CARBON SEQUESTRATION AND SOIL HEALTH UNDER DIFFERENT ORGANIC SOURCES IN WETLAND RICE

By

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(2014-21-125)

THESIS

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DECLARATION

I, Rajalekshmi K. (2014-21-125) hereby declare that the thesis entitled **"Carbon sequestration and soil health under different organic sources in wetland rice"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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Rajalekshmi K.

DEDICATED TO MY FATHER

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LIST OF ABBREVIATIONS

AICRP	All India Coordinated Research Programme
ANOVA	Analysis of variance
@	at the rate of
B	Boron
Ca	Calcium
cmol (p+) kg^{-1}	centimols per kilogram
CD	Critical Difference
cm	Centimetre
^{o}C	degree Celsius
^{o}E	Degree east
^{o}N	Degree north
Cu	Copper
dS m^{-1}	deci Siemen per metre
EC	Electrical conductivity
et al.	and co-workers
Fe	Iron
Fig.	Figure
g	gram
g^{-1}	Per gram
g L^{-1}	gram per Litre
g mol^{-1}	gram per mole
Gt	Giga tonnes

h	hour
ha	Hectare
ha^{-1}	per hectare
HCl	Hydrochloric acid
K	Potassium
KAU	Kerala Agricultural University
kg	kilogram
kg ha^{-1}	kilogram per hectare
K_2O	Potash
L^{-1}	Per litre
Mg	Magnesium
m	metre
m^2	metre square
m^{-2}	Per metre square
m^3	Metre cube
Mg	Mega gram
mg	Milli gram
mm	Milli metre
mg kg^{-1}	milligram per kilogram
min	minute
MBC	microbial biomass carbon
μg	microgram
μg C g^{-1} day^{-1}	micrograms of carbon produced per gram per day
μg TPF g^{-1} day^{-1}	micrograms of triphenyl formazan produced per gram soil per day

N	Nitrogen
N	normal
NH_4OAc	Neutral normal ammonium acetate
No.	Number
NS	Non-significant
O.M.	Organic matter
P	Phosphorous
Pg	Peta gram
POP	Package of practices recommendation
%	Per cent
P_2O_5	Phosphate
pH	Hydrogen ion concentration
ppm	parts per million
PMT	Permanent Manurial Trial
RBD	Randomized block design
Rs	Rupees
S	Sulphur
SOC	Soil Organic Carbon
t	tonne
$t_{1/2}$	Half-life
Tg	Tera gram
TPF	Triphenyl Formazan
TTC	2,3,5,-triphenyl tetrazolium chloride
viz	namely
WASP	Web based Agricultural statistics software package

INTRODUCTION

1. INTRODUCTION

Soil, a natural four-dimensional body at the atmosphere-lithosphere interface, is organic-carbon mediated realm where solid, liquid and gaseous phases interact at a range of scales and generate numerous ecosystem goods and services. Soil organic carbon (SOC) is the largest pool of terrestrial C, with an average content of 1500 Pg upto a depth of 1 m (Batjes, 1996), which is twice the amount of atmospheric pool and thrice the biotic pool (IPCC WGI, 2001). A small manipulation in the global SOC stock could significantly affect the concentration of atmospheric CO_2. Hence, knowledge about the mechanisms of storage and stability of organic carbon (OC) in soils has greater importance. The carbon (C) fixed in soils as a result of photosynthetic activity by plants undergoes the following changes (Kell, 2012) (Fig.1).

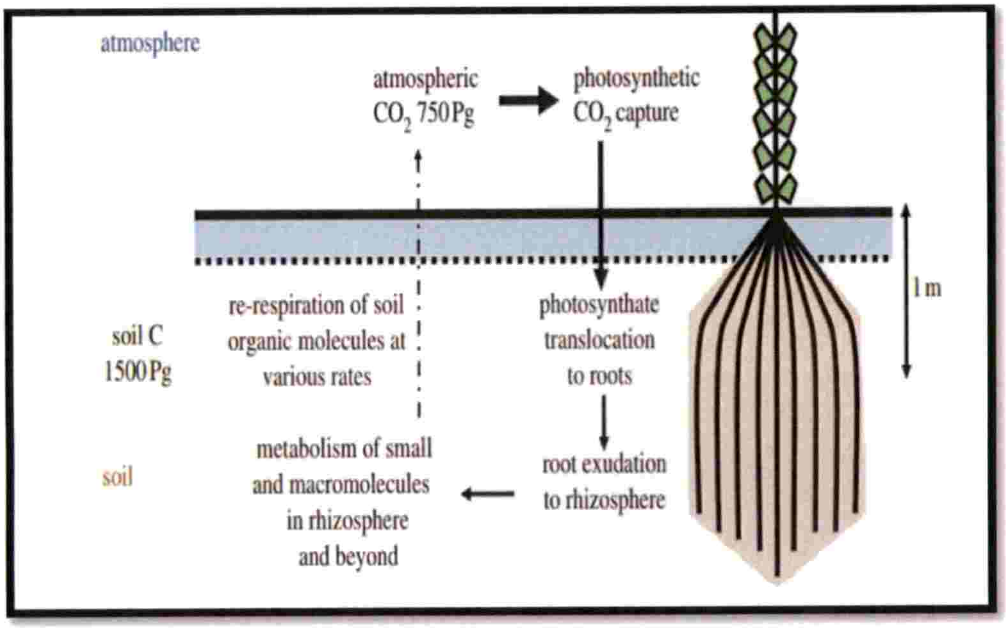

Fig. 1. Major processes in soil carbon sequestration for photosynthetically fixed CO_2

The global emission of carbon is estimated to be 270 Pg for the land use and soil cultivation practices during the last 150 years. The CO_2 emission has increased abnormally to more than 3 per cent since 21st century from 1 to 1.5 per cent during 1990-1999. The rate of future increase in atmospheric CO_2 concentration will depend on the nature and magnitude of anthropogenic activities and the consequent interaction of C flows among different global C pools. The global surface temperature increased by 0.6 °C since the late 19th century with a current average warming rate of 0.17 °C per decade.

Wetland characteristics add the deposition of organic matter in the soil and sediment, serving as carbon (C) sinks and making them one of the most effective ecosystems for storing soil carbon. Different types of wetlands contain approximately 350-535 Gt C, which is 20-25 per cent of world's soil organic carbon. The amount of various pools of SOC in flooded rice soils is small although it has the largest C pool size formed due to waterlogging. The anaerobic conditions lower the microbial decomposition of organic matter. But on draining, decomposition proceeds rapidly leading to a reduction in long term storage and release of C to the atmosphere from paddy fields. Hence, wetlands are dynamic ecosystems where significant quantities of C may also be trapped and stored in sediments.

In the current scenario of climate change, wetland paddy fields act as major sources of greenhouse gases, especially methane (CH_4) and carbon-di-oxide (CO_2) as they experience both dry and wet conditions depending on water availability. The total annual global emission of methane amounts to be 500 Tg yr^{-1} and nearly a quarter of this is attributed to wetland rice fields. According to OECD (2000), agricultural activity produces 1 per cent of the excess CO_2 to global emissions. The emission of greenhouse gases results in a decrease in stored soil carbon and thus affects the process of soil carbon sequestration. The soil type, temperature, vegetation type, erosion and land management has a great influence on the loss and gain of organic C in soils. Decomposition of SOC in cultivated soils has contributed approximately 50 Pg C to the atmosphere (Paustian *et al.*, 1997). This has promoted a strategy of enhancing soil carbon sequestration in agricultural systems to offset CO_2 increase.

Sequestration of SOC is one of the most effective methods to increase SOM reserves and for mitigating the potential greenhouse effect (Lal, 2004). As per IPCC (2000), carbon sequestration by terrestrial ecosystem is the net removal of carbon-di-oxide from the atmosphere or the avoidance of emission of carbon-di-oxide into the atmosphere from terrestrial ecosystems. The carbon sequestration potential of the world crop land soils was reported as 0.4-0.9 Pg C yr^{-1} within a 50 year period. The size and nature of the stable SOC pool varies with soil and ecosystem properties like land use, climate, soil type, soil texture and soil depth. In general, with increase in soil depth, the proportion of stable SOC pool increases. This increase in SOC content reduces soil erosion, enhances soil quality, improves water quality, increases crop growth and agronomic productivity. It also promotes environmental quality by adsorbing pollutants from water and reducing CO_2 concentrations in the atmosphere. According to Goyal *et al.* (1999) usage of different organic sources like manures, plant residues and waste materials in farming could improve chemical and biological properties of soils. In addition, judicious and combined use of organic and inorganic sources of nutrients augments soil fertility and crop productivity. The OC in soils of variable charge (e.g. Andisols and Oxisols) is more stable compared to other soils cropping regime (Parfitt *et al.* 1997).

Recently, perennial cropping systems have gained importance as this prevents the loss of C into atmosphere which helps in soil carbon sequestration and mitigating climate change. However, in the tropics short-term manipulations may yield larger responses, where turnover times for fast-cycling soil C are shorter (Trumbore, 1997). Little attention has been paid on the short-term effects of a wide range of organic sources on carbon sequestration and on its fractions. In light of this, the present study was undertaken for two continuous cropping seasons in rice crop under rainfed condition to assess the effect of four contrasting organic sources [Farm yard manure, *Artocarpus* (jack tree) leaves, *Sesbania aculeata* (daincha) and rice husk biochar] in the absence or presence of N mineral fertilizer. The main objectives of the study were to assess the effect of different organic sources on carbon sequestration and soil health in wetlands (Ultisols) under rice –rice cropping system and to compare carbon distribution and fluxes with that of adjoining fallow land.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The Soil organic carbon (SOC), an important component of soil contributes significantly to soil fertility, soil tilth, crop production and overall soil sustainability. Rice- rice cropping system is the most prevalent and dominant cropping system adopted by the farmers in the southern part of peninsular India. According to Cassman *et al.* (1995) growing rice especially in low land flooded ecology could increase stable SOC levels compared to upland rice cropping system. When organic sources like green manure, animal waste and farmyard manure (FYM) are traditionally applied to rice soils, soil organic matter content enhances. This in turn has effect on levels of plant nutrients to improve the physical, chemical and biological soil properties that directly or indirectly affect soil fertility. The effect of different organic and inorganic nutrients on C sequestration and soil health in wetland soils are discussed under the following headings:

2.1. Soil carbon sequestration
2.2. Soil carbon pools
2.3. Soil quality and carbon sequestration
2.4. Integrated nutrient management and crop productivity
2.5. Wetland rice soil as carbon sink
2.6. Nutrient management and greenhouse gas emission

2.1. SOIL CARBON SEQUESTRATION

Soil organic matter (SOM) or organic carbon (SOC) is a key attribute of soil fertility and productivity because of its importance to soil physical, chemical as well as biological properties (Stevenson, 1986; Reeves, 1997). Lal (2000) stated that global pool of SOM is 1500 Pg of carbon upto 1 m depth and the total soil organic pool in India varies from 21 to 63 Pg for 150 cm depth. He also observed from his research work that nutrient is one of the crucial factors controlling biomass production and decomposition of residues, which is important for soil carbon sequestration (Lal, 2003).

Sundermeir *et al.* (2005) defined soil carbon sequestration as the process of transferring carbon-di-oxide from the atmosphere into the soil through crop residues and other organic solids, and in a form that is not immediately re-emitted.

Pathak *et al.* (2011) reported that C sequestration potential across different agro-climatic zones of India under various nutrient management practices ranged between 2.1 and 4.8 Mg C ha^{-1} with a total potential of 300 to 620 Mt. The effects of chemical fertilizer and manure application were influenced by cropping intensity, climate, soil type and even the manure type and its management (Lu *et al.*, 2009; Ding *et al.*, 2014).

In this section, works pertaining to carbon sequestration capacity of different organic and inorganic materials, their residue decomposition rates and sequestration as affected by depth are discussed.

2.1.1. Manures and fertilizers

Fertilizer application has proved to be a lucrative strategy for strengthening C sequestration (Lal *et al.*, 1999). Organic sources such as manures, composts and bio-char could lead either to a gain of soil C over time (Marek and Lal, 2003), or a reduction in the rate at which organic matter would be lost from soils (Goyal *et al.*, 1992).

Lal (2004) studied the carbon sequestration potential in different types of soils and the results revealed that soil carbon sequestration increased in cultivated soils with practices such as manuring, cover cropping, mulch farming and conservation tillage.

Fertilizer additions had a positive effect on soil C, which was primarily attributed to increased plant biomass production (Campbell *et al.*, 1991; Mazumder and Kuzyakov, 2010). In contrast, fertilizer addition had also aggravated the rate of decomposition of SOM, thereby depleting C content. For instance, a recent New

Zealand study on SOM revealed that in some highly productive dairy pastures, soil C had decreased but on low fertility hill country pastures, it was increased (Schipper *et al.*, 2007). Thus changes in management which prevents major limitation on crop growth resulted in increased productivity and a greater C return to the soil. However, any increase in C inputs to the soil may be cancelled by increased decomposition rates, especially when the productivity gains are the result of fertilization and irrigation.

Lin *et al.* (2008) analyzed the change of soil organic carbon (SOC) under different cropland management regimes by estimating carbon sequestration under cropland management in China. They found that the most successful management system for increasing SOC was using inorganic and organic fertilizers together, which could increase SOC by 0.889 t ha^{-1} yr^{-1}. Lu *et al.* (2008) found that the application of synthetic nitrogen fertilizer alone could bring about a carbon sequestration potential of 21.9 Tg C in current situation and 30.2 Tg C with fertilization as recommended. However, under the two scenarios, the greenhouse gas leakage caused by fertilizer production and application would reach 72.9 and 91.4 Tg C and thus, the actual available carbon sequestration potential would be -51.0 and -61.2 Tg C, respectively. The situation was even worse under the 'fertilization as recommended' scenario, because the increase in the amount of nitrogen fertilization would lead to 10.1 Tg C or more net greenhouse gas emission. All these results indicated that the application of synthetic nitrogen fertilizer could not be taken as a feasible measure for the carbon sequestration of cropland soil.

Bradley *et al.* (2008) studied net global warming potential (GWP) and carbon sequestration rates by cover crop (*Secale cereale* L.), manure and compost on a short-term, in a corn-soybean (*Glycine max* L.) rotation with complete corn stover removal in America over a three year period. Manure and compost raised soil C levels in the surface soil but not in the subsurface soil. Total soil organic C (SOC) in the surface soil increased by 41 and 25 per cent for the compost and manure treatments respectively and decreased by 3 per cent for the untreated check. Accordingly the net GWP were also of −1811 and −1060 g CO_2 m^{-2} yr^{-1} respectively, compared to 12 g CO_2 m^{-2} yr^{-1} for the untreated.

Kukal *et al.* (2009) studied two long term experiments involving application of FYM and inorganic fertilizer in rice-wheat and maize-wheat cropping systems. The results showed that in FYM plots, the SOC sequestration rate was higher in comparison to NPK plots in both cropping systems. Further, the sequestration rate was three times higher in rice-wheat than in maize-wheat cropping system.

Combined application of organic and inorganic fertilizers increased SOC stock by enhancing biomass production and decreasing decomposition of soil OM. For example, Srinivasarao *et al.* (2012) found regular application of biomass-C with chemical fertilizer enhanced the SOC sequestration in central India by improving soil quality and minimizing the depletion of SOC stock under continuous cropping.

From a nutrient study conducted in India, Benbi (2013) reported that balanced usage of fertilizers could enhance SOC concentration by 6 to 100 per cent and C sequestration by 20-600 kg ha^{-1} yr^{-1}, while integrated nutrient management practices could increase C by 100-1200 kg C ha^{-1} yr^{-1} with an enhanced SOC concentration of 17-132 per cent under various soil, crop and climatic conditions. Under rainfed production systems, the carbon-sequestration potential of different nutrient management practices ranged between 0.04 to 0.45 Mg ha^{-1} yr^{-1} (Srinivasarao *et al.*, 2014).

2.1.2. Legumes and plant residues

Enhanced crop management could sequester 258 MMT of SOC in 2040 (IPCC, 2000). Sudha and George (2011) experimented with crop residue surface mulching in coconut gardens for a period of two years and found that this could sequester organic carbon up to 1.37 per cent. Soil C sequestration to great depths could be achieved by incorporating legumes in soil, which might be due to better utilisation of soil water (Ganeshamurthy, 2011).

Benbi and Khosa (2014) reported that adding partially decomposed manures and composts in the field could provide greater C stabilisation with longer residence time than those with low C/ N ratio such as green manures.

2.1.3. Bio-char

Bio-char is gaining importance as a viable option of storing carbon permanently. It is different from charcoal in the mode of usage, which is mainly for atmospheric carbon capture and storage, and application to soil. Black carbon, having aromatic structure, is resistant to decay and can therefore be stored as stable organic carbon for a prolonged period within the soil (Kuhlbusch *et al.,* 1996).

Lehmann *et al.* (2006) conducted a study with biomass–derived black C or biochar with an aim to improve the stabilisation of added C in soil and he found that upto 50 per cent of the initial biomass C could be sequestered through conversion of plant material to biochar. Estimates suggest that around 0.05–0.20 Pg C yr^{-1} of black carbon or charcoal are stored annually in soil (Kuhlbusch, 1998; Lehmann *et al.,* 2005 and Nguyen *et al.,* 2008).

It has been shown that biochar has multiple uses. When added to soil, it could significantly reduce greenhouse gas emission and increase carbon sequestration (Lehmann *et al*., 2007) and also improve soil fertility (Rodríguez *et al*., 2009). Biochar increased the mean residence time of soil organic C (OC) content and soil fertility (Glaser and Amelung, 2009).

Durenkamp *et al.* (2010) illustrated bio-char as an excellent soil amendment and easily accessible cheap source of organic carbon (OC) and it improved water retention as well as microbial biomass carbon in soil. Globally, the technical potential for C sequestration over a century through biochar application has been estimated as 130 Pg C (Woolf *et al*., 2010). A study of rice straw and biochar compost revealed that organic source decomposition depended on the quantity of decomposable and recalcitrant C pools (Benbi and Yadav, 2015). They also reported that biochar and rice straw compost with high MRT (1100- 2000 days) would lead to long term C sequestration.

Plant-derived biochar could be a potential source of plant-available Si (Abbas *et al*., 2017). The form of Si in biochar depends upon the producing temperature. At low producing temperature (300 °C), Si in biochar mostly exists in amophous form, whereas high producing temperature converts Si from amorphous to crystalline form (Guo and Chen, 2014). Biochar from rice straw has higher plant available Si contents than other feedstocks studied, such as miscanthus, sugarcane harvest residues, and switch grass (Wang *et al*., 2018).

A very brief description on decomposition of plant residues and influence of residue composition on it is reviewed hereunder:

2.1.4. Decomposition

The method of addition of plant residues to the soil affects the rate of decomposition and buildup of organic matter reserves. The rate of decomposition varies with depth of placement as depth affects temperature, aeration and moisture. When left on the surface as mulch, it would be desiccated and decomposed more slowly than when incorporated (Shield and Paul, 1973).

Jenkinson and Ayanaba (1977) opined that plant residue remaining on the soil surface in the field could serve as carbon and energy sources for microbes and newly formed humic compounds were less stable than the old ones, as the latter decomposes at the rate of 1.5 - 2.0 per cent per year.

Decomposition is a key ecological process for maintaining the supply of most essential plant nutrients. In natural ecosystems, nutrient recycling *via* decomposition often accounts for more than 90 per cent of plant-available N and P and more than 70 per cent of K and Ca (Chapin *et al.,* 2002). According to Sanderman *et al.* (2010) three concurrent processes *viz.,* fragmentation, leaching of soluble compounds and microbial catabolism contribute to the process of decomposition.

