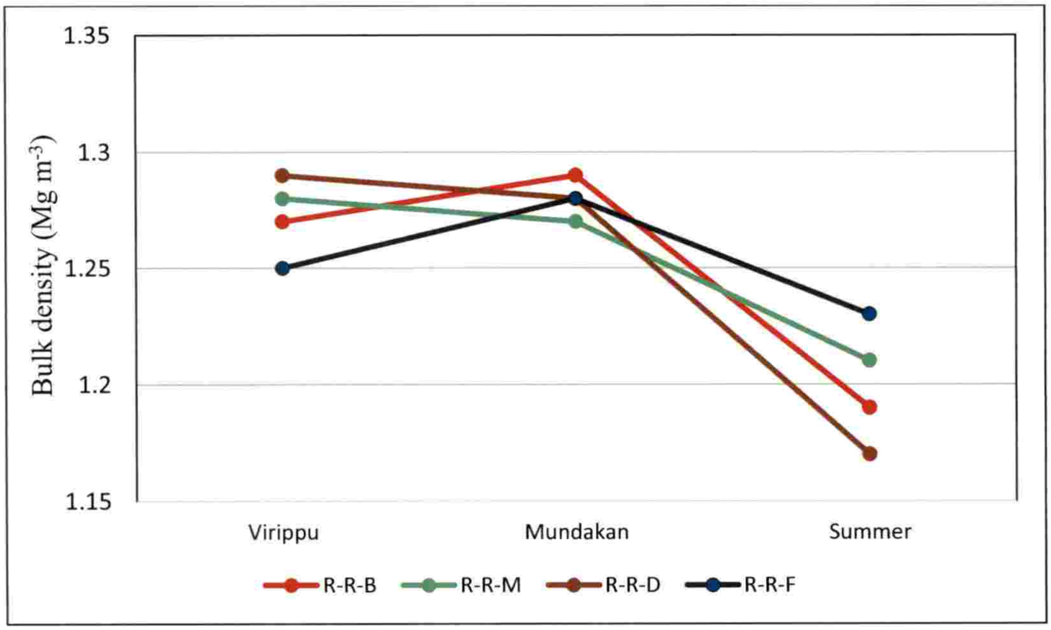


Fig 3. Soil bulk density at different cropping season

and in cereal based cropping system compared to vegetable based system was reported by Bhavya *et al.* (2018), Loria *et al.* (2016), Nayak *et al.* (2012) and Cheng *et al.* (2011). Deeper layers suffer from much pressure due to poor root penetration and soil aggregation resulting in increased bulk density.

5.2 INFLUENCE OF CROPPING SEQUENCES ON SOIL CHEMICAL PROPERTIES

5.2.1 Carbon dynamics

Sustainable land management practices demand an understanding of the various soil carbon fractions. Soil organic carbon plays an important role in influencing soil physical, chemical and biological properties (Pan *et al.*, 2009) and thereby, soil quality. Here, soil carbon fractions *viz.*, TOC, POC, LC and MBC under different rice based cropping systems at varied soil depths were studied. In general, the soil carbon decreased with depth. This is in conformity with the finding of Jobbagy and Jackson (2000) that increase in soil mass at deeper layers may result in more total organic carbon storage in the sub surface layers.

5.2.1.1 Total organic carbon

The role of intensive cropping systems in improving TOC is evident from Fig. 4. Cropping systems had shown significant influence in total organic carbon content. Rice-rice-daincha sequence recorded the highest TOC content (22.2g kg^{-1}) at the end of the cropping period in the surface soil (0-15cm) while R-R-F sequence, the least. Compared to R-R-F system, 18.0, 5.5 and 6.3 per cent increase was noticed in TOC in R-R-D, R-R-B and R-R-M sequence, respectively. Similar increase in TOC with the inclusion of green manure crop, daincha in rice based system was reported by Yazhini *et al.* (2019) and Sarwar *et al.* (2017). Incorporation of daincha might have resulted in organic matter addition and improvement in soil physical properties (Sultani *et al.*, 2007). Reduction in TOC with depth may be attributed to the lower addition of crop residues and manures to soil (Alemayehu *et al.,* 2010).

5.2.1.2 Particulate organic carbon

The easily decomposable fraction of SOC, *viz.,* POC can improve stability of aggregates, soil aeration, cation exchange capacity, buffering capacity and retention of pollutants. Agronomic management practices like tillage, crop rotation and intensive cropping increases POC and thereby plant nutrient availability in soil (Cambardella and Elliot, 1992). In the present study, compared to R-R-F sequence, all other cropping systems resulted in increased POC content in soil (Fig. 5) Moharana *et al.* (2017) also reported much increase in POC in a wheat- pearl millet field than that of a fallow field. Intensive cropping systems could result in accumulation of POC through addition of above and below ground plant parts (Kalambukattu *et al*., 2013). The significantly higher content of POC in surface layer and drastic reduction with depth may be due to less addition of organic debris and microbial activities (Six *et al.,* 2002).

5.2.1.3 Labile carbon

At the end of the cropping season, LC content in the soil surface layer increased by 14 per cent and 3.0 per cent, respectively in R-R-D and R-R-M compared to that of previous year (Fig. 6). Except the surface layer, there was a drastic reduction in the LC content, irrespective of the cropping sequences. Sharma *et al*. (2014) also observed a sharp decline in LC of cultivated soils compared to the surface. This may be due to fact that LC reflects a readily decomposable portion of organic carbon present near the surface and decomposes within a few weeks or months (Mc Lauchlan and Hobble, 2004). The labile fraction of SOC has a major influence on the soil quality and hence, more susceptible to the impacts of cropping system (He *et al.*, 2008). This fraction is highly positively correlated with soil organic carbon, particulate organic carbon, microbial biomass carbon and bulk density as reported by Six *et al.* (2002). The quantity of litter fall incorporated and its rate of turnover has significance in assessing

LC portion (Casado-Murillo and Abril, 2013) and thus soil quality (Bongiorno *et al.*, 2019).