2.1.4.1. *Residue composition and their influence on decomposition*

Nitrogen rich fresh plant residues are decomposed more rapidly than N-poor residues. Labile nutrients would make the residues more vulnerable to microbial decomposition by supplying nutrients for microbes (Theng *et al.*, 1989). Gusewell and Gessner (2009) observed residues with different chemical composition had a variable decomposition rate. Therefore, residue composition either by nutrient content or different substrates (eg. lignin, cellulose and so on) in the residues could affect its decomposition or by nutrient amendment in soil for plant uptake. Similar results were also reported by Bengtsson *et al.*, 2012.

2.1.4.2. *Nature of residues*

In general, fresh or green plant residues are decomposed rapidly by soil microbes due to the difference in their chemical composition. Theng *et al.* (1989) from their study found that fresh organic residues or labile constituents of SOM decomposed within few weeks or months.

Zech *et al.* (1997) pointed out that different plant parts also differ in the decomposition rate: for example, root xylem, epidermis and leaf veins rich in lignin proved to be more resistant to decomposition.

According to Carreiro *et al.* (2000), first rapid decomposition occured in nutrient poor especially in N poor, and easily decomposable substances such as carbohydrates and cellulose through nutrient addition by removing nutrient limitation for microbes. In later stage of litter decomposition when relatively recalcitrant compounds were degraded, nutrient additions would suppress C decomposition.

Sridevi *et al.* (2003) studied the dynamics of C mineralisation and microbial biomass in soil amended with residues and residue fractions like sorghum straw and *Glyricidia* prunings and found that the peak rate of C mineralisation was immediately following incorporation in case of sorghum straw, *Glyricidia* prunings and fibre fractions of prunings whereas in fibre fractions of sorghum straw it reached peak only after 10 days.

The decomposition rate may be slower in fresh plant litter if there is a lack of macronutrients, such as N, P and S. Decomposition of organic matter was affected by its biochemical composition – *i.e.* sugars, cellulose, hemicelluloses, lignin and so on (Cornwell *et al.*, 2008). Carrillo *et al.* (2011) opined that decomposition of plant residues was also affected by variation in the substrate quality of the residues, environmental factors and availability of decomposing community in the system. Similar results were also reported by Alamgir *et al.*, 2012.

2.1.4.3. *Elemental stoichiometry*

Jama and Nair (1996) observed a slower decomposition rate in the second phase of *Leucaena leucocephala* and *Cassia siamea* mulch decomposition due to higher C: N ratio of 36 and 31, respectively whereas the initial C: N ratio was 18.9 and 23.4, respectively. It is expected that decomposition of organic material and N release would be rapid if the C: N ratio is below 20 or N concentration in organic matter is above 2.5 per cent (Datta and Devi, 2001). Stevenson and Cole (1999) reported that decomposition of organic materials was accelerated at C:N and C:P ratios of less than 20 and 200 respectively and was reduced at higher ratios.

As decomposition of organic residues is the result of microbial enzymatic action and enzyme production requires nutrients, the elemental composition of organic residues (*i.e.* elemental stoichiometry) may have a significant impact on the decomposition rate (Schimel and Weintraub, 2003; Leitner *et al.*, 2012). Plants could fix a greater amount of C through photosynthesis by increasing atmospheric CO_2, thereby resulting in higher C:N or C:P ratios of plant components (Dodds and Martin, 2004).

Microbial decomposition processes seem to be limited by N when the N:P supply ratio is low and by P when the N:P supply ratio is high. The N:P ratio of litter is a useful parameter to determine the relative importance of bacteria and fungi in the decomposition process where low N:P ratio promotes bacteria and high N:P ratio promotes fungi. Thus, the N:P ratio of the crop residues seem to be a vital factor in decomposition. Gusewell and Gessner (2009) reported that the N:P ratio of plant biomass could vary with variation in N and P supply ratio in the system and this N:P ratio of plant litter might indicate whether N or P limits the decomposition rate. Moreover, biomass production was positively related to the N and P supply rates in the system while microbial decomposition rates depended on N and P content of plant residues.

Elemental stoichiometry or C:N:P ratios could act as quality indexes of decomposing organic matter in different ecosystems (Hattenschwiler and Jorgensen, 2010). These ratios indicate the relative abundance of nutrients considered and some thresholds have been established where decomposition readily occurs (Manzoni *et al.*, 2010). Residue stoichiometry can be changed by varying atmospheric CO_2 concentration and soil nutrient availability.

The initial N content of plant residues is one of the vital factors for accelerating or inhibiting residue decay by microbes in soil. Usually, the decomposition rate of plant litter is primarily regulated by its N concentration (Sardans *et al.*, 2012). It is well documented that the activities of extracellular C-acquiring enzymes such as cellulases and amylases were limited by N supply and N availability in plant residues with low C: N could enhance the activities of these enzymes (Berg, 2000; Leitner *et al.*, 2012). There is strong positive correlation between P concentration of residues and decomposition of organic materials. Generally, plant material with high P concentration (> 5 mg P kg^{-1}) decompose faster than that of low P concentration because these plant residues contain enough P (and N) to satisfy the P and N demand of the microbes which have low C:N and C:P ratios (Alamgir *et al.*, 2012). Plant materials poor in P concentration (high in C:P ratio) often show slow decomposition in soil with low P levels.

2.1.5. Cropping intensity and distribution of SOC

Gupta and Rao (1994) reported that OC stock of surface to subsurface depth of 186 cm in the soils is 24.3 Pg. Integrated nutrient management with legumes and cover crops in the cropping systems resulted in increasing SOC density and distribution of SOC in the subsoil (Lal, 1997).

Plant production and patterns of biomass allocation strongly influenced relative distribution of C with soil depth (Jobbagy and Jackson, 2000). The deeper in the soil profile, the older stored SOC is likely to be. They also reported that both oxidisable and total organic carbon significantly decreased with depth in all the land uses which might be due to the decreasing input of surface litter.

Fontane *et al.* (2007) proposed an increase of mean residence time of SOC of upto 2000 - 10000 years for depths beyond 20 cm which reduced the microbial activity and SOC turn over at greater depths. Alvaro-Fuentes and Lopez (2008) compared the effect of tillage treatments such as conventional, reduced and no tillage on the SOC content in various depths of the soil. They reported that the lowest SOC concentration values corresponded to conventional tillage in surface layer whereas at deeper depths it recorded higher values.

Benbi and Brar (2009) observed that the intensive rice–wheat cropping in Punjab could improve SOC concentration in the surface (0-20 cm) soil by 38 per cent over the 25 year period from 2.9 g kg^{-1} to 4.0 g kg^{-1}. On the other hand, Lu *et al.* (2009) from their study reported the average sequestration rate was 157 and 198 kg C ha^{-1} yr^{-1} with double crop in the north and south China. These values were lower than the average rates of 225 and 390 kg C ha^{-1} yr^{-1} in the north east and north west China which were of single-crop regions. Luo *et al.* (2010) conducted a meta analysis on the SOC response to change in tillage practices and illustrated that an increase in cropping intensity and crop species could enhance SOC sequestration.

The influence of tree species such as *Leucaena, Dalbergia, Acacia* sps, on organic matter and nutrient content of soil in varying depths of sub montane zone of Punjab were evaluated by Singh and Sharma (2012) and they reported that OC and nutrient contents decreased with increase in depth irrespective of tree species.

Available nitrogen and micronutrients were higher in soil under subabul in the surface soil as well as whole soil profile.

Datta *et al.* (2015) studied the effect of horticultural land uses on soil properties and organic carbon distribution in a reclaimed sodic soil and found that in all the land uses, with increase in depth, there existed a significant decrease and increase in active and passive pools of carbon.

2.2. SOIL CARBON POOLS

The total SOC pool size in Indian soil is about 24.3 Pg (Gupta and Rao, 1994). Certain fractions of soil organic carbon are more important in maintaining soil fertility and are, therefore, more sensitive indicators of the effects of management practices compared with the soil TOC (Cambardella and Elliott, 1992; Freixo *et al.*, 2002).

The total SOC consists of (i) labile or active pool and (ii) non labile or resistant /recalcitrant or passive pool with varying residence time. Labile C pool is the fraction of SOC with rapid turnover rates which serves as the energy source for the microbes and thus influences nutrient cycling for maintaining soil quality and its productivity.

Mandal *et al.* (2008a) demonstrated that management of soil could have a significant impact not only on the total organic carbon (TOC) content of arable soils but also on the proportion of SOC fractions present. However, TOC might not be sensitive to changes in soil quality resulting from soil management practices after a relatively short time.

As soil organic carbon is a heterogenous mixture of organic substances, the different forms or fractions of SOC might have different effects on soil fertility and quality. Physical fractionation of SOM according to size and/ or density is considered useful for the study of its functions and turnover in soil. Particulate organic matter representing uncomplexed organic matter such as plant residues in various stages of decomposition along with microbial biomass and microbial debris had been shown to be a sensitive indicator of management effects on SOC (Benbi *et al.*, 2012). They also quoted that in rice –wheat system, application of organic amendments influenced light fraction organic C (LFOC) or POC to a greater extent than the sand sized heavy fractions (HF) and silt and clay sized mineral associated organic C (Min OC) and these represented active, slow and passive pools of SOC respectively. Particulate organic matter (POC) constituted 23- 34 per cent of SOC and majority of SOC (46-68%) was associated with the silt and clay fraction.

Sulaiman (2017) found that after 20 years of long term fertilizer experiment at Pattambi, the percentage contribution of each pool to total soil organic carbon in paddy soils was in the order: passive (55%) > slow (36%) > active (9%).

2.2.1. Active pool

Active pool of soil carbon refers to the accumulation of carbon in labile form with short residence time. Estimates of microbial biomass carbon (MBC) in wetland soils (Marumoto, 1984) exhibited higher ratios to total soil C (4-8%) than that reported for upland arable lands (Jenkinson, 1981).

Parton *et al.* (1987) observed that active pools of SOC consisted of living microbes and microbial products along with soil organic carbon with a short turnover time (1 to 5 years). Nannipieri *et al.* (1990) pointed out that the living soil organic C pool or MBC, another important component of the active SOC and soil enzyme activity is an index of functional microbial activity. Goyal *et al.* (1994) reported that biomass C in the soil was considerably higher, 90 days after incorporation of wheat straw than the initial level. MBC is recognised as sensitive indicator of cultivation – induced changes in both SOC and biological properties of soil quality and soil health (Karlen *et al.,* 1997). Microbial biomass has been assigned important role in rice soils as a nutrient pool, driving force of nutrient turnover and early indicator of soil/ crop management (Shibahara and Inubushi, 1997). Total MBC may be larger in flooded soils because of the development of the aquatic microbial community.The pool size of microbial biomass carbon in rice soils accounts for only 2-4 per cent of total C that represents an important and most labile fraction of SOM and this pool is turned over very rapidly (Reichardt *et al.*, 1997).

The capacity of a soil to supply nutrients is often defined by the proportion of total soil organic carbon that is labile. The active or labile fraction consists of smaller pools that can be readily utilized by micro-organisms. A decline in active fractions of C and N after long-term cultivation of soil leads to depletion of soil fertility through reduction of labile sources of nutrients, faster decomposition and lower bio-available nutrients. This fraction originates from new residues and living organisms (including micro-organisms) and turnover generally occurs within 2–3 years and represents only 1–5 per cent of total soil organic matter (Curtin and Wen, 1999). However, since this soil fraction is more sensitive to changes in management practices, significant differences can generally be measured earlier than in the larger, more stable pools.

Datta *et al.* (2001) reported that the content of biomass carbon was the highest under organic treatment followed by integrated nutrient management in French bean grown soil in acid Alfisol. Lupwayi *et al.* (2005) applied cattle manure, hog manure or inorganic fertilizers annually or triennially in field trials conducted at two sites over 3 years along with a control treatment without manure or fertilizer. Canola (*Brassica napus*) was grown in year 1, hulless barley (*Hordeum vulgare*) in year 2 and wheat (*Triticum aestivum*) in year 3. Cattle manure increased MBC by 26 per cent to three-fold, hog manure by 31 per cent to two-fold and inorganic fertilizers reduced MBC by 20-64 per cent. Similar effects, except the reduction by inorganic fertilizers, were observed for functional diversity of soil bacteria and Shannon index, H.

Stabilized fraction is composed of organic materials that are highly resistant to microbial decomposition and hardly serves as a good indicator for assessing soil quality and productivity (Majumder *et al.,* 2008). Active carbon fractions are energy sources for the soil food web and thus influence nutrient cycling (Chan and Xu, 2009). Moreover, the labile fractions of SOC respond rapidly to changes in C supply and are considered to be important indicators of soil quality.

Nakhro and Dkhar (2010) worked on the impact of organic and inorganic fertilizers on microbial populations and biomass carbon in paddy field soil. Results showed that the organically treated plot recorded the maximum microbial population counts and MBC, followed by the inorganically treated plot and control. The application of organic fertilizers increased the OC content of the soil and thereby increasing the microbial counts and MBC while the reverse happened with the use of inorganic fertilizers although it increased the soil's NPK level which could be explained by the rates of fertilizers being applied.

Basak *et al.* (2012) studied the comparative effectiveness of value added manures on soil carbon pools and CO_2 emission in an Inceptisol and they found that mineralisable C increased with combined application of value added manures and chemical fertilizers which might be due to increased plant growth and biomass production including greater root biomass.

An experiment was conducted during Kharif season by Khursheed *et al.* (2013) to ascertain the response of different organic sources *viz*., wheat straw, farm yard manure (FYM), vermicompost and poultry manure to rice (*Oryza sativa*) and also to monitor the effect of manuring on soil carbon pools. Application of poultry manure and vermicompost along with chemical fertilizers for supply of nitrogen, phosphorus and potassium (NPK) resulted in highest grain yield. Soil carbon, labile carbon and water soluble carbon contents also improved with application of organic sources of N.

2.2.2. Slow pool

Cambardella and Elliott (1992) isolated the particulate organic matter (POM) in soil which is more sensitive to soil management practices than total soil organic matter (SOM). Particulate organic C (POC) representing the slow pool of SOC is a sensitive indicator of soil management effects on SOC, particularly in the upper soil layer (0–10 cm) (Elliott *et al.*, 1996).

Hassink (1997) from his study showed a more stabilised SOM fraction than the POC, termed as min-C (mineral associated carbon), a fraction chemically stabilised on silt and clay surfaces and less sensitive to soil management. Lal *et al.* (1998) concluded that soil fertility/nutrient management practices on cropland could enhance the SOC pool from 50 to 150 kg ha^{-1} yr^{-1}. Soil water soluble carbon and light fraction organic carbon (LFOC) responded more rapidly under different tillage and stubble treatments. Hence potentially they are the most sensitive indicators of agricultural management – induced changes than soil TOC. The use of organic manures and compost enhanced the SOC pools more than the application of the same amount of nutrients as inorganic fertilizers (Gregorich *et al.,* 2001).

The chronic fertilizer additions increased the turnover of labile soil carbon pool (Neff *et al.,* 2002), compounds that were derived from recent additions and important for increasing soil carbon pools over time. Different pools of soil C changed rapidly in response to land use change and contributed to nearly 20 per cent of greenhouse gas emissions (UN REDD 2009). John *et al.* (2005) reported that the POM contributed approximately 13 per cent in fields, 14 per cent in grassland and 52 per cent in forest to the total SOC stored in the A horizon. Sophi *et al.* (2012) studied the soil organic pools in apple orchards of Kashmir at different depths and found that total soil organic carbon, labile soil organic carbon, microbial biomass carbon decreased significantly at lower depths while particulate soil organic carbon pool showed a reverse trend.

2.2.3. Passive pool

Galdo *et al.* (2003) found that most of the relatively recalcitrant C was associated with micro-aggregates in the silt and clay fraction, indicating more permanent C sequestration. Under long periods of soil submergence in rice

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cultivation, formation of passive pools of SOC was promoted to a tune of 29 per cent of stabilized recalcitrant C pools (Mandal *et al.,* 2008b).

Verma *et al.* (2010) found that organic amendments with wider C: N ratio had more impact on relatively stabilized fractions of SOC, while the same with narrower C: N ratio exerted more impact on the active fractions of SOC. In a study to assess the impact of land–use change on soil carbon sequestration in agricultural soils, Benbi *et al.* (2012) reported that the POM had wider C/N ratio and the ratio narrowed down as the SOM fractions degraded into finer particle size suggesting that the crop and organic matter derived C would be first transferred to POM which on decomposition could get stabilised into silt and clay sized fractions.

2.3. SOIL QUALITY AND CARBON SEQUESTRATION

Soil organic matter, an indicator of soil quality due to its nutrient sink and source character could improve soil physical, chemical and biological properties (Salazar *et al.,* 2011).

2.3.1. Soil physical properties

Whalen and Chang (2002) reported that manure application promoted the formation and stabilization of soil macro aggregates. Incorporation of organic matter either through crop residues or organic manure improved the SOC, soil structure and water retention capacity and decreased bulk density (Liu *et al.*, 2003).

Biochar can act as a soil conditioner, enhancing plant growth by supplying, more importantly, retaining nutrients and by providing other services such as improving the physical and biological properties of soils (Lehmann and Rondon, 2005; Glaser and Amelung, 2009). The improvement of physical properties of soil by aggregation was also proposed to explain the strong SOC sequestration in paddy soils (Zhou *et al.,* 2008).

Tweeten *et al.* (2009) worked on the possibilities and constraints for consideration of organic agriculture within carbon accounting system and found that

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carbon sequestration through soil organic amendments improved soil tilth, nutrient release and moisture holding capacity.

2.3.2. Soil chemical properties

Kaleemulla (1984) conducted a manurial study in Alfisol at Bangalore and found that relatively higher available nitrogen content was observed in FYM applied plot compared to the plots treated with N alone and no fertilizer treatment. Kumar and Singh (1997) noted that application of FYM @ 10 t ha^{-1} to both wheat and rice crop increased available N and P status of soil over no application of FYM and initial value. The available potassium status was found to be declined with FYM application as compared to initial values.

Duraisami *et al.* (2001) reported that inorganic N along with other sources applied to soils registered significantly higher available N than the inorganic N source alone in soils.

Selvi and Selvaseelan (2003) pointed out that continuous application of inorganic nitrogen increased the available nitrogen content of soil and this was more pronounced when applied along with P and K. Immobilization of N could also lead to maintenance of definite levels of available N under the addition of organic matter and crop residue management. Similar results were also published by Mairan *et al.*, 2005. Kumar and Prasad (2008) found that the application of crop residues along with FYM and green manure significantly increased the available N content of soil.

Behera and Singh (2009) noticed that the highest P was achieved under 100 per cent NPK+FYM treated plots than the plots where inorganic fertilizers were applied alone.

Dhull *et al.* (2010) worked on the effect of chemical fertilizers and organic amendments on soil chemical and microbiological properties over a period of 3 years. Soil organic carbon and total N increased in treatments receiving a combination of organic amendments and different doses of chemical fertilizers compared to soils

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receiving chemical fertilizers alone. Mineral N and available P in the soil were greater with the integrated use of chemical fertilizers and organic inputs. Microbial biomass carbon increased significantly with the combined application of chemical fertilizers and organic amendments, in comparison to soils receiving chemical fertilizers alone. The results indicated an improvement in soil organic matter, microbial activities and crop yields due to the use of chemical fertilizers along with organic manures. Such positive effects of organic inputs could help in maintaining organic matter level and sustain good crop yields over a period of time without deteriorating soil health.

Glyricidia leaves mixed in the soil before crop sowing serve as soil mulch, manure, provides nutrients as well as water during intermittent drought spells (Srinivasarao *et al.*, 2011). Ge *et al.* (2011) reported that increasing soil organic matter content improves soil fertility; however, conventional farming practices generally lead to a reduction in such organic material. A comparative study of organic and conventional arable farming systems was conducted in China to determine the influence of management practices on soil chemistry, microbial activity and biomass. Organic production systems significantly improved soil microbial characteristics and increased soil organic C, thus improving soil quality and fertility.

Dong *et al.* (2012) observed substantial increase in SOC, available N, P and K under organic manure and NPK treatments in red soil regions of southern China. Application of FYM showed a significant increase in major nutrient concentration of soil by mineralisation and release of these elements from reserve source of FYM (Ghosh *et al.*, 2012). Total organic carbon (TOC), soil microbial biomass carbon (SMBC), available N, P and K status of the soil were maximum when 50 per cent recommended dose of NPK was applied through inorganic and remaining 50 per cent through poultry manure (Kumar *et al.*, 2012).

Jien and Wang (2013) found that biochar application improved the physico-chemical and biological properties of highly weathered soils. Soil pH increased significantly from 3.9 to 5.1, CEC from 7.41 to 10.8 cmol (p^+) kg^{-1}, base cation percentage from 6 to 26 per cent and microbial biomass carbon from 835 to 1262 mg kg^{-1}.

2.3.3. Soil biological properties

High rates of N-fertilization caused a reduction of soil microbial biomass which might be attributed to fertilizer-induced acidification, unfavourable for microbial growth (Smolander *et al*., 1994).

It has been well-documented that more biologically active soils are characterized by higher microbial biomass leading to enhanced soil enzyme activities and soil respiration (Doran *et al*., 1996). Aparna (2000) reported that application of organic amendments such as vermicompost in combination with lime and fertilizers recorded higher activities of dehydrogenase, urease, phosphatase, protease and cellulase in an alluvial soil than that of FYM or green leaf manure. The increase in dehydrogenase and phosphatase activities with increasing dose of chemical fertilizers as well as organic amendments were reflections of organic matter build up which led to an increase in microbial activities (Pascual *et al.,* 2002).

Goyal *et al*. (2006) worked on soil organic matter level, microbial biomass C and N, mineralizable C and N and dehydrogenase activity in soils from a field experiment under rice-barley rotation receiving inorganic fertilizers and a combination of inorganic fertilizers and organic amendments. The amounts of soil organic matter and mineralizable C and N increased with the application of inorganic fertilizers. Microbial biomass C and N increased significantly with the addition of organic along with inorganic fertilizers (536 mg kg^{-1}) than unfertilized soil (241 mg kg^{-1}). The results indicated that improvement in organic matter, microbial activities and crop yields due to use of inorganic fertilizers along with organic manures could help in sustaining the long-term productivity of the soil. Therefore, soil fertility build up was essential to improve soil organic carbon and enhance crop yield (Stark *et al*., 2007).

Saha *et al.* (2008) found that activity of urease was significantly higher in plots under control followed by NPK + FYM treated plots in a long term fertility experiment. On the other hand, Dinesh *et al.* (2008) worked on the influence of short term incorporation of organic manures and biofertilizers on biochemical and microbial characteristics of soils under an annual crop (turmeric) and concluded that application of organic manures and biofertilizers positively influenced microbial biomass carbon, nitrogen mineralization, soil respiration and enzyme activities. The findings imply that even short term incorporation of organic manures and biofertilizers promoted soil microbial and enzyme activities and these parameters are sensitive enough to detect changes in soil quality.

Xie *et al.* (2009) reported that the application of inorganic fertilizers had fairly less effect on the dehydrogenase activity of soil enzymes than organic fertilizers. Dehydrogenases play a major role in the biological oxidation of SOM by transferring hydrogen from organic substrates to inorganic receptors (Zhang *et al.*, 2010).

As per the findings of Singh *et al.* (2010) microbial population, microbial biomass C and N served as good indices of soil health on the basis of results of long term experiments in a rice-rice cropping sequence. Katkar *et al.* (2011) reported that the biological parameters *viz.*, soil microbial biomass carbon, soil microbial biomass nitrogen and dehydrogenase activities were highest in the plots with application of 100 per cent NPK + FYM compared to 150 per cent NPK through chemical fertilizers without organics. Soil microbial biomass C was found to increase by 24.1 per cent with the integrated use of 100 per cent NPK and FYM than with 100 per cent of NPK fertilizers alone (Bhatt *et al.*, 2015).

Sarma *et al.* (2017) in an incubation study to find the response of enzymes and carbon mineralisation to applied organic amendments like FYM, vermicompost and biochar in acidic sandy loam soil found that vermicompost and FYM application recorded enhanced activities of soil enzymes such as urease, phosphatase and dehydrogenase and C mineralisation rate while biochar application noted higher C half-life and soil pH. Thus addition of biochar in acid soil would be a sustainable option to reduce the C mineralisation and also to maintain nutrient status of sandy loam soils.

2.4. INTEGRATED NUTRIENT MANAGEMENT AND CROP PRODUCTIVITY

Swarup (1998) indicated that integrated application of both chemical fertilizers and organic manures has a promising effect not only for sustaining higher productivity but also in intensive farming systems for providing maximum stability to crop production. Application of 10 t FYM ha^{-1} significantly increased the grain and straw yields of rice and wheat (Singh *et al.*, 1999).

Combined application of chemical nitrogen fertilizer and organic manures like FYM or *Sesbania* resulted in higher rice grain and straw yield compared to the treatment where nitrogen fertilizer as urea alone was applied (Ram and Saha, 1999).

Sharma *et al.* (2000) observed that green manuring along with 40 kg N ha^{-1} in rice produced highest grain and straw yields than application of green manure alone or over dose of 120 kg N ha^{-1}.

The highest plant height, number of tillers per hill, leaf area index and dry matter production was observed in *in situ* incorporation of daincha plots (Hemalatha *et al.*, 2000). Combined application of NPK through inorganic fertilizers + organic manures (FYM or *Sesbania*) produced significantly higher yield in rice and wheat than those supplied under the application of 100 per cent NPK through chemical fertilizers alone. It was found that FYM produced highest grain yield of rice when compared to other organics such as rice straw, green manure and succeeding wheat crop (Singh *et al.*, 2001; Yaduvanshi, 2001).

Mendhe *et al.* (2002) reported that increase in nitrogen levels up to 150 kg N ha^{-1} increased the number of panicles, 1000 grain weight and grain yield. On the other hand, Pramanik *et al.* (2004) documented that plant height and total number of tillers per hill of rice were significantly higher in daincha applied plots.

Manna *et al.* (2005) studied the long term effect of fertilizer and manure application on soil fertility, organic carbon storage and crop yield of some sub humid tropical soils and opined that the application of N alone or with P led to decline in soil biomass carbon and nitrogen, which improved with the addition of N, P, K or NPK+ FYM. In Punjab, Benbi and Chand (2007) reported that increase in SOC pool by 1 Mg C ha^{-1} increased the yield of wheat by 15 to 33 kg ha^{-1}, while Srinivasarao *et al.* (2014) found an increase of 160 kg ha^{-1} for rice and 145 kg ha^{-1} for soy bean. They also found that application of chemical fertilizer increased SOC sequestration rates more in double crop than in single crop regions.

Regular applications of manure on rice, wheat and maize rotation increased the SOC concentration and grain yield in China (Zhang *et al.*, 2009). A pot experiment was set up by Xinjian *et al.* (2009) to investigate the effects of different organic fertilizers on soil microbial biomass and yield of groundnut. The results showed that economic and biological yields of groundnut were improved by applying fertilizers. It was found that certain microbial population increased by application of various organic fertilizers compared with treatments of inorganic fertilizer. Also the application of different organic fertilizers improved microbial biomass though to different degrees. Therefore, it can be concluded that different organic fertilizers affected both soil microbial biomass and diversity trait.

A field experiment was conducted by Babu *et al.*, (2010) during *Rabi* season of 2008-09 on clay loamy soil under long term organic manurial trial at TNAU, Coimbatore, to study the effect of green manure and different sources of organic manures on yield and soil chemical properties of rice. Green manure incorporation along with poultry manure application resulted in higher soil available N, P, K status and increased uptake.

Organic mulches provide better soil water status and improved plant canopy in terms of biomass , root growth , leaf area index and grain yield which subsequently resulted in higher water and N uptake and improved their use efficiencies (Chakraborty *et al*., 2010). Incorporation of green manure *in situ*, vermicompost and poultry manure decreased the soil electrical conductivity, pH and increased the organic carbon content of soil compared to all other combination of treatments (Deshpande and Devasenapathy, 2010).

A field experiment to evaluate soil organic carbon and maize grain yield under different soil amendments and cropping systems was conducted in 2006 and 2007 at the Soil Research Institute, Ghana. It was observed that poultry manure + chemical fertilizer produced the highest range of SOC (1.14-1.37%) and the least (0.98-1.28%) in control plots. Plots amended with chemical fertilizer alone or in combination with poultry manure out yielded the control in maize grain yield (Logah *et al*., 2011).

Adebayo *et al*. (2011) worked on assessment of organic amendments on vegetative development and nutrient uptake of *Moringa oleifera* L. and results indicated that treatments significantly affected ($p < 0.05$) growth parameters, except stem girth. Cow dung application significantly had higher number of leaves and also recorded higher plant height throughout the observation period. Dry matter accumulation was also influenced by organic amendment. Significant higher stem, leaf and root dry weights were recorded under cow dung application.

Yan *et al*. (2011) worked on the role of chemical and organic fertilizers on yield, yield variability in rice and soil carbon sequestration and concluded that use of organic fertilizers increased soil organic matter and soil fertility and consequently resulted in a higher yield trend when compared to balanced chemical fertilizers. Long term use of organic fertilizer also contributed to carbon sequestration by favouring root development.

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2.5. WETLAND RICE SOIL AS CARBON SINK

The rate of soil organic matter decomposition is lessened in submerged rice soils, apparently due to excessively reduced conditions (Jenkinson, 1988).

Kobak *et al.* (1998) estimated C sequestration in wetlands/ peat soils since the post-glaciation period and it was found C accumulated at the rate of 0.1 Pg C yr^{-1} over 10,000–18,000 years. However, drainage of peat lands and their subsequent cultivation made these ecosystems a net source of CO_2. It was estimated that different kinds of wetlands contain 350-535 Gt C, corresponding to 20-25 per cent of world's soil organic carbon (Gorham, 1998). However, long term storage is often limited by rapid decomposition processes and release of C to the atmosphere from paddy fields. Hence, wetlands are dynamic ecosystems where significant quantities of C may also be trapped and stored in sediments.

The rate of SOC sequestration on cropland by adopting improved systems of crop management ranges from 0.02 to 0.76 Mg C ha^{-1} yr^{-1} and 0.25 to 0.5 Mg C ha^{-1} yr^{-1} for rice land management (Lal, 2000; IPCC, 2000). The soil CO_2 efflux generally increased with temperature (Fang and Moncrieff, 2001).

Jarecki and Lal (2003) reported for rice, the potentials of SOC sequestration as 401 kg C ha^{-1} yr^{-1}. Despite the known importance of wetlands in global carbon budgets, the lack of systematic studies and adequate models, and limited information on their carbon turnover rates and temporal dynamics, has probably led to an underestimation of their relevance to global and regional levels, to the point that they were typically omitted from large-scale assessments (Trettin and Jurgensen 2003). The methane efflux from the lateritic soils of Kerala is generally low, to the tune of 1.64 mg m^{-2} hr^{-1} during the first crop season and 3.5 mg m^{-2} hr^{-1} during the second crop season and emission pattern revealed evening peaks (Mathew, 2003).

Kolar *et al.* (2006) reported that high SOM content with a high TOC value in permanently waterlogged soils could be blocked in inert form by the limited mineralization process. On the other hand, the reduction of TOC under critical limit affected soil properties and productivity negatively and hence balanced organic matter turnover is necessary for sustainable ecosystems (Stewart *et al.,* 2008).

Prolonged submerged soil conditions stimulated SOM accumulation and C sequestration in wetland soils and sediments. (Pampolino *et al.,* 2008) studied the land use transitions (between C_3 and C_4 systems) using stable isotopes ^{13}C and found that areas under C_3 had approximately 124 per cent more soil carbon than C_4, while SOC concentrations were 37.3 and 14.8 g Mg C kg^{-1} respectively.

Joseph (2010) found that the methane emission production from rice field under continuous flooding was more (0.19 to 1.92 kg ha^{-1} day^{-1}) than aerobic cultivation (0.12 to 0.27 kg ha^{-1} day^{-1}).

2.6. NUTRIENT MANAGEMENT AND GHG EMISSION

The management practices adopted in rice farming are keyfactors for the greenhouse gas emission. Shalini *et al.* (1997) reported that the physiology of rice plants regulated methane emission by making available sources of methanogenic substrates through carbon in the roots, including exudates, and also by transporting CH_4 through aerenchyma. Several studies have confirmed variations in the emission levels of different rice cultivars (Ghosh *et al*., 1995; Dong *et al*., 2013).

Use of fertilizer has gained importance in increasing crop production but the negative aspect is the aggravation of methane emission. Govaerts *et al.* (2006) reported that increased percentage of easily decomposable organic matter in soil could lead to higher evolution of CO_2. Application of biochar could significantly reduce greenhouse gases emission from flooded rice soils (Haefele, 2007). The aromatic nature and presence of highly stable C in biochar provided resistance to microbial mineralisation thereby reducing the CO_2 emission from soil (Novak *et al*., 2010; Lehmann *et al*., 2011).

Methane and nitrous oxide emission are impacted directly by water management and fertilizer application respectively.The mineralisation rate of SOM and CO_2 emission varied according to the nature and composition of the organic amendments, rate of application and soil type (Luo *et al.*, 2011; Case *et al.*, 2012).

Khosa *et al.*, (2012) studied the effects of organic materials on methane emission from straw, farmyard manure, green manure, and rice-straw amended plots over two farming seasons. The emission was higher from all plots except rice-straw compost amended plots. This might be due to the effect of carbon (C): Nitrogen (N) ratio of the material.

Sampanpanish (2012) assessed the impact of organic and inorganic fertilizers on the emission levels of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) and found that emission from chemical fertilizers were higher when compared with organic fertilizers. Linguist *et al.* (2012) found that CH_4 emission from farmyard manure increased by 26 per cent when compared with urea applied at the same rate. Green manure (*Sesbania*) also increased CH_4 emission by as much as 192 per cent and many research works showed that different green manure species varied in CH_4 emission. The study also showed lesser doses of inorganic fertilizers (upto 75 kg N ha^{-1}) increased CH_4 emission while higher application rates (249 kg N ha^{-1}) decreased emission. Nungkat and Kusuma (2015) agreed with the above results and in their study to determine the effects of the use of organic manures on methane emission from rice fields in Indonesia, they found no correlation between the use of organic fertilizers and methane emission.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study entitled "Carbon sequestration and soil health under different organic sources on soil health" was carried out in rice crop for two continuous seasons in 2015-16 in Thrissur district of Kerala. The study was carried out in three phases as given below:

1. Effect of combined organic and inorganic sources on carbon stock and soil health
2. Evaluation of greenhouse gas flux from cultivated and fallow wetlands
3. Soil profile characterisation of cultivated and fallow wetland

3.1. EFFECT OF COMBINED ORGANIC AND INORGANIC SOURCES ON CARBON STOCK AND SOIL HEALTH

3.1.1. General experimental conditions

3.1.1.1. *Location*

The experiment was conducted at farmer's field in Varadium of Thrissur district during 2015-16. The field is located at 10°31'49" N latitude and 76°12'53" E longitude and at an altitude of 10 m above MSL. The soil of the experimental site was sandy clay loam in lateritic lowland region.

3.1.1.2. *Climate*

The annual rainfall in this area is normally around 3000 mm, 70 to 75 per cent of which is received from the South West Monsoon, coinciding with the first crop season (Virippu) of June- September; 15 to 30 per cent from the North East Monsoon during the second crop season (Mundakan) from October to January and the rest during summer months. In the experimental season in 2015- 2016, the temperature ranged from a maximum of 35.5°C during April –May 2015 to a minimum of 19.9 °C during December – January 2016. The relative humidity varied from a minimum of 75 to 80 per cent during the summer months to around 97 per cent during July-

August. Highest total evaporation of 159.40 mm was recorded during January, while the lowest during June (77.00 mm).

3.1.1.3. *Cropping history*

The cropping sequence of the experimental field during the preceding years was rice- rice - fallow. Generally the first crop is taken as direct seeded crop followed by a transplanted one.

3.1.2. Experimental methods

3.1.2.1. *Design*

The experiment was taken up during Virippu (Kharif) season of 2015-16 and continued thereof in the Mundakan (Rabi) season using five organic sources in combination with an inorganic nitrogen source destined to yield nitrogen at four different levels. The organic sources were farmyard manure (FYM), *Artocarpus* sp. (ART) leaves, daincha (DNC), rice husk biochar (RHB) and no organic manure (NOM). The inorganic nitrogen source, urea was applied at different levels viz., 0, 35, 70 and 105 kg N ha^{-1} represented as N_0, N_1, N_2 and N_3 respectively. The design used was factorial RBD with twenty treatments and three replications. The treatment details are as follows (Table 1).

3.1.2.2. *Variety*

Jyothi, a short duration variety of 105- 110 days duration, tolerant to brown plant hopper and rice blast was used for the study.

3.1.2.3. *Layout of experimental field*

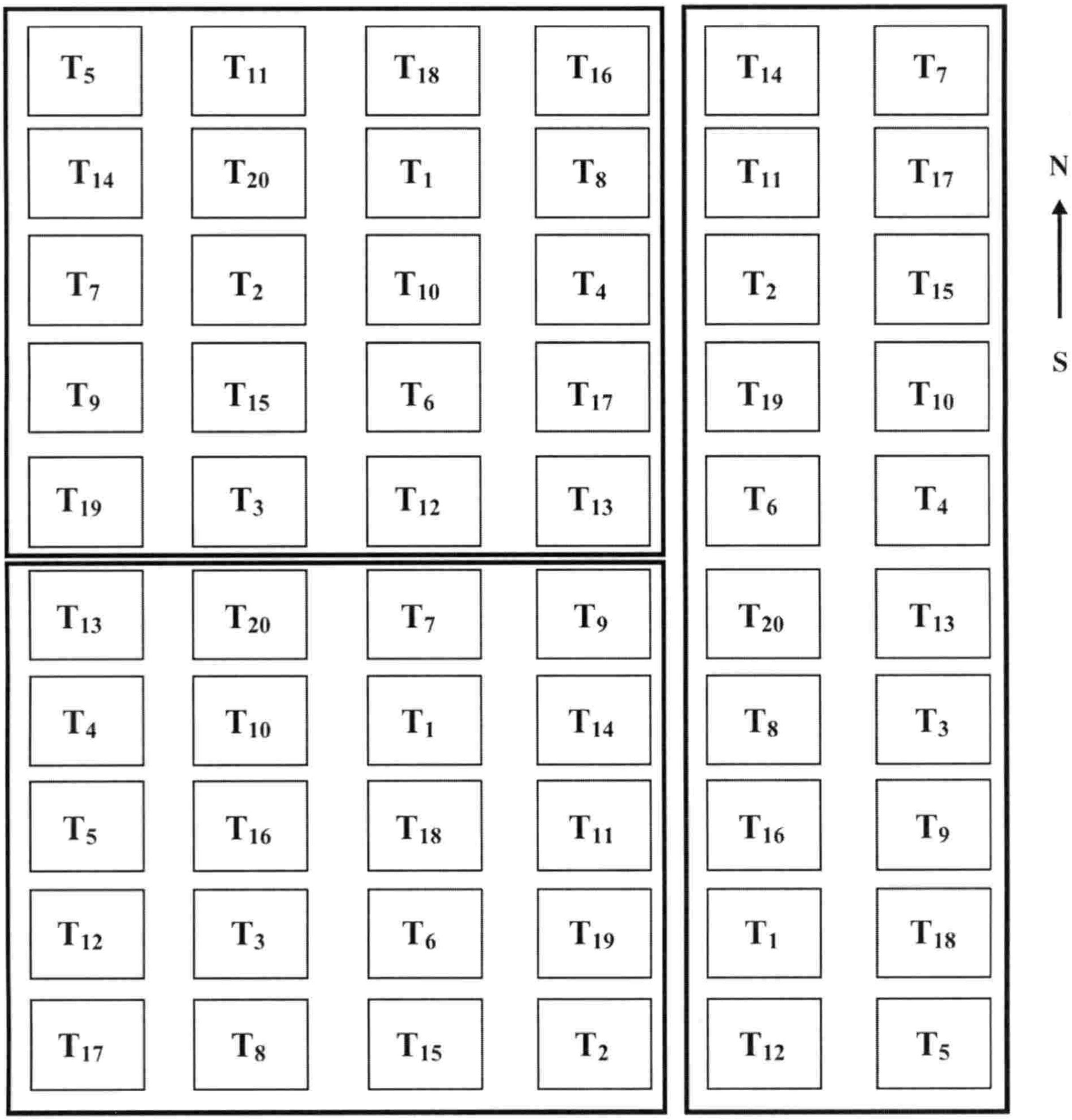
The lay out of the field was done as shown in Fig.2.