5.2.1.4 Microbial biomass carbon

Though MBC constitutes only 1-3 per cent of total soil carbon, it is the most active fraction of SOC. It acts as a reservoir of plant nutrients and is more susceptible to soil management practices. The content of MBC is directly related to organic substrate availability in soil and hence regular incorporation of crop residues help in the maintenance of MBC and soil fertility (Singh *et al.*, 2005). This is quite evident from the MBC content of soil at the end of cropping sequences (Fig. 7). According to Ramesh and Chandrasekharan (2004), inclusion of daincha in rice- rice cropping system either as intercrop or during fallow, improved the SOC status and thus helped in sustainable management of soil. Daincha accumulated more green biomass and produced an increase in organic carbon due to its incorporation (Ali *et al.,* 2012)

5.2.2 Soil electrochemical properties

pH and EC were the major electrochemical properties studied under the different cropping systems. Soil pH was acidic as the field was submerged for most part of the period during the cropping cycle. At the end of the cropping period, R-R-M and R-R-F recorded the highest and lowest values, respectively. Variation in soil pH with depth was also noticed and may be due to leaching of basic cations, presence of pyrite layer, hydrology of the field, cultivation practices and rate of decomposition of organic matter that produces organic acids (Haynes and Naidu, 1998 and Thampatti and Jose, 2000).

R-R-B, R-R-D and R-R-F sequences recorded 28, 27 and 33 per cent decrease in EC, respectively, after the completion of the experiment while R-R-M, showed a three per cent increase. The decrease in electrical conductivity could be due to leaching of salts in the presence of organic acids produced from organic sources (Behera and