3.1.2.4. *Land preparation*

The experimental area was ploughed well and plots of 5m x 4m were prepared by constructing bunds of 30 cm width. Irrigation channels (20cm width) were provided between each plot (Plate 1). Representative samples of soil and organic sources such as FYM,

Table 1. Treatment combinations

Sl.No.	Treatments	Details of treatments
1	T_1	No organic manure + 0 kg N ha^{-1}
2	T_2	No organic manure + 35 kg N ha^{-1}
3	T_3	No organic manure + 70 kg N ha^{-1}
4	T_4	No organic manure + 105 kg N ha^{-1}
5	T_5	Farmyard manure @ 5t ha^{-1} + 0 kg N ha^{-1}
6	T_6	Farmyard manure @ 5t ha^{-1} + 35 kg N ha^{-1}
7	T_7	Farmyard manure @ 5t ha^{-1} + 70 kg N ha^{-1}
8	T_8	Farmyard manure @ 5t ha^{-1} + 105 kg N ha^{-1}
9	T_9	*Artocarpus* sp. @ 5t ha^{-1} + 0 kg N ha^{-1}
10	T_{10}	*Artocarpus* sp. @ 5t ha^{-1}+ 35 kg N ha^{-1}
11	T_{11}	*Artocarpus* sp. @ 5t ha^{-1} + 70 kg N ha^{-1}
12	T_{12}	*Artocarpus* sp. @ 5t ha^{-1} + 105 kg N ha^{-1}
13	T_{13}	Daincha @ 5t ha^{-1} + 0 kg N ha^{-1}
14	T_{14}	Daincha @ 5t ha^{-1}+ 35 kg N ha^{-1}
15	T_{15}	Daincha @ 5t ha^{-1} + 70 kg N ha^{-1}
16	T_{16}	Daincha @ 5t ha^{-1}+ 105 kg N ha^{-1}
17	T_{17}	Rice husk biochar @ 5t ha^{-1} + 0 kg N ha^{-1}
18	T_{18}	Rice husk biochar @ 5t ha^{-1}+ 35 kg N ha^{-1}
19	T_{19}	Rice husk biochar @ 5t ha^{-1} + 70 kg N ha^{-1}
20	T_{20}	Rice husk biochar @ 5t ha^{-1} + 105 kg N ha^{-1}



T_5	T_{11}	T_{18}	T_{16}
T_{14}	T_{20}	T_1	T_8
T_7	T_2	T_{10}	T_4
T_9	T_{15}	T_6	T_{17}
T_{19}	T_3	T_{12}	T_{13}

T_{13}	T_{20}	T_7	T_9
T_4	T_{10}	T_1	T_{14}
T_5	T_{16}	T_{18}	T_{11}
T_{12}	T_3	T_6	T_{19}
T_{17}	T_8	T_{15}	T_2

T_{14}	T_7
T_{11}	T_{17}
T_2	T_{15}
T_{19}	T_{10}
T_6	T_4
T_{20}	T_{13}
T_8	T_3
T_{16}	T_9
T_1	T_{18}
T_{12}	T_5

Fig. 2. Layout of experimental field

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Artocarpus, daincha and RHB were collected and tested for nutrient content (Tables 2 and 3). The organic amendments were applied @ 5t ha^{-1} at the time of land preparation and they were incorporated into the plots 15 days prior to transplanting.

3.1.2.5. *Cultivation practices*

Phosphorus and potassium were applied as per the POP recommendations (KAU, 2011). The full quantity of phosphorus, half the quantity of nitrogen and half the quantity of potassium were applied in the field as basal dressing. Eighteen days old rice seedlings were transplanted in the field at a spacing of 15 cm x 10 cm @ 2-3 seedlings per hill (Plate 2, Appendix 1). The remaining quantity of nitrogen and potassium were applied as top dressing one week prior to panicle initiation (Plates 3 and 4). After harvest of the crop, the observations were recorded.

3.1.3. Observations recorded

3.1.3.1. *Biometric observations*

Observations on biometric characters like plant height at panicle initiation stage and at harvest, leaf area index (LAI) at panicle initiation stage and root biomass were recorded. Yield contributing characters *viz*., number of productive tillers, percentage of filled grains per panicle, thousand grain weight were also noted. Grain and straw yield of rice and harvest index were calculated.

3.1.3.2. *Analysis of soil and plant samples*

The soil samples of surface and sub-surface depths *viz*., 0-15 and 15-30 cm and plant samples were analysed after harvest of the crop to asess the impact of different treatments.

3.1.3.2.1. *Soil analysis*

Soil samples (Plate 5) drawn from each plot from the two depths were dried under shade, sieved and analysed for pH, EC, OC and available nutrients N, P, K, Ca, Mg, S and micronutrients Fe, Mn, Zn, Cu and B as per the procedure (Table 4). The biological analyses were done in the freshly collected samples.

Table 2. Physico- chemical properties soils of experimental site

Sl.No	Property	Surface	Sub-surface
		0-15 cm	15-30 cm
1	pH	4.66	4.68
2	EC (dS m^{-1})	0.058	0.044
3	CEC (cmol (p+) kg^{-1})	6.02	6.00
4	Bulk density (Mg m^{-3})	1.36	1.38
5	WHC (%)	48.47	48.03
6	OC (%)	1.05	1.00
7	Available N (kg ha^{-1})	401.76	360.43
8	Available P (kg ha^{-1})	18.46	17.74
9	Available K (kg ha^{-1})	87.34	84.14
10	Available Ca (mg kg^{-1})	300.42	268.36
11	Available Mg (mg kg^{-1})	31.25	26.56
12	Available S (mg kg^{-1})	5.89	5.04
13	Available Fe (mg kg^{-1})	235.73	213.45
14	Available Mn (mg kg^{-1})	5.43	4.36
15	Available Zn (mg kg^{-1})	2.84	2.44
16	Available Cu (mg kg^{-1})	6.87	6.39
17	Available B (mg kg^{-1})	0.27	0.23
18	MBC (mg kg^{-1})	153.30	131.27
19	Phosphatase (µg PNP $h^{-1}g^{-1}$)	59.17	51.23
20	Dehydrogenase (µg TPF day^{-1} kg^{-1})	60.34	54.05
21	Texture	Sandy clay loam	

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Table 3. Physico- chemical properties of organic sources

Sl.No.	Property	Farmyard manure	Rice husk biochar	Daincha	*Artocarpus*
1	pH	7.50	9.10	5.80	4.35
2	EC (dS m^{-1})	0.31	0.26	0.45	0.14
3	OC (%)	22.32	43.7	9.17	20.36
4	Total N (%)	1.73	0.64	3.40	2.60
5	Total P (%)	0.33	0.16	0.38	2.10
6	Total K (%)	0.73	0.56	3.20	0.93
7	C:N ratio	12.90	68.28	2.70	7.83
8	Total Ca (mg kg^{-1})	25.60	39.06	27.40	34.00
9	Total Mg (mg kg^{-1})	15.80	1.17	26.62	37.00
10	Total S (mg kg^{-1})	5.00	4.93	2.55	4.90
11	Total Fe (mg kg^{-1})	352.50	21.76	200.00	0.60
12	Total Mn (mg kg^{-1})	200.90	23.82	440.00	0.19
13	Total Cu (mg kg^{-1})	24.30	11.37	5.00	24.99
14	Total Zn (mg kg^{-1})	36.30	37.91	40.00	42.00
15	Total B (mg kg^{-1})	20.00	12.17	19.34	4.70
16	WHC (%)	38.15	233.52	45.34	4.10

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Plate1. Field preparation

Plate 2. View of transplanted paddy field

Plate 3. Rice crop at tillering stage

Plate 4. Rice crop at harvest stage

Fractions of organic matter

a. Size fractions

Physical fractions such as coarse and fine particulate organic matter were estimated as per the method described by Cambardella and Elliott (1992). In this method, soil was dispersed using sodium hexametaphosphate and then passed through a set of sieves to obtain the fractions.

b. Density fractions

The density fractions of organic matter were isolated in accordance with the method described by Janzen *et al.* (1992) and Hassink (1995). Here the soil was shaken with a solution of sodium iodide of specific gravity 1.72 and the material was filtered through sieves after equilibrating at room temperature. The floating material was aspirated and separated by suction. The process was repeated to obtain all the fractions.

The soil organic carbon (SOC) stock was calculated from the organic carbon content and bulk density of soil at 30 cm depth and expressed in Mg ha^{-1}.

SOC (Mg C ha^{-1}) = BD (kg m^{-3}) x OC (%) x depth (m)

Table 4. Standard procedures followed for the soil analysis

Sl.No.	Characteristics	Method		Reference
		Extraction	Estimation	
1	Bulk density	Keen- Raczkowski brass cup method		Piper, 1942
2	Water holding capacity			
3	pH	1:2.5 soil water suspension	Potentiometry	Jackson, 1958
4	EC		Conductometry	
5	Texture	International pipette method	Sedimentation	Piper, 1942
6	Organic carbon	Wet digestion		Walkley and Black, 1934
7	Available N	Alkaline permanganometry		Subbiah and Asija, 1956
8	Available P	Bray No. 1	Colorimetry	Bray and Kurtz,1945
9	Available K	1 N NH_4OAc	Flame photometry	Jackson, 1958
10	Available Ca		ICP OES (Model: Optima 8x00 series) Jackson, 1958	
11	Available Mg			
12	Available S	Turbidimetric method	Chesnin and Yien, 1951	
13	Micronutrients (Available Fe, Mn, Zn, Cu)	0.1 HCl	ICP OES (Model Optima 8x00 series)	Sims and Johnson, 1991
	Available B	Hot water	Colorimetry	Berger and Troug, 1939; Gupta,1979
14	Total C	CHNS analyser (Model: Elementar's vario EL cube)		
15	Total N			
16	Microbial biomass carbon	Chloroform fumigation	Wet oxidation	Jenkinson and Powlson , 1976
17	Phosphatase activity	*P*-nitrophenol phosphate	Colorimetry	Tabatabai and Bremner, 1969
18	Dehydrogenase activity	TTC	TPF	Casida *et al*. (1964)

3.1.3.2.2. *Analysis of plant samples*

Samples of straw, grain and root of rice plant were collected from each plot, dried and powdered and analysed for the nutrient contents as per standard procedures (Table 5).

Table 5. Standard procedures followed for plant analysis

Sl. No.	Element	Method		Reference
		Extraction	Estimation	
1	Total N	Modified kjeldahls digestion	Kelplus distillation	Jackson, 1958
2	Total P	Diacid digestion	Vanado molybdophosphoric yellow colour method	Piper, 1966
3	Total K		Flame photometry	
4	Total Ca		ICP OES (Model Optima 8x00 series)	
	Total Mg			
5	Total S		Spectrophotometer	
6	Total micronutrients (Fe, Mn, Zn, Cu)	Diacid digestion	ICP OES (Model Optima 8x00 series)	Hart, 1961
	Total B	Dry ashing	Spectrophotometer	Gaines and Mitchell, 1979; Bingham, 1982

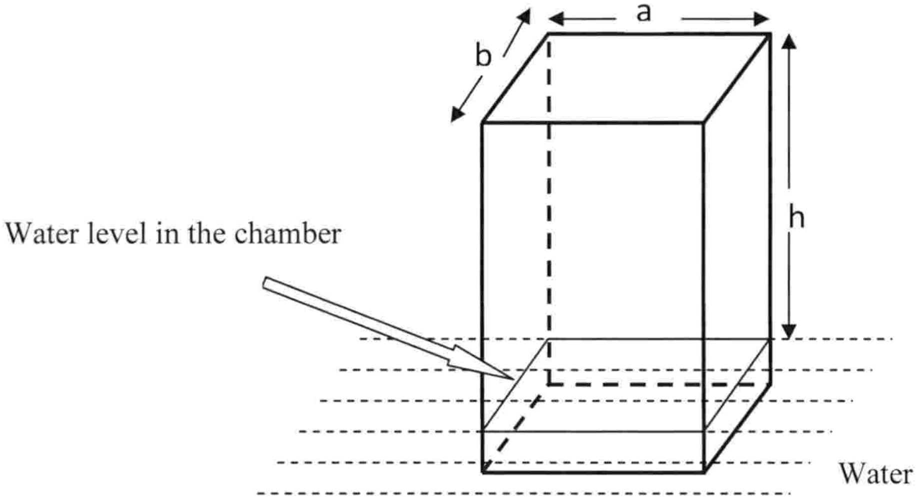
3.2. EVALUATION OF GREENHOUSE GAS FLUX FROM CULTIVATED AND FALLOW WETLANDS

3.2.1. Measurement of soil CO_2 flux, soil temperature and moisture

The soil CO_2 fluxes were measured from bare plot (5m x 4m) established at the site for the crop growth period and from cultivated plots using the closed chamber method (Hutchinson and Mosier, 1981).

Here, iron channel bases were fixed permanently well in advance of sampling at the measurement sites. The bases were mounted with a U-shaped channel to hold water. An acryllic box (30 cm x 40 cm x 95 cm) with one end open and the other end equipped with a sampling port fitted with a rubber septum was placed over the iron base. The open end of the acryllic box rested in the channel. The water in the channel acted as a seal making the system airtight. Six hills per chamber were measured at booting stage of the crop (Plates 6 and 7).

At the start of the sampling (time, t = 0), air sample from the box was drawn into a 20 ml plastic syringe fitted with a three way stop-cock and closed. A second sample was collected in the same manner after a time interval of 20 minutes (time, t = 20 min). Sampling was done between 11 AM to 1 PM. The samples were brought to the laboratory and carbon di oxide and methane concentration were determined by gas chromatography on a Flame Ionization Detector (FID).



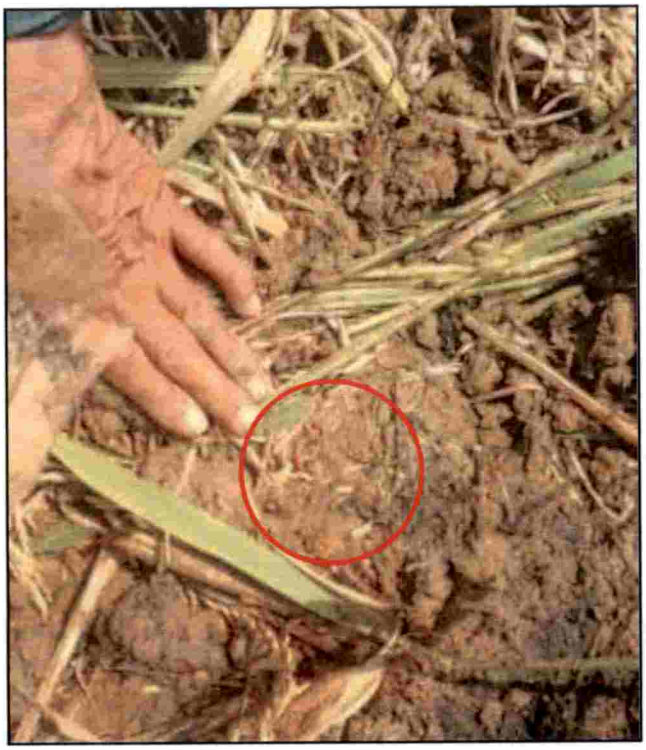


Plate 5. Biochar treated plot with earthworms

Plate 6. Box chamber with hills placed in the field for GHG collection

Side ‘a’ of chamber = a

Side ‘b’ of chamber = b

Height above water level in the chamber = h

Aperture (mouth) area of chamber = $a \times b = A\ m^2$

Volume of chamber = $a \times b \times h = A \times h = V\ m^3$

Collection duration = T hours

Density of GHG = D

Initial concentration of GHG in chamber = C_1 ppmV

Final concentration of GHG in chamber = C_2 ppmV

Increase in concentration of GHG in chamber= $[C_2 - C_1]$ ppmV

Volume of GHG collected during T hrs = $[C_2 - C_1] \times V\ m^3$

Mass of GHG collected during T hrs = $[C_2 - C_1] \times V \times D$ kg

Mass of GHG collected per unit area per hour = $[C_2 - C_1] \times V \times D \times A^{-1} \times T^{-1}\ kgm^{-2}$

GHG Efflux = $[C_2 - C_1] \times V \times D \times A^{-1} \times T^{-1} \times 10^6\ mg\ m^{-2}\ hr^{-1}$

The soil temperature and soil moisture were recorded next to each chamber using digital thermometer and soil moisture meter respectively at the time of gas flux. *Insitu* measurement of oxidation-reduction potential at the time of gas sampling was also noted.

3.2.1.1. *Collection of gas samples*

Gas samples for the emission studies were collected at three stages of the crop *viz*., active tillering, panicle initiation and near harvest from the cultivated and fallow wetland plots in Mundakan season (Plate 8). Out of the total number of 20 treatments, 15 treatments in integrated nutrient management involving fertilizer nitrogen application were selected for the evaluation of green house gas flux. The emission of gases from the fields with N fertilizer were compared with the emission from the fallow wetlands.

Plate 7. Experimental field view during GHG collection

Plate 8. Collection of GHG using syringe

3.2.1.2. *Analysis of carbon di oxide (CO_2) and methane (CH_4) efflux*

Gas chromatographic facilities at Centre for Earth Science Studies (CESS), Aakkulam, Thiruvananthapuram (Plate 9) were used for the measurement of greenhouse gas concentrations in the samples.

3.3. SOIL CHARACTERISATION OF CULTIVATED AND FALLOW WETLANDS

Soil profiles were taken in the cultivated (Plate 10) and fallow wet lands and differentiated into horizons. The soil samples were collected from each horizon and they were analysed for the physico-chemical characteristics similar to soil samples.

3.4. STATISTICAL ANALYSIS

Analysis of variance (ANOVA) was done using OP-STAT and WASP to test the level of significant difference between treatment means (Sheoran *et al*., 1998).

Plate 9. Analysis of GHG using GLC

Plate 10. View of soil profile in biochar treated plot

RESULTS

4. RESULTS

The study entitled "Carbon sequestration and soil health under different organic sources in wetland rice" to unravel the significance of carbon sequestration leading to a healthy soil profile when the crop - wetland rice, amended using organic sources along with inorganic fertilizers was carried out in farmers field. The results of the experiments are presented in this chapter.