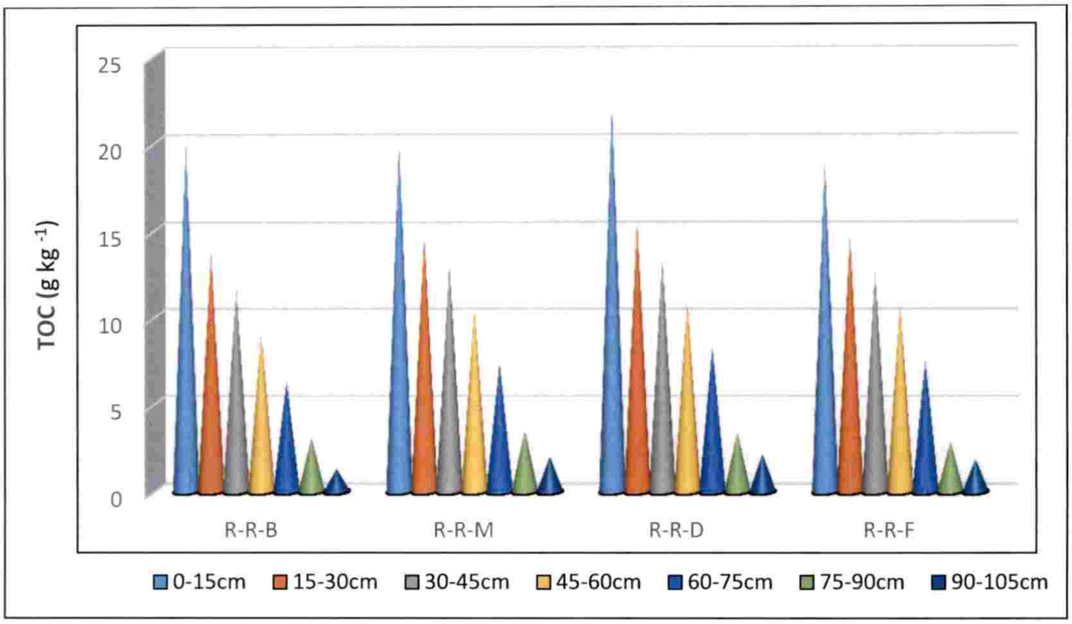


Fig.4 Influence of cropping sequence on soil TOC at varied depths

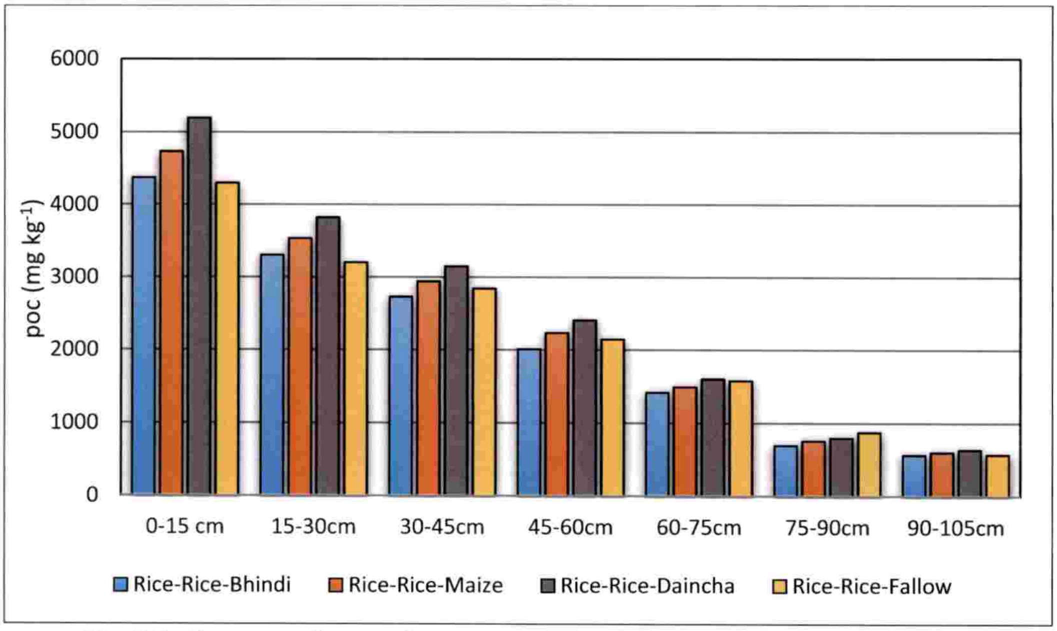


Fig.5 Influence of cropping sequence on soil POC at varied depths

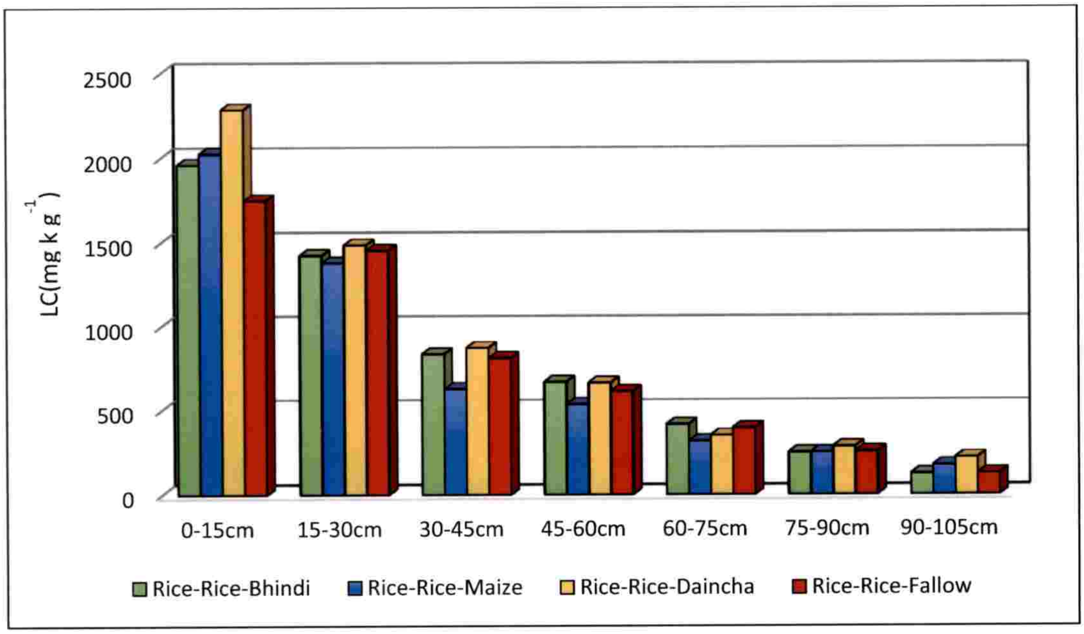


Fig.6 Influence of cropping sequence on soil LC at varied depths

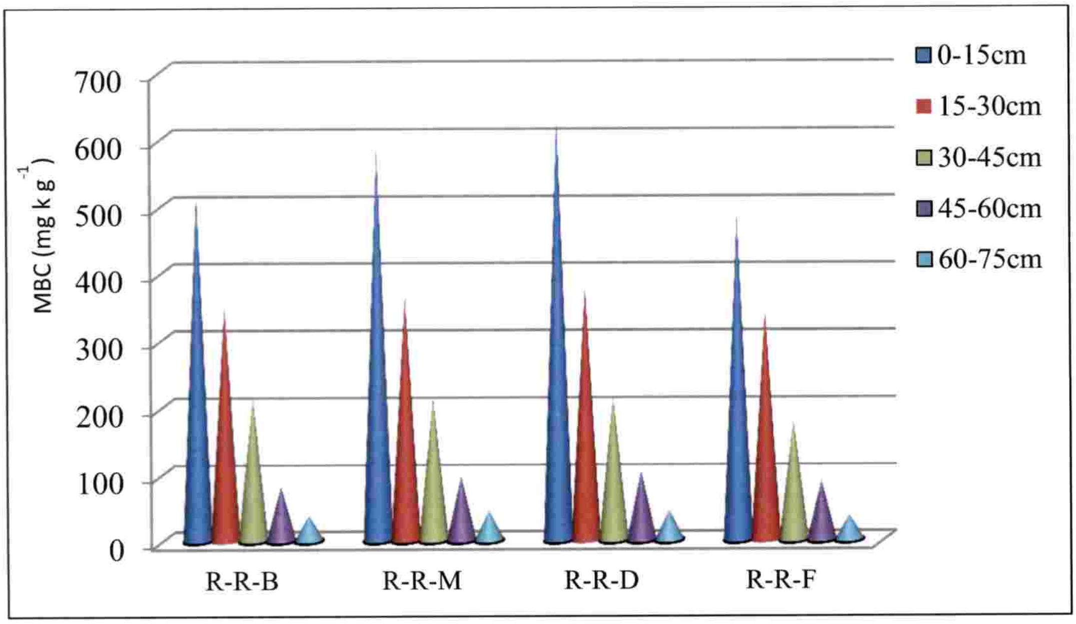


Fig.7 Influence of cropping sequence on soil MBC at varied depths

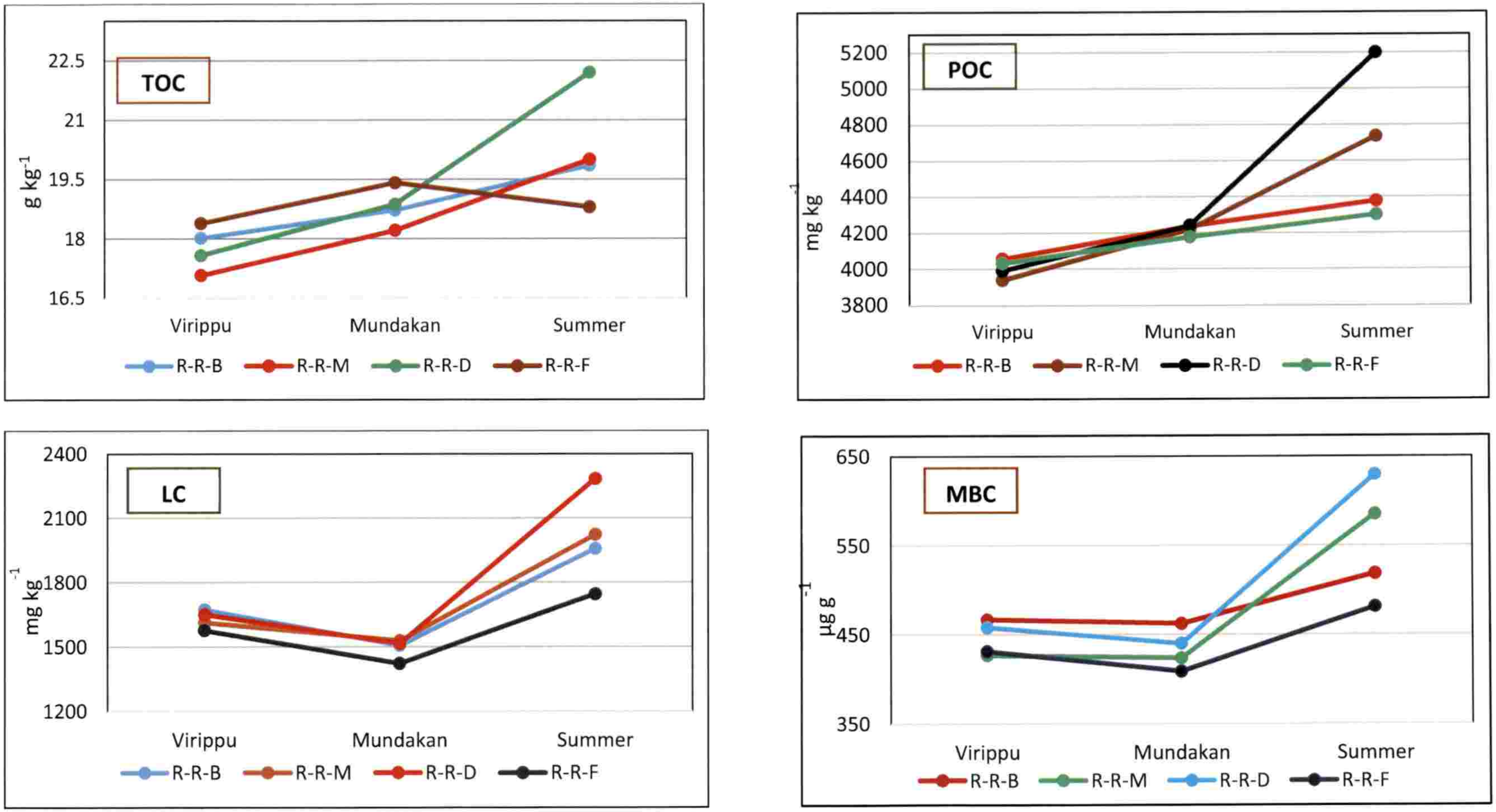


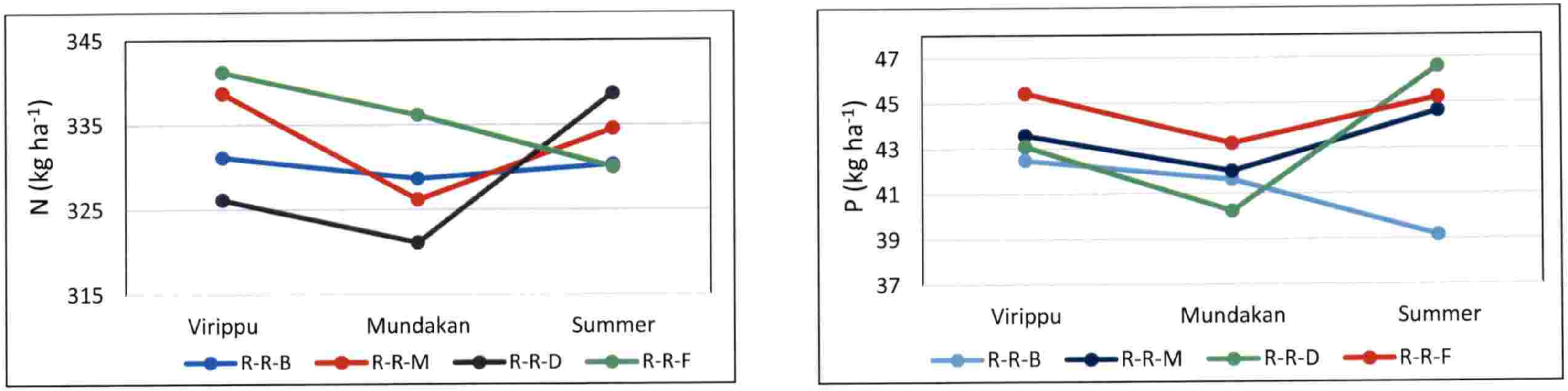
Fig. 8 Dynamics of soil carbon fractions in different cropping seasons

Shukla, 2015). This reduction of electrical conductivity with soil depth may be due to less availability of soluble salts as the depth progresses (Sarwar *et al.* 2017).

5.2.3 Soil major nutrients

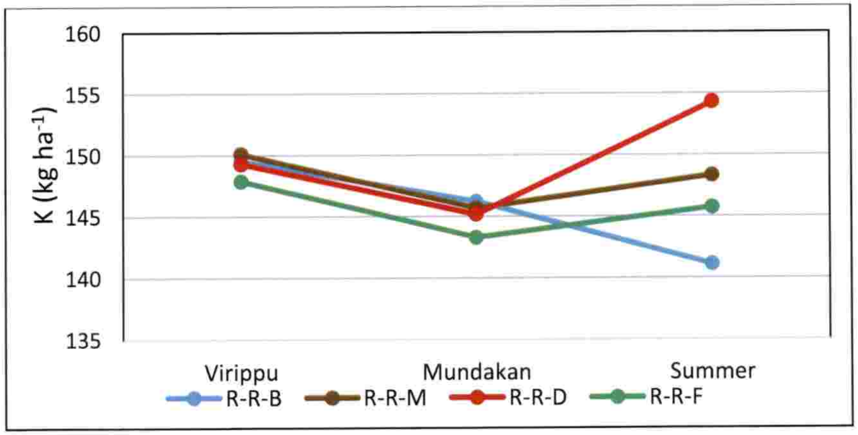
Compared to *Mundakan* season, there was 5.31, 15.10, 6.21, 3.1 and 13.1 per cent increase in N, P, K, Ca and Mg status of soil at the end of the cropping cycle. Similar results on increase in organic matter and N content of soils due to daincha incorporation were observed by Sarwar *et al.* (2017) and Mann *et al.* (2000). Nitrogen mineralization in the presence of daincha green manure and fast multiplication of soil micro flora might have resulted in the conversion of organically bound N to inorganic form (Rahman *et al.,* 2013). According to Qudratullah *et al.* (2010), incorporation of green manure increases the availability of phosphate for succeeding crop and hence, available P. Organic acids produced by microbial activity solubilize native soil P and increases the availability (Prasad *et al*., 2000). Organic matter addition reduces K fixation and releases K from the exchange sites and increases its availability (Singh and Kumar, 2008).

At the end of summer season, available S alone was significantly influenced by the different cropping systems. However, incorporation of crop residues had resulted in an increase in the exchangeable Ca content of R-R-D and R-R-M sequences while it did not affect the Mg availability. These results are in conformity with that observed by Nathiya and Sanjivkumar (2014). Reduction in exchangeable Mg content in soil might be due to higher removal by the crops and cultivation practices (Gogoi *et al*., 2015). Enhanced microbial activity due to green manure incorporation might have resulted in the release of sulphate by-product (Assefa *et al.,* 2014). Also reduction in leaching losses improved the status of available S in soil (Vaneet and Nayyar, 2000). The decrease in major nutrients with soil depth may be due to reduced organic matter content and microbial activity (Blume *et al.* 2002).



Nitrogen

Phosphorous



Potassium

Fig 9. Influence of cropping sequence on soil primary nutrients

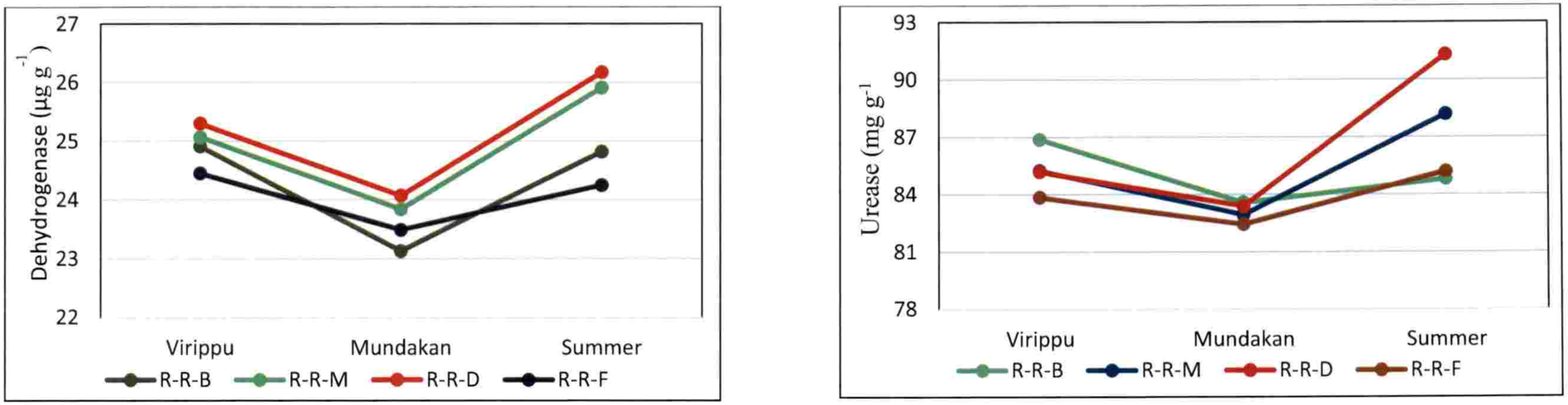
5.2.4 Soil micronutrients

Except for boron, a decrease in all other micro nutrients was noticed at the end of the cropping cycle. This may be due to slight variation in soil pH that has resulted from the cropping sequences and incorporation of crop residues (Dhaliwal *et al.*, 2011).Continuous cropping without the addition of any micro nutrient support can also cause reduction of their available content in soils (Ilori and Shittu, 2015).

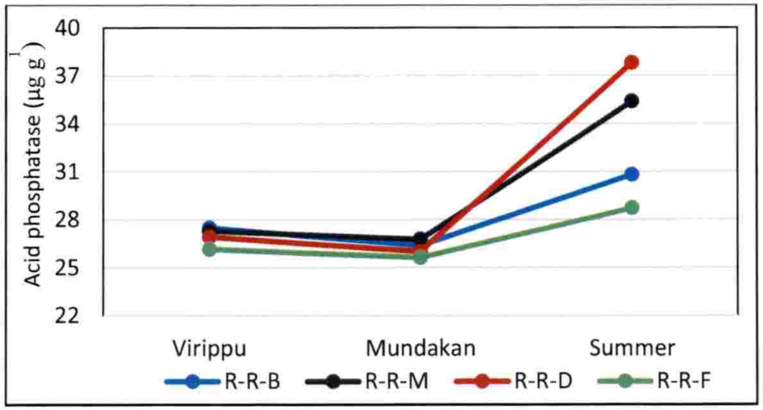
5.3 INFLUENCE OF CROPPING SEQUENCES ON SOIL BIOLOGICAL PROPERTIES

5.3.1 Soil enzyme activities

Soil enzymes provide an indication of soil organic matter status, physical condition, and microbial biomass and hence, is an effective tool for assessing the soil health. The activity of major enzymes *viz.,* dehydrogenase, urease and acid phosphatase were studied at the end of all the three crop seasons. For all the three enzymes, a slight reduction in activity was noticed at the end of second crop season and thereafter increased (Fig. 10). Decreased microbial biomass (McLatchey and Reddy, 1998) and accumulation of phenolic compounds under flooded condition (Freeman *et al.*, 2001) may account for reduced activity during *Mundakan* season. Continuous cropping can also hinder enzyme activities in soil (Roy *et al.,* 2011).There is much correlation between enzyme activity and soil temperature as reflected by enhanced activity during summer crop (Kunito *et al.,* 2018). At the end of cropping cycle, R-R-D sequence recorded 6.55, 6.68 and 50.70 per cent increase in dehydrogenase, urease and acid phosphatase activities, respectively, compared to previous year. Fast decomposition of green manure releases organic matter which act as source of carbon and energy for the growth and multiplication of microorganisms, thus enhancing soil enzyme activities (Bhattacharyya *et al.*, 2015; Rai and Janardan, 2011).