4.1. EFFECT OF COMBINED ORGANIC AND INORGANIC SOURCES ON CARBON STOCK AND SOIL HEALTH

4.1.1. Effect of organic sources on inherent soil characteristics

4.1.1.1. *Soil physical characteristics*

Bulk density (BD)

The impact of organic amendments on bulk density of surface soil is given in Table 6a. The seasonal effect was significant on surface soil bulk density. Among orgnic sources, RHB had the maximum effect in reducing the BD. The treatment with ART at N_0 nitrogen level was on par with it. In virippu, bulk density was significantly minimum with a value of 1.10 Mg m^{-3} for the treatment RHB without N. The treatments ART without N and RHB with 35 kg N ha^{-1} showed same value of 1.12 Mg m^{-3} while it was the highest in the treatment where 105 kg N ha^{-1} alone was applied (1.38 Mg m^{-3}). In mundakan season also, RHB without N / with 35 kg N ha^{-1} recorded the lowest value of 1.06 Mg m^{-3}.

The sub-surface soil BD was higher than in the surface soil. The seasonal effect was significant and bulk density was minimum for the treatment ART with no added nitrogen in sub-surface soil in virippu and mundakan seasons (Table 6b) with values of 1.14 Mg m^{-3} and 1.12 Mg m^{-3} respectively.

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Table 6a. Effect of different organic sources on bulk density of surface soil

Treatments	Bulk density (Mg m^{-3})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	1.33	1.25	1.12	1.23	1.10	1.34	1.22	1.12	1.15	1.06
N_1	1.35	1.27	1.16	1.26	1.12	1.37	1.26	1.14	1.18	1.06
N_2	1.36	1.29	1.17	1.28	1.14	1.37	1.28	1.12	1.19	1.08
N_3	1.38	1.30	1.19	1.29	1.15	1.39	1.29	1.15	1.20	1.08

CD (0.05) - A- 0.003; B- 0.005; C- 0.005; A x B – 0.007 ; A x C - 0.006; BxC – 0.010 A x B x C – 0.014

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 6b. Effect of different organic sources on bulk density of sub-surface soil

Treatments	Bulk density (Mg m^{-3})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	1.35	1.27	1.14	1.25	1.18	1.35	1.26	1.12	1.20	1.15
N_1	1.37	1.28	1.18	1.27	1.19	1.37	1.26	1.15	1.22	1.16
N_2	1.38	1.31	1.18	1.30	1.22	1.39	1.28	1.16	1.23	1.18
N_3	1.39	1.31	1.20	1.30	1.24	1.39	1.29	1.18	1.25	1.21

CD(0.05) - A - 0.005; B - 0.009 ; C - 0.008; A x B – 0.012; A xC – NS; B x C – NS ; A x B x C – NS

A- Cropping season ; B- Organic source ; C- Nitrogen level

Water holding capacity (WHC)

The results (Table 7a) revealed that significant seasonal effect was exhibited on WHC. The maximum WHC of surface soil during virippu season (51.54 %) was attained in the treatment RHB with no added inorganic nitrogen. The same organic source with higher dose of nitrogen also received value more than 50.00 per cent. The results showed the same trend during mundakan season also, with the highest value of 51.66 per cent in the RHB treatment.

The seasonal effect was smilar to that of surface soil. The significant maximum WHC of sub-surface soil was obtained for the treatment daincha without nitrogen with values 49.05 per cent and 49.66 per cent in virippu and mundakan seasons respectively (Table 7b).

4.1.1.2. *Soil chemical characteristics*

pH

The data on pH of surface soil is presented in Table 8a. There was no significant seasonal effect. Maximum pH of 5.10 was observed in virippu season in the treatment RHB without N source and was significant over other treatments. During mundakan season also, the highest and significant pH value of 5.28 was recorded for the same treatment. In both seasons, the treatment with 105 kg nitrogen source showed minimum pH of 4.58.

The sub-surface soil pH (Table 8b) was significantly higher during mundakan season. It was maximum in the treatment with RHB alone in both virippu and mundakan seasons with values of 5.14 and 5.32 respectively.

Electrical conductivity (EC)

It is inferred from data (Table 9a) that neither the seasons nor the organic sources and nitrogen levels individually had significant effect on EC. The highest significant EC value of 0.164 dS m^{-1} of surface soil was obtained for the treatment daincha with 105 kg N ha^{-1} during virippu season. The minimum value was found to be significant with values of 0.092 dS m^{-1} and 0.036 dS m^{-1} in virippu and mundakan

Table 7a. Effect of different organic sources on water holding capacity of surface soil

Treatments	Water holding capacity (%)									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	45.65	48.47	47.51	49.54	51.54	46.03	49.77	48.23	50.30	51.66
N_1	45.49	48.40	47.44	49.44	50.44	45.76	50.05	47.78	49.53	51.23
N_2	45.39	47.47	47.31	47.51	50.43	45.36	49.33	48.20	48.11	51.14
N_3	44.76	47.43	46.60	46.40	50.26	45.07	49.54	47.46	48.65	50.94
CD(0.05) - A - 0.223 ; B - 0.352 ; C- 0.315 ; A x B – 0.498 ; A x C – NS ; B x C - 0.705 ; A x B x C - NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 7b. Effect of different organic sources on water holding capacity of sub-surface soil

Treatments	Water holding capacity (%)									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART.	DNC	RHB
N_0	44.45	47.03	47.08	49.05	47.45	45.23	47.34	46.24	49.66	48.23
N_1	44.35	47.52	45.41	47.45	47.11	45.00	47.20	45.66	48.81	47.34
N_2	44.56	46.83	45.30	47.73	45.88	45.10	46.34	45.02	47.55	47.05
N_3	43.37	46.54	45.07	45.48	45.34	44.12	45.78	44.86	47.28	46.25
CD (0.05) - A - 0.118 ; B - 0.187 ; C- 0.167 ; A x B – 0.264 ; A x C- NS ; B x C - 0.373 ; A x B x C - 0.528										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 8a. Effect of different organic sources on pH of surface soil

Treatments	pH									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	4.64	4.67	4.65	4.78	5.10	4.60	4.65	4.64	4.76	5.28
N_1	4.63	4.65	4.64	4.75	5.02	4.60	4.63	4.63	4.73	5.15
N_2	4.58	4.64	4.63	4.76	4.98	4.59	4.62	4.61	4.70	5.01
N_3	4.58	4.62	4.61	4.75	4.96	4.58	4.62	4.61	4.70	5.00

CD (0.05) - A - NS ; B - 0.006 ; C - 0.005 ; A x B - 0.008 ; A x C - 0.007 ; B x C – 0.012 ; A x B x C – 0.016

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 8b. Effect of different organic sources on pH of sub-surface soil

Treatments	pH									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	4.66	4.69	4.66	4.79	5.14	4.62	4.68	4.66	4.76	5.32
N_1	4.65	4.66	4.66	4.78	5.05	4.62	4.65	4.65	4.75	5.18
N_2	4.63	4.65	4.64	4.76	5.00	4.61	4.65	4.63	4.75	5.03
N_3	4.62	4.63	4.65	4.76	5.00	4.60	4.64	4.63	4.72	5.03

CD(0.05) - A - 0.003 ; B - 0.005 ; C - 0.005 ; A x B – 0.008 ; A x C - 0.007 ; B x C – 0.011 ; A x B x C – 0.015

A- Cropping season ; B- Organic source ; C- Nitrogen level

seasons respectively in RHB treatment without nitrogen. In general, there was a decrease in EC values in the second season.

The seasonal effect was nil in the sub- surface soil and even the conductivity was lesser in the sub-surface soil. The treatments, ART and / no organic manure showed lesser EC and it was on par with FYM. The N_0 nitrogen level had significant low EC value. Minimum EC value (Table 9b) for sub-surface soil was obtained for the treatment with RHB without N source in virippu season (0.044 dS m^{-1}). The treatment, ART without N also showed an on par EC value of 0.085 dS m^{-1}. But during mundakan season, the value was minimum in the treatment ART without N (0.015 dS m^{-1}).

Cation exchange capacity (CEC)

The CEC was found to be significantly higher in mundakan season (Table 10a) than in virippu season. The surface soil showed higher CEC values compared to the sub-surface soil. The significantly higher CEC value of surface soil (6.58 cmol (p+) kg^{-1}) in virippu season was obtained in daincha with 35 kg N ha^{-1}. The treatments, FYM along with 35/70 kg N ha^{-1} and daincha with 105 kg N ha^{-1} were on par with each other. During mundakan season, FYM with 70 kg N ha^{-1} showed the maximum significant CEC value of 6.66 cmol (p+) kg^{-1}. Treatments with daincha supplemented with 35 and 70 kg N ha^{-1} showed values of 6.59 and 6.58 cmol (p+) kg^{-1} which were on par with the highest.

The seasonal effect was found to be similar to that of surface soil. The maximum CEC value for sub-surface soil of 6.35 cmol (p+) kg^{-1} was obtained in daincha with 70 kg N ha^{-1} (Table 10b) followed by the same organic source supplemented with higher dose and FYM with 35 kg N ha^{-1} (6.33 cmol (p+) kg^{-1}). FYM with higher doses and RHB with 35 kg N ha^{-1} also showed an on par value. In mundakan season, the maximum CEC was found in the plot treated with daincha with 70 kg N ha^{-1} (6.45 cmol (p+) kg^{-1}). The treatment with same organic source and 35 kg N ha^{-1} also showed an on par value of 6.43 cmol (p+) kg^{-1}.

Table 9a. Effect of different organic sources on electrical conductivity of surface soil

Treatments	Electrical conductivity (dS m^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	0.095	0.108	0.138	0.144	0.092	0.042	0.055	0.038	0.045	0.036
N_1	0.124	0.125	0.139	0.151	0.109	0.045	0.055	0.043	0.063	0.045
N_2	0.125	0.137	0.143	0.153	0.119	0.056	0.055	0.046	0.117	0.086
N_3	0.134	0.141	0.149	0.164	0.128	0.058	0.064	0.048	0.145	0.144

CD(0.05) - A – 0.001 ; B- 0.001 ; C- 0.001 ; A x B – 0.001; A x C - 0.001; B x C – 0.001 ; A x B x C – 0.001

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 9b. Effect of different organic sources on electrical conductivity of sub-surface soil

Treatments	Electrical conductivity (dS m^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	0.094	0.094	0.085	0.104	0.044	0.041	0.046	0.015	0.055	0.025
N_1	0.097	0.117	0.094	0.124	0.108	0.045	0.048	0.018	0.059	0.041
N_2	0.108	0.122	0.138	0.127	0.113	0.046	0.053	0.025	0.069	0.045
N_3	0.109	0.137	0.139	0.135	0.125	0.046	0.065	0.073	0.070	0.048

CD (0.05) - A – NS ; B - 0.017 ; C -0.015 ; A x B – 0.024 ; A x C - NS ; B x C – 0.034 ; A x B x C – 0.048

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 10a. Effect of different organic sources on cation exchange capacity of surface soil

Treatments	Cation exchange capacity (cmol (p+) kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	6.16	6.25	6.27	6.29	6.33	6.24	6.52	6.30	6.35	6.37
N_1	6.25	6.47	6.31	6.58	6.38	6.27	6.54	6.45	6.59	6.41
N_2	6.37	6.44	6.34	6.38	6.39	6.36	6.66	6.41	6.58	6.39
N_3	6.40	6.39	6.33	6.44	6.38	6.42	6.51	6.37	6.48	6.38

CD(0.05) - A - 0.012 ; B - 0.019 ; C - 0.017 ; A x B – 0.027 ; A x C - 0.024 ; B x C – 0.039; A x B x C – 0.055

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 10b. Effect of different organic sources on cation exchange capacity of sub-surface soil

Treatments	Cation exchange capacity (cmol (p+) kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	6.01	6.20	6.13	6.20	6.24	6.19	6.36	6.19	6.31	6.36
N_1	6.13	6.33	6.22	6.23	6.32	6.22	6.41	6.31	6.43	6.36
N_2	6.25	6.32	6.26	6.35	6.28	6.29	6.41	6.36	6.45	6.33
N_3	6.24	6.31	6.25	6.33	6.21	6.32	6.41	6.30	6.36	6.34

CD (0.05) - A – 0.008 ; B - 0.012 ; C - 0.011 ; A x B – 0.017 ; A x C - 0.015 ; B x C – 0.024 ; A x B x C – 0.034

A- Cropping season ; B- Organic source ; C- Nitrogen level

Organic carbon (OC)

A significant higher seasonal effect was noticed in the virippu season. During virippu season, application of RHB alone recorded the highest OC value of 1.67 per cent for surface soil which was also significant followed by the same organic source with 35 kg N ha^{-1} (1.58 %) (Table 11a). Farm yard manure with 35/70 kg N ha^{-1} recorded the same value of 1.38 per cent. The control treatment at level N_0, showed minimum value of 1.13 per cent. In mundakan season also, RHB applied alone recorded maximum value of 2.05 per cent. The OC values showed a decreasing trend in the second season under different organic sources except RHB where higher values were obtained in the lowest levels of inorganic N (N_0 and N_1).

In the sub-surface soil, the OC values were lower than that of surface soil and during virippu season, the maximum significant OC value of 1.33 per cent (Table 11b) was obtained for the treatment FYM with 35 kg N ha^{-1}. But in mundakan season, the maximum value of 1.08 per cent was recorded for the treatments, ART with 35 kg N ha^{-1} and daincha with 35 kg N ha^{-1}. Rice husk biochar with no added N also showed an on par value of 1.07 per cent.

Available nitrogen

The data on available nitrogen of surface soil is presented in Table 12a. The values were significantly higher in mundakan season. The treatment with daincha and 105 kg N ha^{-1} recorded significant maximum value of 521.78 kg ha^{-1}. A non significant and low value of 513.14 kg ha^{-1} was obtained in the treatment with same organic source and recommended dose of N as per KAU package of practices. The treatments FYM with 70 kg N ha^{-1} and daincha with 35 kg N ha^{-1} recorded 502.95 kg ha^{-1} and 502.46 kg ha^{-1} and they were on par. In mundakan season, available nitrogen was maximum in daincha with 105 kg N ha^{-1} with a value of 596.38 kg ha^{-1}. The treatment daincha with 70 kg N ha^{-1} (595.71 kg ha^{-1}) was on par with the maximum value.

Table 11a. Effect of different organic sources on organic carbon content of surface soil

Treatments	Organic carbon (%)									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	1.13	1.34	1.27	1.23	1.67	0.94	1.15	0.91	1.03	2.05
N_1	1.17	1.38	1.28	1.26	1.58	0.64	1.16	1.20	1.06	1.94
N_2	1.19	1.38	1.26	1.35	1.30	0.94	1.14	1.01	1.14	1.23
N_3	1.14	1.13	1.24	1.28	1.27	0.82	1.11	1.01	1.12	1.05

CD(0.05) - A - 0.012 ; B - 0.010 ; C -0.009 ; A x B – 0.014 ; A x C - 0.012 ; B x C – 0.020 ; A x B x C - 0.028

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 11b. Effect of different organic sources on organic carbon content of sub-surface soil

Treatments	Organic carbon (%)									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	1.01	1.05	1.15	1.22	1.18	0.83	0.92	0.95	0.92	1.07
N_1	1.05	1.33	1.13	1.22	1.21	0.86	0.98	1.08	1.08	0.98
N_2	1.09	1.19	1.12	1.23	1.04	0.89	0.99	0.96	0.92	0.95
N_3	1.10	1.15	1.10	1.09	1.05	1.02	0.83	0.92	0.66	0.87

CD(0.05) - A – 0.031 ; B - 0.049 ; C - 0.044 ; A x B – 0.069 ; A x C - NS ; B x C – 0.098 ; A x B x C - NS

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 12a. Effect of different organic sources on available nitrogen of surface soil

Treatments	Available nitrogen (kg ha^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	411.75	447.72	419.06	455.57	422.42	420.45	455.40	424.35	464.61	454.18
N_1	425.61	464.51	421.84	502.46	430.39	427.85	463.35	425.89	590.69	475.44
N_2	432.23	502.95	429.20	513.14	440.36	438.23	474.30	431.61	595.71	477.28
N_3	439.28	485.22	448.76	521.78	456.33	451.49	459.40	453.98	596.38	487.51

CD(0.05) - A - 0.518 ; B - 0.818 ; C -0.732 ; A x B – 1.157 ; A x C - 1.035 ; B x C – 1.637 ; A x B x C – 2.315

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 12b. Effect of different organic sources on available nitrogen of sub-surface soil

Treatments	Available nitrogen (kg ha^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	395.36	425.41	400.47	440.72	442.80	350.52	416.30	402.63	414.68	380.45
N_1	411.43	471.64	415.45	467.39	458.26	413.57	417.28	411.48	531.49	418.32
N_2	423.49	487.64	420.73	500.45	474.74	365.73	420.63	411.53	457.37	436.53
N_3	429.36	467.52	450.59	512.56	453.64	403.63	438.42	438.26	445.33	440.57

CD(0.05) - A – 0.303 ; B - 0.479 ; C - 0.429 ; A x B – 0.678 ; A x C - 0.606 ; B x C – 0.959 ; A x B x C – 1.356

A- Cropping season ; B- Organic source ; C- Nitrogen level

Available N of the sub-surface soil was significantly higher in virippu season. The highest (Table 12b) and also significant available nitrogen was recorded with daincha and 105 kg N ha^{-1} (512.56 kg ha^{-1}) during virippu season. A slightly lesser value of 500.45 kg ha^{-1} was recorded in daincha with 70 kg N ha^{-1}. During mundakan season, application of daincha with 35 kg N ha^{-1} showed significant maximum value of 531.49 kg ha^{-1}. In general, the treatment RHB with or without N recorded lower values in the second season.

Available phosphorus

A perusal of data in Table 13a showed that available phosphorus of surface soil was maximum during virippu season in the treatment consisting of FYM with 35 kg N ha^{-1} (55.62 kg ha^{-1}). The treatment ART with 35 kg N ha^{-1} and RHB with 70 kg N ha^{-1} recorded values of 55.38 and 55.02 kg ha^{-1} respectively. During mundakan season, the amount was the highest in the treatment, RHB with 105 kg N ha $^{-1}$ (60.38 kg ha^{-1}). Slightly lesser values of 59.66 and 59.46 kg ha^{-1} were obtained in the treatments ART combined with 35 kg N ha^{-1} and RHB with 70 kg N ha^{-1}.

It was found that in sub-surface soil the values were significantly higher during virippu season and application of daincha and 105 kg N ha^{-1} showed a significant maximum value of 42.45 kg ha^{-1} (Table 13b) followed by the same organic source with 70 kg N ha^{-1} (41.62 kg ha^{-1}). In mundakan season, FYM with 70 kg N ha^{-1} showed maximum value of 56.17 kg ha^{-1}. The treatment, FYM with 35 kg N ha^{-1} (46.34 kg ha^{-1}) was on par with ART supplied with 35 kg N ha^{-1} with a value 47.90 kg ha^{-1}.