Dehydrogenase Urease



Acid phosphatase

Fig 10. Influence of cropping sequence on soil enzyme activities

Much improvement in acid phosphatase activity was noticed under all the cropping sequences- 50.70, 41.05, 22.84 and 14.47 per cent increase over previous year's activity for R-R-D, R-R-M, R-R-B and R-R-F sequences, respectively. Increase in organic matter may lead to P stress condition (Sharma *et al.*, 2015) which will stimulate the roots to secrete more of acid phosphatase enzyme to tackle the condition (Balemi and Negisho, 2012). A drastic decline in enzyme activities was noticed with depth and was almost negligible beyond 75 cm depth. Oxygen depleted atmosphere and reduction in microbial population may cause reduced activity in deeper depths. (Bandick and Dick, 1999).

5.3.2 Soil microbial count

R-R-D sequence recorded the highest microbial (bacteria, fungi and actinomycetes) count after summer crop. Inclusion of green manure crop in cropping system provide more carbon and moisture in soil and thereby, improve soil aggregation (Tejada *et al.*, 2009) and thus facilitate congenial environment for microbial growth (Dubey *et al.,* 2015; Singh *et al.,* 2011). Microbial activity was drastically reduced beyond 75cm depth in all the cropping systems, due to less aeration and organic sources. These results are in conformity with the findings of Ocio *et al.* (1991).

5.4 INFLUENCE OF CROPPING SEQUENCES ON CROP YIELD AND PLANT NUTRIENT CONTENT

R-R-D cropping sequence obtained significantly higher yield (both main produce and by-product) during the second crop period, which was 14.9 and 34 per cent more than that of R-R-F system. Improvement in soil physical, chemical and biological properties due to incorporation of crop residues had resulted in a very good soil health (Ghosh *et al.,* 2012). This type of cropping system management practice has positively influenced the soil organic carbon status (Lal, 2007), ultimately reflecting on crop economic yield. Cropping system practices did not affect the nutrient content of plant products. In general, nitrogen content was higher in paddy grain compared to straw. Both grain and straw obtained from R-R-M cropping sequence contained the highest P, Ca and Mg while K content was highest in R-R-D sequence. Plant micro nutrients were not significantly influenced by the cropping sequences. Among the summer crops, daincha contained the highest N and P and bhindi, contained K, Ca, Mg and micronutrients.

5.5 CORRELATION OF CARBON FRACTION WITH WEATHER PARAMETERS AND ENZYME ACTIVITIES

Among the weather parameters, minimum temperature showed positive correlation with LC alone while maximum temperature, with TOC, POC and MBC. Both RF and RH were found to be negatively correlated with the carbon fractions. According to Aanderud *et al.* (2010), hydrological processes like surface runoff and ground water infiltration might adversely affect the soil carbon dynamics and thus excess RF would lead to reduction in soil C pool. The significantly higher positive correlation of enzyme activities with carbon dynamics may be accounted for enhanced organic matter decomposition and nutrient cycling by soil enzymes and microflora (Wang *et al.,* 2013).

5.6 INFLUENCE OF CROPPING SEQUENCES ON CARBON MANAGEMENT INDEX

Based on the carbon fractions present in the reference soil sample, some indices *viz.*, CPI, CLI and CMI were calculated to assess the soil quality under different cropping system management practices. CMI, which is the product of CLI and CPI, determines the sustainability of soil under land management practices. CMI value above 100 is an indication of positive influence of agronomic measures on soil organic carbon status and soil quality (Blair *et al.*, 1995). CLI measures the effect of cropping systems in maintaining soil labile carbon (LC). Incorporation of crop residues naturally increases POC, which in turn influences CPI. In the present study, both R-R-D and R-

R-M sequences resulted in CMI value above 100. This is a clear indication of the role of organic matter addition in improving the soil carbon status (Moura *et al.,* 2017).

The net carbon stock resulted in the different cropping systems at one metre depth were as follows: 129.65, 142.47, 148.62 and 141.52 Mg ha^{-1} for R-R-B, R-R-M, R-R-D and R-R-F sequence (Table 59), respectively. This further ascertains the role of green manure incorporation in improving soil carbon fractions and soil fertility.

Table 60. Soil carbon stock under different rice based cropping systems, Mg ha^{-1}

Depth	R-R-B	R-R-M	R-R-D	R-R-F
0-15cm	35.43	36.30	38.96	34.76
15-30cm	26.00	28.14	28.83	28.34
30-45cm	24.17	25.61	25.74	26.61
45-60cm	19.54	22.18	22.82	23.34
60-75cm	14.18	16.24	18.27	16.97
75-90cm	7.17	8.80	8.46	6.91
90-105cm	3.17	5.19	5.55	4.59
Total	129.65	142.47	148.62	141.52

R-R-B: rice-rice-bhindi, R-R-M: rice-rice-maize, R-R-D: rice-rice-daincha, R-R-F: rice-rice-fallow

Summary

6. SUMMARY

Drastic increase in the atmospheric CO_2 concentration, since industrial revolution resulted in global warming and climate change. Soil is the major sink for carbon, especially in deeper depths where carbon stock is less. The present study was conducted to assess the soil carbon dynamics in a rice based cropping system with the specific objective of studying and comparing the soil carbon dynamics in different rice based cropping systems *viz.*, rice-rice-maize, rice-rice-vegetable and rice- rice- daincha in a riverine alluvium. The investigation was carried out at Integrated Farming System Research Station (IFSRS), Karamana where these rice based cropping sequences have been in practice since 2011-12. Surface soil samples were collected after each crop season and samples up to 105cm depth at 15cm intervals, before and after the experiment. Major physical, chemical and biological properties of the soil were analysed and carbon fractions *viz.*, total organic carbon (TOC), particulate organic carbon (POC), labile carbon (LC) and microbial biomass carbon (MBC) were determined as per standard procedures. The results were compared with rice-rice-fallow system. The salient findings are summarized in this chapter.