Available potassium

The data on the amount of available potassium of surface soil revealed that it was significantly higher in virippu season (Table 14a). The highest and also significant value of 174.28 kg ha^{-1} was obtained in daincha supplemented with 35 kg N ha^{-1}. The treatment of daincha with higher doses of N recorded values of 154.40 and 154.82 kg ha^{-1} which were on par with each other. During mundakan season, the

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Table 13a. Effect of different organic sources on available phosphorus of surface soil

Treatments	Available phosphorus (kg ha^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	35.69	37.79	39.44	43.62	43.15	29.64	39.81	48.44	33.40	50.35
N_1	34.30	55.62	55.38	39.17	44.42	30.27	46.01	59.66	46.59	55.41
N_2	37.78	40.21	38.52	44.35	55.02	30.58	35.88	45.42	47.92	59.46
N_3	39.06	28.64	32.36	43.16	47.30	39.07	44.10	36.26	56.08	60.38

CD (0.05) - A - 0.358 ; B - 0.565 ; C - 0.506 ; A x B – 0.799 ; A x C - 0.715 ; B x C - 1.131 ; A x B x C –1.599

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 13b. Effect of different organic sources on available phosphorus of sub-surface soil

Treatments	Available phosphorus (kg ha^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	30.36	35.98	22.50	39.99	25.12	28.19	35.41	34.09	40.52	32.65
N_1	30.96	27.54	39.35	34.36	36.21	34.26	46.34	47.90	40.53	36.32
N_2	27.12	27.37	31.80	41.62	21.94	34.31	56.17	36.24	45.52	30.69
N_3	32.76	28.61	35.99	42.45	24.81	38.98	38.19	42.01	46.64	34.64

CD (0.05) - A - 0.255 ; B - 0.402 ; C - 0.360 ; A x B -0.716 ; A x C - 0.509 ; B x C – 1.012 ; A x B x C – 1.432

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 14a. Effect of different organic sources on available potassium of surface soil

Treatments	Available potassium (kg ha^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	96.45	113.34	112.52	116.33	108.65	76.21	83.48	85.40	87.44	80.55
N_1	100.40	120.41	128.70	174.28	111.38	83.48	94.22	90.97	94.55	94.15
N_2	102.43	126.39	135.77	154.40	111.54	86.55	113.34	112.77	120.35	105.50
N_3	104.62	134.45	167.49	154.82	119.41	87.28	113.54	117.26	120.38	110.43

CD (0.05) - A - 0.263 ; B - 0.417 ; C - 0.373 ; A x B – 0.589 ; A x C - 0.527 ; B x C - 0.833 ; A x B x C –1.178

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 14b. Effect of different organic sources on available potassium of sub-surface soil

Treatments	Available potassium (kg ha^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	81.26	83.39	87.59	84.43	80.34	55.70	55.64	55.68	64.69	55.43
N_1	84.30	93.33	94.40	98.52	89.52	73.61	63.64	65.65	65.28	60.35
N_2	86.31	96.55	97.48	103.59	98.52	78.42	66.17	83.63	88.48	62.23
N_3	86.44	116.41	157.55	120.64	118.68	104.56	90.33	85.36	110.56	65.53

CD (0.05) - A - 0.254 ; B - 0.402 ; C - 0.359 ; A x B – 0.568 ; A x C - 0.508 ; B x C – 0.804 ; A x B x C – 1.136

A- Cropping season ; B- Organic source ; C- Nitrogen level

treatments, daincha with 70/105 kg N ha^{-1} recorded values of 120.35 and 120.38 kg ha^{-1} and they were on par with each other.

The seasonal effect was found to be similar to that of surface soil but available potassium contents were lesser. The treatment with ART and 105 kg N ha^{-1} showed significant maximum value of 157.55 kg ha^{-1}in sub-surface soil (Table 14b). During mundakan season, the highest value was obtained for daincha with 105 kg N ha^{-1} (110.56 kg ha^{-1}).

The secondary nutrients in soil were found to be affected by seasons and organic + inorganic sources. These nutrients were significantly higher in virippu season than in mundakan and they were high in surface soil than the sub-surface soil.

Available calcium

In virippu season, the available calcium of surface soil was significantly highest in the treatment which included organic source daincha with 105 kg N ha^{-1} (444.73 mg kg^{-1}) (Table 15a). In mundakan season, the values showed a decrease compared to the first season and RHB without N source recorded a value of 302.14 mg kg^{-1}.

Available Ca content of sub-surface soil was significant and the highest value (Table 15b) was recorded for daincha with 105 kg N ha^{-1} (384.07 mg kg^{-1}) in virippu season. During mundakan season, it was significantly higher in the treatment daincha without any nitrogen source (294.01 mg kg^{-1}). Treatments, ART with 35 kg N ha^{-1} and RHB with 35 kg N ha^{-1} were on par. In general, the values of available Ca decreased during the second season.

Available magnesium

The data presented in Table 16a showed that available magnesium content of surface soil was significantly higher in the treatment daincha with no added nitrogen (39.67 mg kg^{-1}). Daincha with 35 kg N ha^{-1} (38.69 mg kg^{-1}) was on par with it. The treatment, RHB without nitrogen showed a significantly higher value of 42.27 mg kg^{-1} during mundakan season.

Table 15a. Effect of different organic sources on available calcium of surface soil

Treatments	Available calcium (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	285.29	317.34	300.71	335.38	312.47	166.38	191.52	170.93	174.59	302.14
N_1	310.48	371.81	327.04	356.16	334.41	165.68	216.18	205.40	219.21	249.48
N_2	313.23	378.42	335.30	360.35	354.76	160.17	179.69	215.48	215.45	228.69
N_3	323.41	388.40	332.40	444.73	376.62	169.58	185.33	215.65	224.13	200.37

CD(0.05) - A - 0.514 ; B - 0.812 ; C - 0.726 ; A x B – 1.149 ; A x C - 1.027 ; B x C – 1.624 ; A x B x C – 2.297

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 15b. Effect of different organic sources on available calcium of sub-surface soil

Treatments	Available calcium (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	207.63	210.36	244.78	281.77	202.04	154.60	279.65	174.97	294.01	133.67
N_1	223.78	277.16	231.87	239.11	220.35	165.09	138.25	204.65	220.39	205.37
N_2	233.70	233.88	194.13	264.40	279.74	161.76	142.96	158.22	136.47	230.72
N_3	241.46	248.09	329.51	384.07	232.13	180.61	163.67	168.51	212.69	271.33

CD (0.05) - A - 0.935 ; B - 1.478 ; C - 1.322 ; A x B – 2.091 ; A x C - 1.870 ; B x C – 2.957 ; A x B x C – 4.182

A- Cropping season ; B- Organic source ; C- Nitrogen level

It was observed that in sub-surface soil, the maximum value of 28.74 mg kg^{-1} was obtained for the treatment, daincha with 105 kg N ha^{-1} (Table 16b). During mundakan season, a higher significant value of 30.49 mg kg^{-1} was observed in the treatment RHB with 105 kg N ha^{-1} followed by daincha with 35 kg N ha^{-1} (28.53 mg kg^{-1}).

Available sulphur

A perusal of data presented in Table 17a revealed that in the surface soil, the maximum sulphur content of 8.46 mg kg^{-1} was recorded in the treatment, daincha with 70 kg N ha^{-1} and the same trend was observed in mundakan season also with a value of 6.74 mg kg^{-1} for the same treatment.

Available S of sub-surface soil was significantly higher (Table 17b) in treatment daincha with 70 kg N ha^{-1} (5.43 mg kg^{-1}). The treatment with same organic source in combination with next higher dose of N showed a lesser value of 5.38 mg kg^{-1}. During mundakan season, the highest value was observed for the treatment daincha with 105 kg N ha^{-1} (4.73 mg kg^{-1}). The same organic source with 35 and 70 kg N ha^{-1} showed on par values of 4.69 and 4.70 mg kg^{-1} respectively.

Available iron

The status of available Fe content of surface soil (Table 18a) was significantly higher in virippu season and it was reduced to half the content in mundakan season. The amount was significantly minimum for RHB with 70 kg N ha^{-1} (123.34 mg kg^{-1}) in the first crop season of virippu. The same organic source with 105 kg N ha^{-1} showed Fe content of 146.59 mg kg^{-1}. The treatments with organic and inorganic sources showed an irregular pattern in the Fe content with increasing N levels.

The seasonal effect was similar to that of surface soil. The available Fe content of sub-surface soil (Table 18b) was minimum with RHB and 0 kg N ha^{-1} (143.57 mg kg^{-1}) but during mundakan season minimum value was obtained for ART with 0 kg N ha^{-1} (74.93 mg kg^{-1}).

Table 16a. Effect of different organic sources on available magnesium of surface soil

Treatments	Available magnesium (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	28.70	38.06	30.08	39.67	30.39	20.45	30.56	22.73	23.54	42.27
N_1	29.60	35.84	31.63	38.69	34.67	23.66	30.49	27.92	32.55	38.62
N_2	28.68	32.45	31.09	33.80	33.44	22.63	29.46	30.41	33.21	34.22
N_3	30.58	31.60	38.05	32.23	30.17	23.60	27.61	31.35	34.74	26.16

CD (0.05) - A - 0.265 ; B - 0.419 ; C - 0.375 ; A x B – 0.592 ; AxC - 0.530 ; B x C - 0.838 ; A x B x C – 1.185

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 16b. Effect of different organic sources on available magnesium of sub-surface soil

Treatments	Available magnesium (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	22.61	28.05	24.81	25.31	25.00	18.50	24.67	22.19	24.37	15.97
N_1	23.50	26.25	25.28	27.96	28.13	20.52	21.32	24.30	28.53	23.77
N_2	23.75	26.25	24.03	27.57	24.91	21.43	20.90	24.11	18.67	20.41
N_3	24.54	26.77	24.54	28.74	22.59	21.70	22.94	24.52	19.72	30.49

CD(0.05) - A - 0.227 ; B - 0.360 ; C - 0.322 ; A x B - 0.509 ; A x C - 0.455 ; B x C - 0.719 ; A x B x C – 1.017

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 17a. Effect of different organic sources on available sulphur of surface soil

Treatments	Available sulphur(mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	7.84	7.93	7.90	7.97	7.94	5.27	6.17	6.06	6.27	5.96
N_1	7.85	8.13	7.96	8.27	7.95	5.83	6.37	6.15	6.71	6.25
N_2	7.90	8.27	7.96	8.46	7.93	6.10	6.56	6.22	6.74	6.36
N_3	7.92	8.24	8.00	8.38	8.18	6.03	6.46	6.27	6.73	6.46
CD (0.05) - A - 0.064; B - 0.101 ; C - 0.090 ; A x B -.142 ; A x C - 0.127 ; B x C – NS ; A x B x C - NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 17b. Effect of different organic sources on available sulphur of sub-surface soil

Treatments	Available sulphur(mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART.	DNC	RHB
N_0	4.80	4.89	4.92	4.90	4.90	3.78	4.13	3.92	4.22	3.78
N_1	4.84	5.10	4.96	5.27	4.92	3.80	4.15	4.07	4.69	4.15
N_2	4.87	5.25	4.96	5.43	4.91	3.83	4.47	4.13	4.70	4.26
N_3	4.89	5.15	5.01	5.38	5.12	3.86	4.50	4.17	4.73	4.38
CD (0.05) - A - 0.003 ; B - 0.005 ; C - 0.004 ; A x B – 0.007 ; A x C - 0.006 ; B x C – 0.009 ; A x B x C – 0.013										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 18a. Effect of different organic sources on available iron of surface soil

Treatments	Available iron (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	278.20	301.13	264.67	386.55	153.57	109.95	138.22	89.33	144.62	193.12
N_1	294.93	234.82	226.90	321.77	153.32	80.68	151.15	155.29	130.78	68.19
N_2	292.88	222.75	297.36	233.84	123.34	105.52	120.95	164.91	159.85	155.49
N_3	203.82	192.20	311.16	247.51	146.59	88.35	102.27	163.02	140.85	94.78
CD (0.05) - A - 0.236 ; B - 0.373 ; C - 0.333 ; A x B – 0.527 ; A x C - 0.471 ; B x C – 0.745 ; A x B x C – 1.054										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 18b. Effect of different organic sources on available iron of sub-surface soil

Treatments	Available iron (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	243.29	176.65	238.44	198.43	143.57	91.95	85.17	74.93	120.19	111.77
N_1	189.06	200.07	278.82	218.37	168.37	64.41	134.35	153.16	113.61	106.02
N_2	277.38	249.53	273.63	294.37	244.99	113.72	110.06	96.23	132.09	94.13
N_3	189.66	182.74	271.37	187.02	195.68	118.18	121.08	139.75	88.57	64.47
CD (0.05) - A - 0.423 ; B - 0.669 ; C - 0.599 ; A x B – 0.946 ; A x C - 0.846 ; B x C – 0.846 ; A x B x C – 1.338										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Available manganese

It was found that Mn content of surface soil was significantly maximum in mundakan season than in virippu season. It was minimum in RHB with 0 kg N ha^{-1} with a value of 3.54 mg kg^{-1} and was significantly superior over other treatments (Table 19a). In mundakan season, Mn content was significantly minimum in the treatment ART with 0 kg N ha^{-1} (4.22 mg kg^{-1}). The organic source, daincha with 0 kg N ha^{-1} also recorded a lesser value of 4.25 mg kg^{-1}.

But in sub-surface soil, reverse was the seasonal effect. The lowest and significant value (Table 19b) of manganese of sub-surface soil was obtained for NOM with 0 kg N ha^{-1} (3.62 mg kg^{-1}) during virippu season. In mundakan season, the significant minimum value was recorded in the treatment RHB with 0 kg N ha^{-1}(2.67 mg kg^{-1}). The same organic source with 35 kg N ha^{-1} reeived 2.74 mg kg^{-1} which was on par with the lowest value.

Available zinc

The seasonal effect was significant and it was higher in virippu season. In mundakan season, the amount was found to be very meagre. From the perusal of data in Table 20a, available zinc of surface soil was found to be significantly maximum in the treatment RHB with 105 kg N ha^{-1} (8.01 mg kg^{-1}) in virippu season. But during the mundakan season, significant higher value of 3.70 mg kg^{-1} was recorded for the treatment, FYM applied without any N source. Similarly, rice husk biochar applied at 0 kg N also recorded a value of 3.21 mg kg^{-1}. All other treatments showed lesser values for zinc during this season.

The available zinc of sub-surface soil was the highest (Table 20b) in virippu season, in the treatment daincha with 35 kg N ha^{-1} (10.15 mg kg^{-1}). This value was found to be significant over all other values in virippu season. The same pattern was observed during mundakan season also where the highest maximum value was 2.18 mg kg^{-1} for the same treatment.

Table 19a. Effect of different organic sources on available manganese of surface soil

Treatments	Available manganese (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	4.39	4.52	4.5	4.62	3.54	4.58	4.76	4.22	4.25	4.74
N_1	4.68	4.68	4.65	5.58	3.84	4.72	5.28	4.41	4.42	4.78
N_2	4.71	5.29	4.98	5.66	5.08	4.79	5.35	7.16	4.91	5.74
N_3	4.98	5.48	5.58	6.27	5.47	5.22	5.81	9.42	5.26	6.57

CD (0.05) - A - 0.003 ; B - 0.004 ; C - 0.004 ; A x B -0.006 ; A x C - 0.005 ; B x C – 0.009 ; A x B x C – 0.012

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 19b. Effect of different organic sources on available manganese of sub-surface soil

Treatments	Available manganese (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	3.62	4.32	4.84	4.24	4.28	3.44	3.19	3.64	3.04	2.67
N_1	3.84	4.45	4.37	4.43	4.31	3.73	3.99	4.12	3.56	2.74
N_2	3.95	4.55	4.97	4.53	4.40	4.94	4.52	4.94	3.77	5.48
N_3	3.96	4.91	4.87	5.20	4.97	5.61	5.42	6.35	3.83	7.43

CD (0.05) - A - 0.033 ; B - 0.053 ; C - 0.047 ; A x B -0.075 ; A xC - 0.067 ; B x C – 0.106 ; A x B x C – 0.150

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 20a. Effect of different organic sources on available zinc of surface soil

Treatments	Available zinc (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	2.46	5.72	4.19	6.83	4.03	0.95	3.70	1.28	1.40	3.21
N_1	4.23	5.30	4.51	5.42	4.30	1.05	2.58	2.65	1.87	2.03
N_2	4.38	3.33	5.71	7.04	6.10	1.26	2.19	1.66	1.47	2.37
N_3	3.48	5.52	4.38	6.46	8.01	1.26	2.19	2.67	1.82	1.45

CD (0.05) - A - 0.131 ; B - 0.207 ; C - 0.185 ; A x B – 0.293 ; A x C - 0.262 ; B x C – 0.414 ; A x B x C – 0.585

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 20b. Effect of different organic sources on available zinc of sub-surface soil

Treatments	Available zinc (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	2.03	3.54	6.13	8.19	4.71	0.89	1.12	1.38	1.38	1.80
N_1	3.18	3.92	8.06	10.15	4.32	0.93	1.36	1.73	2.18	1.96
N_2	3.51	3.78	9.61	5.67	9.83	1.26	1.32	1.85	1.08	2.07
N_3	3.86	3.35	6.25	4.02	6.77	1.28	1.47	1.59	1.14	1.49

CD (0.05) - A - 0.105 ; B - 0.166 ; C - 0.148 ; A x B – 0.235 ; A x C - 0.210 ; B x C – 0.332 ; A x B x C –0.469

A- Cropping season ; B- Organic source ; C- Nitrogen level

Available copper

The seasonal effect was significantly higher in virippu season than in mundakan season. The data presented in Table 21a revealed that available copper content of surface soil was significantly higher during virippu season in the treatment ART without any N source (9.75 mg kg^{-1}) which was followed by daincha without any N source with a value 9.38 mg kg^{-1}. During mundakan season, the Cu content was maximum in the plot treated with FYM and 70 kg N ha^{-1} (7.71 mg kg^{-1}). The treatments with same organic source supplemented with 35 kg N ha^{-1} and without N also recorded values of 7.69 and 7.62 mg kg^{-1} which were on par with the highest value obtained.

The treatment FYM with 70 kg N ha^{-1} showed significant maximum value (Table 21b) of 10.66 mg kg^{-1} in sub-surface soil followed by daincha with 70 kg N ha^{-1}(9.30 mg kg^{-1}). The value was significant and also highest in ARTwith 35 kg N ha^{-1} (9.16 mg kg^{-1}) during mundakan season.

Available boron

Available boron of surface soil was significantly maximum (Table 22a) in virippu season. But the interaction effect of treatments on boron content was non significant. The content ranged between 0.26 and 0.49 mg kg^{-1} in virippu, while in mundakan season, the content was in between 0.22 and 0.42 mg kg$^{-1.}$). In general, the organic sources FYM, DNC and RHB were acting as good sources of B than ART in the integrated treatments.

As in the case of manganese, the available boron content of sub-surface soil was also not significant between treatments (Table 22b). The seasonal effect was similar to the surface soil. The values of boron ranged between 0.22 and 0.46 mg kg^{-1} in virippu and 0.20 and 0.44 mg kg^{-1} in mundakan season respectively. Here also, the higher values were obtained for the integrated treatments involving FYM, DNC and RHB than ART treatment.

Table 21a. Effect of different organic sources on available copper of surface soil

Treatments	Available copper (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	6.85	7.21	9.75	9.38	6.10	5.46	7.62	5.48	6.65	5.37
N_1	7.74	7.38	5.68	7.32	6.10	4.44	7.69	7.27	6.41	4.51
N_2	7.82	6.15	6.73	7.38	5.47	5.71	7.71	5.59	7.19	6.83
N_3	5.66	5.84	8.51	7.27	7.28	5.08	5.45	9.25	6.38	4.84
CD(0.05) - A - 0.007 ; B - 0.011 ; C - 0.010 ; A x B – 0.097 ; A x C -0.014 ; B x C - 0.137 ; A x B x C - 0.194										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 21b. Effect of different organic sources on available copper of sub-surface soil

Treatments	Available copper (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	6.35	8.00	6.44	7.12	5.50	5.42	5.06	5.18	5.28	5.42
N_1	6.39	8.84	7.04	7.31	6.14	4.44	5.76	9.16	5.29	5.26
N_2	7.04	10.66	7.28	9.30	7.07	6.70	5.69	4.58	5.38	5.48
N_3	5.94	6.62	7.64	6.15	6.66	5.65	5.76	5.68	4.26	4.48
CD (0.05) - A - 0.016; B - 0.026; C - 0.023; A x B – 0.036 ; A x C - 0.033; B x C – 0.052 ; A x B x C – 0.073										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 22a. Effect of different organic sources on available boron of surface soil

Treatments	Available boron (mg kg^{-1})									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	0.26	0.40	0.29	0.36	0.28	0.22	0.36	0.26	0.31	0.25
N_1	0.28	0.46	0.32	0.38	0.36	0.23	0.40	0.27	0.32	0.33
N_2	0.34	0.48	0.31	0.41	0.38	0.28	0.41	0.27	0.36	0.33
N_3	0.36	0.49	0.36	0.45	0.41	0.29	0.42	0.30	0.40	0.38
CD (0.05) - A - 0.003 ; B - 0.004 ; C - 0.004 ; A x B – 0.006 ; A x C - 0.006 ; B x C – 0.009 ; A x B x C - NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 22b. Effect of different organic sources on available boron of sub-surface soil

Treatments	Available boron (mg kg^{-1})									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	0.22	0.37	0.27	0.32	0.26	0.20	0.35	0.26	0.30	0.24
N_1	0.24	0.41	0.28	0.33	0.34	0.23	0.39	0.26	0.31	0.32
N_2	0.30	0.46	0.28	0.37	0.36	0.27	0.44	0.26	0.35	0.32
N_3	0.23	0.44	0.33	0.42	0.39	0.29	0.42	0.31	0.39	0.37
CD (0.05) - A - 0.009 ; B - 0.014 ; C - 0.012 ; A x B – NS ; A x C – NS ; B x C – 0.028 ; A x B x C - NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

4.1.1.3. *Soil biological characteristics*

The seasonal effect on enzyme activities in both surface and sub-surface soil was significant and it was higher in mundakan season. The enzyme contents were high in the treatments with organic sources and the values increased with increase in nitrogen content.

Microbial biomass carbon (MBC)

The data regarding MBC of surface soil is given in Table 23a. Maximum value of MBC was obtained for the treatment ART with 70 kg N ha^{-1}(468.49 mg kg^{-1}) and it was also significant. The same organic source with higher dose of N recorded a lesser value of 436.48 mg kg^{-1}. The values of MBC were lower in the treatments where inorganic source of N alone was applied. During mundakan season, the maximum MBC was obtained in the treatment RHB with 70 kg N ha^{-1} (500.72 mg kg $^{-1}$). The treatments RHB + 35 and 105 kg N ha^{-1}, ART + 75 kg N ha^{-1} and daincha +105 kg N ha^{-1} recorded values of 477.36, 477.29, 478.43 and 478.65 respectively and were on par with each other. In general, the MBC values were higher during mundakan season compared to the virippu.

The treatment, RHB + 70 kg N ha^{-1} showed significant maximum value of 445.75 mg kg $^{-1}$ in virippu season (Table 23b) of sub-surface soil. The treatment with the same organic source and lesser dose of nitrogen showed slightly lesser value of 438.74 mg kg^{-1}. In mundakan season, the highest value of microbial activity (455.62 mg kg^{-1}) was obtained in RHB with 70 kg N ha^{-1}.

Table 23a. Effect of different organic sources on microbial biomass carbon of surface soil

	Microbial biomass carbon (mg kg $^{-1}$)									
Treatments	**Virippu**					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	205.48	300.66	377.48	360.15	368.19	236.04	340.51	389.37	367.51	467.61
N_1	250.41	386.83	405.55	387.15	397.41	257.46	379.26	456.79	437.89	477.36
N_2	266.21	412.08	468.49	427.39	410.52	278.66	456.78	478.43	469.70	500.72
N_3	297.41	425.15	436.48	419.79	377.24	290.01	437.95	423.58	478.65	477.29
CD (0.05) - A - 1.244 ; B - 1.967 ; C - 1.759 ; A x B – 2.782 ; A x C - 2.488 ; B x C – 3.934 ; A x B x C - 5.564										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 23b. Effect of different organic sources on microbial biomass carbon of sub-surface soil

	Microbial biomass carbon (mg kg $^{-1}$)									
Treatments	**Virippu**					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	189.97	278.97	359.33	357.16	417.99	213.21	299.43	346.10	357.44	420.53
N_1	198.04	302.66	390.27	379.31	438.74	232.48	335.40	367.93	435.66	446.66
N_2	211.26	357.33	435.51	417.58	445.75	244.81	368.01	378.74	448.52	455.62
N_3	256.09	378.31	425.88	436.28	437.22	267.62	356.78	401.73	436.10	447.43
CD (0.05) - A - 0.317 ; B - 0.501 ; C - 0.44 ; A x B -0.709 ; A x C - 0.634 ; B x C – 1.003 ; A x B x C – 1.418										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Phosphatase activity

The highest phosphatase activity (Table 24a) of surface soil was recorded for the treatment daincha with 105 kg N ha^{-1} (467.62 μg PNP h^{-1} g^{-1}). The treatment, ART when applied along with 105 kg N ha^{-1} showed a value of 456.87 μg PNP h^{-1} g^{-1} and it was on par with the highest value. During mundakan season, the maximum value was recorded in the treatment daincha with 105 kg N ha^{-1} (489.59 μg PNP h^{-1} g^{-1}). The treatment, RHB with 105 kg N ha^{-1} recorded an on par value of 478.72 μg PNP h^{-1} g^{-1}. As was the case in MBC, the enzyme activity was also higher during the second crop season.

The phosphatase activity (Table 24b) of sub-surface soil was also significantly higher in daincha with 105 kg N ha^{-1} (465.67 μg PNP h^{-1} g^{-1}). In mundakan season, maximum significant value of 368.35 μg PNP h^{-1} g^{-1} was obtained for RHB with 105 kg N ha^{-1}. Treatments, daincha as well as RHB with 70 kg N ha^{-1} showed on par values of 346.23 and 346.51 μg PNP h^{-1} g^{-1} respectively.

Dehydrogenase activity

The table 25a showed that maximum value of dehydrogenase activity of surface soil was obtained for the treatment RHB with 105 kg N ha^{-1} (214.64 μg TPF day ^{1} kg^{-1}) and an on par value of 200.40 μg TPF day^{-1} kg^{-1} was shown for the same organic source with 70 kg N ha^{-1} in virippu season. Similar result was recorded during mundakan season where RHB with 105 kg N ha^{-1} showed the highest dehydrogenase value of 218.07 μg TPF day^{-1} kg^{-1}. The treatment, daincha with 105 kg N ha^{-1} also recorded an on par value of 206.34 μg TPF day^{-1} kg^{-1}. The values were maximum during the second season.

In virippu season the dehydrogenase activity of sub-surface soil (Table 25b) was significantly maximum in RHB with 105 kg N ha^{-1} (187.87 μg TPF day^{-1} kg^{-1}) but in mundakan season it was maximum for daincha with 105 kg N ha^{-1} (179.43 μg TPF day^{-1} kg^{-1}) and the value significantly differed from other tretaments.

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Table 24a. Effect of different organic sources on phosphatase activity of surface soil

Treatments	Phosphatase (µg PNP h^{-1} g^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	89.27	267.49	314.97	367.75	345.46	95.64	232.18	348.92	379.14	367.76
N_1	145.28	316.07	378.19	411.12	367.63	157.00	268.03	387.67	412.91	388.38
N_2	167.18	378.66	425.63	435.69	388.60	177.10	323.54	421.94	456.50	437.54
N_3	200.92	398.43	456.87	467.62	401.80	211.19	319.30	396.88	489.59	478.72

CD (0.05) - A - NS ; B - 4.890 ; C - 4.374 ; A x B – 6.915 ; A x C - 6.185 ; B x C – 9.78 ; A x B x C – 3.831

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 24b. Effect of different organic sources on phosphatase activity of sub-surface soil

Treatments	Phosphatase (µg PNP h^{-1} g^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	76.13	167.90	248.85	377.72	367.98	89.99	168.20	197.75	268.41	300.57
N_1	98.12	198.85	278.78	400.55	389.74	95.97	199.35	235.49	305.15	316.13
N_2	114.25	201.58	330.65	426.32	401.13	124.50	214.47	257.16	346.23	346.51
N_3	134.43	247.58	367.11	465.67	424.56	156.94	245.93	299.85	366.27	368.35

CD(0.05) -A - 0.296 ; B - 0.468 ; C - 0.419 ; A x B – 0.662 ; A x C - 0.592 ; B x C – 0.936 ; A x B x C – 1.323

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 25a. Effect of different organic sources on dehydrogenase activity of surface soil

Treatments	Dehydrogenase (μg TPF day^{-1} kg^{-1})									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	76.51	133.63	123.56	134.41	156.54	98.47	145.89	146.11	157.87	157.11
N_1	87.29	154.78	145.80	156.16	189.72	120.52	157.43	157.52	178.32	170.07
N_2	123.85	164.92	175.93	178.63	200.40	135.17	178.35	178.18	195.93	187.66
N_3	134.42	176.95	186.39	198.52	214.64	157.37	198.61	167.86	206.34	218.07
CD (0.05) - A - 3.275 ; B - 5.178 ; C - 4.631; A x B - 7.322 ; A xC - NS ; B x C – NS ; A x B x C – 14.644										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 25b. Effect of different organic sources on dehydrogenase activity of sub-surface soil

Treatments	Dehydrogenase (μg TPF day^{-1} kg^{-1})									
	Viripppu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	70.03	100.62	124.80	135.13	157.78	75.48	111.82	107.56	121.83	124.68
N_1	75.39	131.35	145.99	156.94	170.46	85.94	137.91	111.23	146.42	148.51
N_2	88.30	146.83	168.57	166.57	176.49	96.22	157.89	113.64	168.31	158.09
N_3	91.17	157.50	155.56	174.98	187.87	101.79	168.57	149.72	179.43	165.70
CD (0.05) - A - 0.284 ; B - 0.449 ; C - 0.401; A x B – 0.634 ; A x C - 0.567 ; B x C – 0.897 ; A x B x C – 1.269										

A- Cropping season ; B- Organic source ; C- Nitrogen level

4.1.4. *Soil carbon characteristics*

The data showed that the total carbon content was sigificantly higher in virippu season than mundakn season and in the sub-surface soil the content was lesser than that of surface soil. The organic sources had high impact on the OC content and it decreased with increase in nitrogen content.

Total carbon

The treatment with FYM at 0 kg N ha^{-1} recorded significant higher value of 4.04 per cent in virippu season in surface soil followed by RHB at the same dose, with a value of 3.45 per cent (Table 26a). In mundakan season, all the treatments which received RHB as organic source, recorded higher carbon content and RHB at 0 kg N ha^{-1} showed the highest significant value of 4.06 per cent.

Similar results (Table 26b) were obtained in the sub-surface soil also with a significant maximum value of 3.98 per cent for the treatment FYM used alone. The RHB alone treatment attained values of 3.91 and 3.17 per cent during virippu and mundakan seasons respectively.

Soil carbon stock

The carbon stock in soil was also influenced by seasons and organic sources and it showed similar pattern as that of the total carbon content. The data in table 27 revealed that the significant maximum value of soil carbon stock was attained in virippu season in FYM with 35 kg N ha^{-1} as organic source which recorded a value of 51.89 Mg ha^{-1}. The same organic source and 70 kg N ha^{-1} also showed an on par value of 50.15 Mg ha^{-1}. But in mundakan season, the treatment with RHB without any N source recorded a significant maximum value of 51.11 Mg ha^{-1}.

Table 26a. Effect of different organic sources on total carbon of surface soil

Treatments	Total carbon (%)									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	2.21	4.04	2.90	2.32	3.45	1.74	2.97	1.76	1.81	4.06
N_1	2.27	2.57	2.87	2.23	2.90	1.74	2.32	2.32	2.32	2.90
N_2	2.32	2.56	2.27	2.21	2.32	1.73	2.32	1.74	1.91	2.57
N_3	1.74	2.54	2.22	2.48	2.26	1.72	2.27	1.79	1.88	2.33

CD (0.05) - A - 0.007 ; B - 0.011 ; C - 0.010; A x B – 0.019 ; A x C -0.014 ; B x C – 0.028 ; A x B x C – 0.039

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 26b. Effect of different organic sources on total carbon of sub-surface soil

Treatments	Total carbon (%)									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	2.08	3.98	2.26	2.24	3.91	1.11	2.87	2.27	1.74	3.17
N_1	2.24	2.53	2.20	2.14	2.87	1.70	2.83	1.69	1.73	2.70
N_2	2.16	2.51	2.20	2.10	2.28	1.11	2.28	1.71	1.73	2.38
N_3	1.71	2.50	2.13	2.07	2.12	1.54	2.24	1.80	1.70	2.20

CD(0.05) - A - 0.009 ; B - 0.014 ; C - 0.012; A x B – 0.030 ; A x C - 0.018 ; B x C – 0.042 ; B x C – 0.059

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 27. Effect of different organic sources on soil carbon stock of soil

Treatments	Soil carbon stock (Mg ha^{-1})									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	42.92	45.06	40.93	45.57	48.42	35.78	38.44	31.24	34.33	51.11
N_1	45.27	51.89	42.27	47.19	48.20	30.76	40.38	39.09	38.47	47.96
N_2	46.78	50.15	41.87	49.97	41.26	37.95	40.90	33.73	37.38	36.69
N_3	46.61	44.64	42.04	45.9	41.49	38.23	37.48	33.71	32.58	32.80
CD (0.05) - A-0.614; B-0.971; C-0.868 A X B- 1.373; AxC-1.228; B X C- 1.942 ; A X B X C – 2.746										

A- Cropping season ; B- Organic source ; C- Nitrogen level

4.1.2. Effect of organic sources on soil organic carbon fractions and on rice grain, straw and root nutrient contents

4.1.2.1. *Fractions of soil organic carbon*

Soil organic carbon can be classified based on particle size and density. Accordingly, they are classified as coarse particulate organic carbon and fine particulate organic carbon (on particle size) and light fraction organic carbon, intra light fraction organic carbon, heavy fraction organic carbon and mineral associated organic carbon (on density).

Coarse particulate organic carbon (CPOC)

The data presented in Table 28a revealed that in virippu season, the carbon fractions were higher than mundakan season. The coarse particulate organic carbon content of surface soil was significantly higher in RHB with 105 kg N ha^{-1} (23.6 g kg^{-1}). All treatments of the same organic source with/ without inorganic N dose showed values more than ten. The results showed similar trend during mundakan season also, where the highest value was 20.70 g kg^{-1} for the treatment RHB with same nitrogen dose.

The CPOC of sub-surface soil also followed the same pattern similar to that of surface soil except for the no organic manure treatment. It was the highest (Table 28b) in control without N fertilizer or organic manure application (24.50 g kg^{-1}) in virippu season and was also significant. During mundakan season, the highest value of 24.70 g kg^{-1} was noticed in the same treatment.

Fine particulate organic carbon (FPOC)

From a perusal of the data in Table 29a, it was seen that the FPOC content of surface soil increased in the second season and the content was the highest in both seasons in ART with 105 kg N ha^{-1} with values of 5.80 g kg^{-1} and 6.30 g kg^{-1} respectively. The treatments did not differ significantly.

The FPOC content of sub-surface soil (Table 29b) also followed the same pattern as that of surface soil except in the no organic manure treatment, where the content decreased. It was significantly maximum in the treatment FYM with 105 kg N ha^{-1} (14.00 g kg^{-1}). Treatments with the same organic source and different levels of nitrogen showed FPOC values above 10.00 g kg^{-1} (1.00 %). All other treatments recorded lesser values. During mundakan season, the values were found to be slightly lesser (than virippu season) with the highest being 5.60 g kg^{-1} for the treatment consisting of DNC and 35 kg N ha^{-1}.

The organic carbon fractions according to density were influenced significantly by seasons and organic sources and the contents were higher in the mundakan season for all fractions except for heavy fraction, although the change was very meagre. The contents were higher in the surface soil than in sub-surface soil for all fractions, while the treatment with no organic manure increased the mineral associated organic carbon fraction of sub-surface soil.

Light fraction organic carbon (LFOC)

It is inferred from the Table 30a, that the LFOC content of surface soil was significantly higher in the treatment with RHB and no added nitrogen (171.30 g kg^{-1}). In general, treatments with RHB had higher LFOC content with values above 100.00 g kg^{-1} compared to other treatments.During mundakan season also the same trend was observed with the highest value of 174.00 g kg^{-1} for RHB treatment without added N.

The significant highest value for sub-surface soil (Table 30b) of LFOC was observed in the treatment FYM without any nitrogen which showed values of 66.10 g kg^{-1} and 66.40 g kg^{-1} in virippu and mundakan seasons respectively.

Table 28a. Effect of different organic sources on coarse particulate organic carbon of surface soil

Treatments	Coarse particulate organic carbon (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	3.40	4.70	8.00	3.10	14.60	3.30	4.50	7.50	2.90	13.50
N_1	4.50	2.90	5.90	3.20	16.40	4.40	2.50	4.30	2.60	14.30
N_2	3.90	1.30	6.50	2.30	18.90	3.80	1.10	4.20	2.40	15.40
N_3	1.60	3.80	6.80	2.50	23.60	1.50	3.50	3.60	2.40	20.70

CD (0.05) - A - 0.004 ; B - 0.007 ; C - 0.006 ; AxB- 0.010 ; A x C - 0.009 ; BxC- 0.013 ; AxBxC- 0.019

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 28b. Effect of different organic sources on coarse particulate organic carbon of sub-surface soil

Treatments	Coarse particulate organic carbon (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	24.50	1.70	2.10	1.10	3.40	24.70	1.50	1.80	1.00	3.80
N_1	23.30	0.90	1.80	6.60	1.40	23.50	0.60	1.60	6.40	1.20
N_2	3.90	2.90	2.40	4.60	2.80	5.30	2.70	2.20	4.40	2.60
N_3	3.50	1.40	1.80	1.50	3.40	3.70	1.10	1.70	1.30	3.10

CD (0.05) - A - NS ; B –0.009 ; C –0.008 ; A X B - 0.013; A x C -0.012; B X C - 0.018; A X B X C- 0.026

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 29a. Effect of different organic sources on fine particulate organic carbon of surface soil

Treatments	Fine particulate organic carbon (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	3.80	5.00	4.30	5.40	2.60	3.90	5.20	4.50	3.80	5.00
N_1	3.30	4.10	5.10	4.00	2.90	3.60	4.50	5.30	3.30	4.10
N_2	4.80	3.30	5.60	3.50	2.80	3.90	3.60	5.90	4.80	3.30
N_3	3.90	3.80	5.80	4.00	2.20	4.00	3.90	6.30	3.90	3.80

CD(0.05) - A - 0.010; B - 0.017 ; C - 0.015 ; A X B-NS; A x C – NS ; B X C -0.033; A X B X C -NS

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 29b. Effect of different organic sources on fine particulate organic carbon of sub-surface soil

Treatments	Fine particulate organic carbon (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	4.90	2.40	3.10	3.80	3.50	4.70	2.60	3.50	4.20	3.50
N_1	4.70	11.20	4.20	5.30	3.40	4.40	1.60	4.10	5.60	3.60
N_2	4.80	13.00	5.50	4.50	3.70	4.40	2.80	5.40	5.00	3.80
N_3	3.30	14.00	2.80	4.30	3.50	3.10	3.00	2.70	4.70	3.80

CD(0.05) - A - B - C -A X B - 0.008; B X C - 0.012; A X B X C - 0.017

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 30a. Effect of different organic sources on light fraction organic carbon of surface soil

Treatments	Light fraction organic carbon (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	36.20	64.40	62.40	74.00	171.30	36.30	64.60	62.60	74.30	174.00
N_1	37.00	61.20	63.20	34.40	158.00	37.20	61.50	63.70	35.40	159.30
N_2	61.80	67.10	67.80	59.70	146.00	62.00	67.40	68.30	59.90	147.20
N_3	44.20	47.30	74.70	30.10	157.00	44.40	47.50	75.00	30.40	157.40
CD(0.05) - A -0.013; B –0.020; C - 0.018; A X B - 0.029; A x C - NS; B X C - 0.040; A X B X C - 0.057										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 30b. Effect of different organic sources on light fraction organic carbon of sub-surface soil

Treatments	Light fraction organic carbon (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	21.50	66.10	34.80	26.60	30.00	21.70	66.40	35.40	26.90	31.10
N_1	29.50	15.50	31.50	33.80	26.00	29.80	16.00	31.70	34.00	26.20
N_2	30.40	42.30	42.60	28.70	26.80	30.60	42.80	42.70	28.90	29.50
N_3	29.60	28.20	25.70	46.10	40.00	29.90	28.60	26.10	46.40	41.50
CD(0.05) - A-0.011; B-0.018; C-0.016; A X B -0.026; AXC-NS; B X C-0.036; A X B X C-0.051										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Intra light fraction organic carbon (iLFOC)

As in case of LFOC, the iLFOC values of surface soil (Table 31a) were also maximum in the treatment RHB without any nitrogen source with values of 143.00 g kg^{-1} and 147.00 g kg^{-1} during virippu and mundakan seasons respectively. The treatments with RHB had higher iLFOC values and the treatment interaction effects were non significant.