The different cropping systems significantly influenced soil carbon dynamics. R-R-D sequence (22.2 g kg^{-1}) obtained the highest total organic carbon (TOC) content at the end of the cropping period in the surface layer (0-15cm) and R-R-F sequence, the least (18.80 g kg^{-1}). TOC content of all the cropping sequences increased at the end of the crop cycle. In general, carbon fractions decreased with soil depth.

Particulate organic carbon (POC) fractions are the active soil carbon pools and sensitive indicators of land management practices. POC of <53 μm size fractions hold more organic carbon and are less resistant to degradation. A gradual increase in both >53 and <53 μm size fractions, under all cropping systems, was noticed over the cropping period. R-R-D cropping sequence recorded the highest

POC of both size fractions i.e. 1901.77 g kg^{-1} of >53 and 3295.13 g kg^{-1} of <53 µm size fractions, at the end of summer season.

R-R-D sequence registered the highest (2283.97 mg kg^{-1}) labile carbon (LC) content at the end of the experiment followed by R-R-M (2023.24 mg kg^{-1}), R-R-B (1958.23 mg kg^{-1}) and R-R-F (1746.62 mg kg^{-1}) sequences. At the end of cropping cycle, LC content increased by 30, 32, 50 and 22 percent in R-R-B, R-R-M, R-R-D and R-R-F sequences, respectively.

Microbial biomass carbon (MBC) content after each crop season was significantly influenced by the different rice based cropping sequences. At the end of crop cycle, R-R-D sequence recorded the highest MBC (629.62 mg kg^{-1}) indicating the role of green manure incorporation in improving the microbial activity in soil.

The bulk density of soil was significantly influenced by green manure incorporation. Soil had acidic pH in all the cropping systems with highest value in R-R-M sequence (5.53) at surface soil and lowest value in R-R-F sequence (4.96) at 15-30cm depth. Soil EC ranged from 0.02 to 0.36 dSm^{-1} at varied depth with highest values in R-R-M sequence (0.36 dSm^{-1}) and lowest in R-R-F sequence (0.2 dSm^{-1}) at top layer 0-15cm. R-R-F sequence obtained the highest bulk density (1.23 Mg m^{-3}) among the cropping systems and R-R-D sequence, the lowest (1.17 Mg m^{-3}). After completion of the experiment, R-R-M sequence recorded the highest bulk density (1.73 Mg m^{-3}) at 90-105cm depth.

Soil available N content ranged from 321.12 to 338.69 kg ha^{-1} among the cropping systems, with the highest content in R-R-D sequence, in the surface layer (0-15cm). Available P content was generally high in the soil and R-R-D sequence recorded the highest (46.6 kg ha^{-1}). It ranged from 10.18 to 46.6 kg ha^{-1} within the 105 cm soil layer. Soil contained medium K under all the cropping systems. R-R-D (154.31 kg ha^{-1}) and R-R-B (141.1 kg ha^{-1}) sequences obtained the highest and lowest available K content, respectively.

An increase in secondary nutrients like exchangeable Ca and Mg and available S were observed at the end of the cropping period for R-R-D and R-R-M sequences. Among the micronutrients, available Fe, Zn and B were highest in R-R-D sequence. Highest Mn and Cu content were observed under R-R-F and R-R-B sequence, respectively.

Soil biological properties like enzyme activities and microbial count were estimated. In general, a drastic decline in enzyme activities and microbial count were observed with depth and was almost negligible beyond 75 cm depth. R-R-D sequence recorded the highest dehydrogenase, urease and acid phosphatase activities at surface soil (0-15cm). Cropping systems significantly influenced the bacterial count alone. R-R-D sequence contained highest bacterial, fungal and actinomycete count at surface layer (0-15cm).

With respect to plant analysis, R-R-D sequence recorded the highest grain N after *Virippu* and K content after both *Virippu* and *Mundakan* seasons. Highest P and Ca contents were obtained with R-R-M and R-R-B sequence, respectively, after both the seasons. Micronutrient content of grain and straw were almost the same in all the systems, after both *Virippu* and *Mundakan*. Economic yield was highest for R-R-B and R-R-D sequence after *Virippu* and *Mundakan*, respectively. After summer, R-R-D sequence had higher N and P while R-R-B contains K, Ca, Mg and micronutrients. Economic and biomass yield of R-R-B and R-R-M sequence were 9.21 and 25.1 t ha^{-1} and 3.6 and 7.89 t ha^{-1}, respectively. Biomass yield of R-R-D sequence was 22.5 t ha^{-1}.

The study revealed that, among the different rice based cropping systems, R-R-D cropping system influenced soil carbon dynamics most significantly followed by R-R-M, thereby indicating the role of crop residue incorporation, particularly green manures, in improving the soil carbon sequestration potential and consequently soil health.

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Abstract

SOIL CARBON DYNAMICS IN A RICE BASED CROPPING SYSTEM

by

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ABSTRACT

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ABSTRACT

An investigation entitled “Soil carbon dynamics in a rice based cropping system” was carried out with the objective of assessing and comparing the soil carbon dynamics in different rice based cropping systems viz., rice-rice-maize (R-R-M), rice-rice-bhindi (R-R-B) and rice-rice-daincha (R-R-D) in a lowland riverine alluvium. The investigation was undertaken at College of Agriculture, Vellayani and Integrated Farming System Research Station (IFSRS), Karamana during 2017-19. At IFSRS, rice based cropping sequence *viz*., rice (*Virippu*) - rice (*Mundakan*) - maize+ bhindi+ daincha has been practicing since 2011-12. The study was undertaken during three seasons of 2018-19 as three experiments.

For experiments 1 (*Virippu*) and 2 (*Mundakan*), medium duration rice variety, *Uma* was cultivated. Surface soil (0-15 cm) samples were collected after each crop harvest and analyzed for soil physical, chemical and biological properties and carbon fractions. The results were compared with that of rice- rice- fallow (R-R-F) sequence. All the carbon fractions (total organic carbon [TOC], particulate organic carbon [POC] - >53 and <53 μm) except labile carbon [LC] slightly increased after *Mundakan* crop. On an average, TOC and POC increased by 5.9 and 5.24 per cent, respectively. There was not much variation in soil bulk density (BD), EC, available K, Ca, Mg, S, Fe, B and microbial count during both the seasons. The pH slightly increased after *Mundakan*, with the highest value for R-R-F (5.14) and R-R-B (5.22) sequences during *Virippu* and *Mundakan*, respectively. Available N, P, Mn, Zn, Cu, microbial biomass carbon (MBC) and enzyme activities (dehydrogenase, urease and acid phosphatase) declined nominally after *Mundakan* season. The lowest enzyme activities were recorded in R-R-F sequence, during both the seasons.

Both paddy grain and straw were analyzed for major, secondary and micronutrients. R-R-D sequence had recorded the highest grain N (1.98 per cent) content after *Virippu*. K content was also highest for R-R-D sequence, after both *Virippu* (1.09) and *Mundakan* (1.42) seasons. Highest P and Ca contents were obtained with R-R-M and R-R-B sequence, respectively, after both the seasons.

Micronutrient content of grain and straw were almost the same in all the systems, after both *Virippu* and *Mundakan*, Economic yield was highest for R-R-B (5.21 t ha^{-1}) and R-R-D (4.09 t ha^{-1}) sequence after *Virippu* and *Mundakan*, respectively.

During the summer season (experiment 3), field was divided into three equal parts and planted with maize (var. *Co 6*), bhindi (var. *Manjima*) and daincha (var. *TN local*), respectively. Daincha at 50 per cent flowering stage and maize leaves after crop harvest were incorporated into the field. Soil samples were drawn at 15 cm intervals up to 105 cm depth and analysed for major soil parameters and carbon fractions. Plant samples were analysed for major, secondary and micro nutrients. Economic and biomass yield of R-R-B and R-R-M sequence were 9.21 and 25.1 t ha^{-1} and 3.6 and 7.89 t ha^{-1}, respectively. Biomass yield of R-R-D sequence was 22.5 t ha^{-1}.

The cropping systems significantly influenced soil carbon dynamics. R-R-D sequence recorded 10, 14, 13 and 22 per cent increase in TOC, LC, POC and MBC, respectively, up to 105 cm depth compared to that of R-R-F sequence at the end of cropping cycle. Enzyme activities (dehydrogenase, urease and acid phosphatase) showed significantly higher positive correlation with the carbon fractions. Among the weather parameters, atmospheric temperature (both minimum and maximum) was found to be positively correlated with soil carbon dynamics. The role of crop residue incorporation in improving soil carbon dynamics was clearly understood from the carbon management index (CMI) value, which was highest in R-R-D (120.56) followed by R-R-M (109.31), R-R-F (106.79) and R-R-B (72.81).

Except BD and available Fe and Mn, all the other soil parameters showed a declining trend with soil depth. BD ranged from 1.19 to 1.62, 1.21 to 1.73, 1.17 to 1.72 and 1.2 to 1.65 g cm^{-3} for R-R-B, R-R-M, R-R-D and R-R-F systems, respectively. Available Fe and Mn increased upto 30 cm depth and thereafter declined. R-R-D system resulted in the highest soil available N, K, Ca, Mg, S, B, MBC, urease, acid phosphatase, TOC, LC and POC upto 30 cm depth. pH and EC increased by 9.3 and 77 per cent, respectively in R-R-M system. Available P and

Ca in the surface layer declined in R-R-B and R-R-M systems compared to R-R-F. Available Fe and Mn contents were reduced in the all systems except R-R-F. The R-R-B system had the highest available Zn and Cu compared to R-R-F (8 and 13 per cent, respectively). Microbial load, enzyme activities and MBC were negligible beyond 75 cm depth. Daincha recorded the highest N (1.47) and P (1.13) content, while the highest K (1.96), Ca (0.85) and Mg (0.21 per cent) were in bhindi.

The study revealed that, among the different rice based cropping systems, R-R-D system influenced soil carbon dynamics most significantly followed by R-R-M, thereby indicating the role of crop residue incorporation particularly, green manures in improving the soil carbon sequestration potential and consequently soil health.

APPENDICES

Appendix I

Weather data during the cropping period

(May, 2018 to May, 2019)- Monthly averages of temperature, relative humidity and Monthly sum rainfall

Standard months	Rainfall (mm)	Temperature (^{0}C)		Relative humidity (%)
		Minimum	Maximum	
May-18	235.3	25.53	31.95	82.14
Jun-18	307.2	24.33	30.15	85.71
Jul-18	262.8	23.87	30.38	81.69
Aug-18	310.8	23.86	30.96	83.3
Sep-18	99.9	24.35	31.66	76.7
Oct-18	203.2	24.45	30.87	83.11
Nov-18	198.5	23.75	31.18	78.46
Dec-18	25	23.98	31.56	79.07
Jan-19	0	21.35	31.61	72.29
Feb-19	1.1	24.01	32.24	73.93
Mar-19	3	25	33.22	75.76
Apr-19	32.5	26.3	33.65	76.8
May-19	96	26.12	32.72	78.67

Appendix II

Nutrient media composition for estimation of microbial count

1. Nutrient Agar - Bacterial Count

Peptone	-5g
Sodium chloride	- 5g
Beef extract	- 3g
Agar	-20g
Distilled water	-1000ml

2. Rose Bengal Agar – Fungal Count

Dextrose	-10g
Peptone	-5g
Potassium dihydrogen Phosphate	-1g
Magnesium sulphate	-0.5g
Agar	-20g
Distilled water	-1000ml

3. Ken knights Medium- Actinomycetes count

Glucose	- 1g
Potassium dihydrogen Phosphate	- 1g
Sodium nitrate	- 0.1g
Potassium chloride	- 0.1g
Magnesium sulphate	- 0.1g
Agar	- 20g
Distilled water	-1000ml