The highest value (Table 31b) of sub-surface soil iLFOC was found in the treatment RHB without any nitrogen during virippu season (75.00 g kg^{-1}) followed by ART with 70 kg N ha^{-1} (64.10 g kg^{-1}). In mundakan season the highest value was observed in the treatment RHB without nitrogen (75.30 g kg^{-1}). All the treatments were non significant to each other.

Heavy fraction organic carbon (HFOC)

The data regarding HFOC content of surface soil are given in Table 32a. The HFOC content was significantly maximum in the control treatment without nitrogen showing a value of 49.50 g kg^{-1} and 49.30 g kg^{-1} during virippu and mundakan seasons respectively.

The highest value (Table 32b) of sub-surface soil HFOC was observed in the treatment RHB without nitrogen with values of 38.10 g kg^{-1} during virippu season and 38.00 g kg^{-1} during mundakan seasons. The treatment effects were non significant to each other.

Mineral associated organic carbon (Min OC)

The fraction, min OC of surface soil ranged from 0.20 to 1.40 g kg^{-1} in virippu (Table 33a) and 0.30 to 1.70 g kg^{-1} in mundakan seasons respectively. The treatments were found to be non-significant.

The highest value (Table 33b) of sub-surface soil Min OC was observed in the treatment daincha with 105kg N ha^{-1} (1.30 g kg^{-1}) during virippu and 1.40 g kg^{-1} during mundakan seasons. The treatments were non significant with each other.

Table 31a. Effect of different organic sources on intra light fraction organic carbon of surface soil

Intra light fraction organic carbon (g kg^{-1})										
Treatments	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	33.60	32.80	26.00	32.80	143.00	33.70	33.00	26.30	33.00	147.00
N_1	20.40	24.30	27.80	24.50	121.00	20.60	24.70	28.00	24.70	124.80
N_2	28.90	53.70	0.20	62.80	125.00	29.10	53.90	0.40	62.10	126.20
N_3	38.80	26.50	0.50	29.70	124.00	39.00	26.80	0.70	30.50	125.00
CD(0.05) - A-0.031; B-0.048; C-0.043; A X B -0.068; AXC- NS; B X C-0.097; A X B X C –NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 31b. Effect of different organic sources on intra light fraction organic carbon of sub-surface soil

Intra light fraction organic carbon (g kg^{-1})										
Treatments	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	39.80	43.90	21.30	29.30	75.00	40.70	44.00	21.60	29.90	75.30
N_1	25.90	34.40	38.80	29.00	13.00	26.20	34.60	39.10	29.50	13.30
N_2	48.80	41.20	64.10	41.50	28.80	49.10	41.50	64.30	41.90	29.10
N_3	30.60	41.90	35.40	32.50	21.60	30.90	42.10	35.70	33.00	21.80
CD(0.05) - A-0.006; B-0.009; C-0.008; A X B -0.013; AXC-NS; B X C-0.019; A X B X C-NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 32a. Effect of different organic sources on heavy fraction organic carbon of surface soil

Treatments	Heavy fraction organic carbon of soil (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	49.50	21.60	23.00	24.80	30.50	49.30	21.50	22.80	24.50	29.00
N_1	25.10	26.80	20.10	26.40	28.70	24.70	26.50	18.00	26.00	28.30
N_2	24.80	22.10	23.90	27.50	24.90	24.60	21.80	23.50	26.70	24.50
N_3	22.90	24.60	25.10	25.40	24.70	21.80	24.30	24.50	25.00	24.30
CD(0.05) - A-0.018; B-0.028; C-0.025; A X B-NS; AXC-NS; B X C -0.056; A X B X C -0.079										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 32b. Effect of different organic sources on heavy fraction organic carbon of sub-surface soil

Treatments	Heavy fraction organic carbon of soil (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	10.20	9.90	13.90	34.10	38.10	9.90	9.80	13.80	34.00	38.00
N_1	3.50	34.10	23.80	8.40	12.70	3.30	34.00	23.70	8.10	12.60
N_2	27.30	29.00	13.40	27.60	7.10	26.00	28.80	13.30	27.50	7.00
N_3	32.40	24.90	4.50	32.20	21.30	32.00	24.70	4.30	32.00	21.10
CD (0.05) - A-0.011; B-0.017; C-0.015; A X B - NS; AXC-NS; B X C - 0.033; A X B X C –NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 33a. Effect of different organic sources on mineral associated organic carbon of surface soil

Treatments	Mineral associated organic carbon (g kg^{-1})									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	0.30	0.90	1.10	0.70	0.60	0.40	1.10	1.30	1.00	1.00
N_1	0.30	1.20	0.50	0.50	1.20	0.30	1.40	0.70	0.70	1.50
N_2	0.20	0.50	0.70	0.70	1.40	0.40	0.60	1.00	1.20	1.70
N_3	0.40	1.00	0.80	0.80	0.40	0.60	1.20	1.20	1.10	0.80
CD(0.05) - A-0.004; B-0.006; C-NS; A X B-0.008; AXC-NS ; B X C -0.011; A X B X C-NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 33b. Effect of different organic sources on mineral associated organic carbon of sub-surface soil

Treatments	Mineral associated organic carbon (g kg^{-1})									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	0.80	0.50	1.00	0.70	0.80	0.90	0.60	1.30	0.90	1.00
N_1	0.70	1.10	1.00	0.50	0.70	0.80	1.40	1.20	0.60	0.90
N_2	0.80	0.70	0.70	0.90	0.70	0.80	0.90	1.00	1.10	1.00
N_3	0.90	0.80	0.80	1.30	0.70	1.00	1.10	0.90	1.40	0.80
CD(0.05) - A-0.004; B -0.007; C-0.006; A X B-NS; AXC –NS; B X C-0.014; A X B X C –NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

4.1.2.2. *Fractions of soil nitrogen*

The organic nitrogen fractions in surface and sub-surface soil were significantly influenced by seasons and organic and inorganic sources. The seasonal effect was positively significant in mundakan season and the contents were higher in the treatments with orgnic sources. The surface soil had higher organic nitrogen content than sub-surface soil except in mineral associated organic nitrogen.

Coarse particulate organic nitrogen (CPON)

The data in table 34a revealed that significantly maximum value of surface soil coarse particulate organic nitrogen was observed in the treatment RHB with 105 kg N ha^{-1} with values 1800 and 2000 mg kg^{-1} in virippu and mundakan seasons respectively.

The maximum values (Table 34b) of sub-surface soil CPON were observed in the treatments, daincha without nitrogen which recorded 2200 and 2600 mg kg^{-1} during virippu and mundakan seasons respectively. The values were found to be significant.

Fine particulate organic nitrogen (FPON)

The highest and significant value of surface soil FPON was seen in ART with 35 kg N ha^{-1} (1400 mg kg^{-1}) in virippu season (Table 35a). During mundakan season, value was the highest with 35 kg N ha^{-1} alone (1600 mg kg^{-1}). The treatment ART with 35 kg N ha^{-1} also recorded an on par value of 1500 mg kg^{-1}.

The highest value (Table 35b) of sub-surface soil FPON was obtained in the treatments with 105 kg N alone and in the control with values 2900 mg kg^{-1}during virippu and 3100 mg kg^{-1} during mundakan seasons respectively.

Light fraction organic nitrogen (LFON)

The highest and significant value of surface soil LFON (Table 36a) was recorded in the treatment ART with 105 kg N ha^{-1} with values 8.60 and 8.80 g kg^{-1} during virippu and mundakan seasons respectively.

Table 34a. Effect of different organic sources on coarse particulate organic nitrogen of surface soil

Treatments	Coarse particulate organic nitrogen (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	500.00	800.00	1300.00	900.00	1100.00	500.00	1000.00	1500.00	1400.00	600.00
N_1	500.00	800.00	600.00	800.00	1100.00	600.00	1100.00	700.00	1700.00	400.00
N_2	1000.00	500.00	500.00	1100.00	1300.00	1300.00	800.00	700.00	1400.00	600.00
N_3	500.00	800.00	400.00	1100.00	1800.00	700.00	1300.00	400.00	1300.00	2000.00

CD(0.05) - A-0.005; B-0.008; C-0.007; A X B-0.011; AXC-NS; B X C -0.015; A X B X C --0.021

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 34b. Effect of different organic sources on coarse particulate organic nitrogen of sub-surface soil

Treatments	Coarse particulate organic nitrogen (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	1600.00	1100.00	1200.00	2200.00	2000.00	1400.00	1300.00	1200.00	2600.00	2200.00
N_1	1800.00	1200.00	1100.00	1200.00	1700.00	1900.00	1300.00	1100.00	1600.00	1900.00
N_2	800.00	1400.00	1600.00	1300.00	1400.00	1000.00	1400.00	1300.00	1600.00	1600.00
N_3	1500.00	900.00	1200.00	1400.00	1500.00	1600.00	1000.00	1400.00	1700.00	1500.00

CD(0.05) - A-0.007; B-0.011; C-0.010; A X B-0.015; AXC-0.014 ; B X C -0.022; A X B X C--0.031

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 35a. Effect of different organic sources on fine particulate organic nitrogen of surface soil

Treatments	Fine particulate organic nitrogen (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	700.00	1100.00	1100.00	800.00	600.00	700.00	1300.00	1300.00	900.00	700.00
N_1	1000.00	700.00	1400.00	800.00	500.00	1600.00	800.00	1500.00	1300.00	500.00
N_2	800.00	800.00	700.00	900.00	700.00	900.00	1000.00	800.00	1200.00	800.00
N_3	900.00	900.00	700.00	1200.00	800.00	1100.00	1200.00	700.00	1400.00	900.00
CD(0.05) - A-0.003; B-0.005; C-0.004; A X B-0.007; AXC-0.006; B X C-0.009; A X B X C--0.013										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 35b. Effect of different organic sources on fine particulate organic nitrogen of sub-surface soil

Treatments	Fine particulate organic nitrogen (mg kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	1600.00	1400.00	600.00	600.00	600.00	3100.00	1700.00	600.00	800.00	700.00
N_1	2100.00	2500.00	800.00	900.00	600.00	2800.00	2700.00	700.00	1200.00	600.00
N_2	2600.00	2600.00	2200.00	1400.00	600.00	2400.00	2800.00	2200.00	1700.00	600.00
N_3	2900.00	2700.00	700.00	2400.00	400.00	1800.00	2900.00	700.00	2600.00	400.00
CD(0.05) - A-0.004; B-0.006; C-0.005; A X B -0.008; AXC-0.007; B X C-0.012; A X B X C --0.017										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 36a. Effect of different organic sources on light fraction organic nitrogen of surface Soil

Treatments	Light fraction organic nitrogen (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	4.80	8.40	5.50	6.00	8.00	6.00	8.60	5.80	4.80	8.40
N_1	5.80	5.70	5.10	2.80	6.60	5.00	5.90	5.40	5.80	5.70
N_2	6.00	6.20	4.70	4.90	4.30	6.10	6.50	4.90	6.00	6.20
N_3	6.70	5.00	8.60	3.70	4.60	6.90	5.30	8.80	6.70	5.00
CD(0.05) -	**A-0.003; B-0.005; C-0.005; A X B -NS; AXC-0.007; B X C -0.011; A X B X C-0.015**									

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 36b. Effect of different organic sources on light fraction organic nitrogen of sub-surface soil

Treatments	Light fraction organic nitrogen (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	2.10	5.20	4.60	3.40	3.70	2.20	5.40	5.20	3.80	3.70
N_1	2.20	1.90	3.90	4.10	3.40	2.30	2.10	4.50	4.70	3.50
N_2	2.30	4.60	4.20	3.90	3.60	2.40	5.10	4.50	4.30	3.80
N_3	2.50	3.70	3.60	4.10	4.40	2.60	4.40	3.80	4.50	4.50
CD(0.05) -	**A-0.004; B-0.006; C-0.005; A X B-0.008; AXC-NS; B X C-0.011; A X B X C--0.016**									

A- Cropping season ; B- Organic source ; C- Nitrogen level

The sub-surface soil value for this parameter was the highest (Table 36b) in the treatment FYM without nitrogen which showed values of 5.20 and 5.40 g kg^{-1} during virippu and mundakan seasons respectively.

Intra light fraction organic nitrogen (iLFON)

Data from Table 37a revealed that the maximum value of surface soil iLFON was in the treatment ART with 70 kg N ha^{-1} with values 7.00 and 9.00 g kg^{-1} in virippu and mundakan seasons respectively. The treatments did not differ significantly from each other.

The maximum value of sub-surface soil iLFON (Table 37b) was recorded in the treatment, daincha with 35 kg N ha^{-1} with values 5.70 and 6.10 g kg^{-1} during virippu and mundakan seasons respectively.

Heavy fraction organic nitrogen (HFON)

A perusal of data in the Table 38a stated that surface soil HFON value was maximum with 35 kg N ha^{-1} alone with values 6.10 and 6.30 g kg^{-1} in virippu and mundakan seasons respectively.

The highest value (Table 38b) was observed in FYM with 35kg N ha^{-1} (4.80 g kg^{-1}) for sub-surface soil followed by daincha without N with a value 4.70 g kg^{-1} in virippu season. During mundakan season the value was significantly highest in FYM with 35 kg N ha^{-1} (5.20 g kg^{-1}). The treatments with daincha without N and FYM with 70 kg N ha^{-1} showed the same value of 4.80 g kg^{-1}.

Mineral associated organic nitrogen (Min ON)

The highest value of surface soil Min ON (Table 39a) was recorded in daincha with 70 kg N ha^{-1} which recorded values of 0.36 and 0.37 g kg^{-1} in virippu and mundakan seasons respectively. In control and also in treatments where fertilizers were applied, the values for Min ON were less than 1.00 g kg^{-1} in both seasons.

The maximum sub-surface soil Min ON (Table 39b) value was obtained in FYM with 35 kg N ha^{-1} with values 0.33 and 0.35 g kg^{-1} in virippu and mundakan seasons respectively.

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Table 37a. Effect of different organic sources on intra light fraction organic nitrogen of surface soil

Treatments	Intra light fraction organic nitrogen (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	3.50	4.60	3.20	4.20	4.30	3.70	4.80	3.40	4.50	4.50
N_1	3.00	3.30	3.60	3.10	5.60	3.40	3.50	3.80	3.20	5.80
N_2	4.40	3.80	7.00	3.80	4.50	4.60	4.00	9.00	4.00	4.70
N_3	5.10	3.50	5.00	3.50	4.30	5.30	3.60	6.00	3.80	4.60
CD (0.05)- A-0.004; B-0.006; C-0.005; A X B -NS; AXC-NS; B X C --0.012; A X B X C--NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 37b. Effect of different organic sources on intra light fraction organic nitrogen of sub-surface soil

Treatments	Intra light fraction organic nitrogen (g kg^{-1})									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	2.80	4.90	4.40	3.90	2.70	4.80	4.90	4.50	4.10	2.80
N_1	2.90	3.90	4.40	5.70	2.70	3.10	4.00	4.50	6.10	2.90
N_2	5.60	4.20	4.30	5.00	4.40	5.80	4.40	4.50	5.20	4.60
N_3	4.60	5.40	4.40	4.00	2.60	4.70	5.50	4.60	4.20	2.70
CD (0.05)- A-0.004; B-0.006; C-0.005; A X B -0.009; AXC-NS; B X C -0.013; A X B X C--0.018										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 38a. Effect of different organic sources on heavy fraction organic nitrogen of surface soil

Treatments	Heavy fraction organic nitrogen (g kg^{-1})									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	6.00	4.20	4.00	3.90	4.10	6.10	4.30	4.10	4.10	4.20
N_1	6.10	4.30	4.10	4.50	4.20	6.30	4.50	4.10	4.50	4.20
N_2	5.70	3.30	3.60	4.50	3.70	5.90	3.50	3.70	4.60	3.80
N_3	5.10	4.40	4.00	4.30	3.30	5.30	4.50	4.10	4.40	3.50
CD (0.05)-	**A-0.003; B-0.004; C-0.004; A X B -NS; AXC-NS; B X C-0.009; A X B X C--NS**									

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 38b. Effect of different organic sources on heavy fraction organic nitrogen of sub-surface soil

Treatments	Heavy fraction organic nitrogen (g kg^{-1})									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	0.90	2.00	2.00	4.70	2.70	0.70	2.10	2.10	4.80	2.90
N_1	1.20	4.80	2.60	1.20	1.90	1.20	5.20	2.50	1.90	2.10
N_2	4.00	4.40	2.70	3.70	1.50	4.30	4.80	2.80	4.10	1.80
N_3	2.20	3.90	1.40	4.10	3.40	2.40	4.10	1.50	4.60	3.80
CD (0.05)-	**A-0.004; B-0.006; C-0.005; A X B -0.008; AXC-0.007; B X C-0.012; A X B X C--0.016**									

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 39a. Effect of different organic sources on mineral associated organic nitrogen of surface soil

	Mineral associated organic nitrogen (g kg^{-1})									
Treatments	**Virippu**					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	0.02	0.32	0.28	0.24	0.27	0.02	0.34	0.30	0.26	0.29
N_1	0.04	0.29	0.29	0.27	0.29	0.04	0.31	0.31	0.28	0.31
N_2	0.04	0.31	0.30	0.36	0.31	0.04	0.33	0.32	0.37	0.32
N_3	0.05	0.35	0.31	0.34	0.29	0.05	0.36	0.33	0.36	0.31
CD (0.05)- A-0.003; B-0.004; C-0.004; A X B --0.006; AXC-NS; B X C-0.009; A X B X C--NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 39b. Effect of different organic sources on mineral associated organic nitrogen of sub-surface soil

	Mineral associated organic nitrogen (g kg^{-1})									
Treatments	**Virippu**					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	0.22	0.27	0.29	0.23	0.29	0.22	0.28	0.29	0.25	0.30
N_1	0.27	0.33	0.31	0.24	0.25	0.28	0.35	0.32	0.25	0.26
N_2	0.31	0.29	0.24	0.28	0.25	0.32	0.29	0.25	0.31	0.26
N_3	0.23	0.25	0.23	0.28	0.22	0.25	0.26	0.25	0.30	0.27
CD (0.05)- A-0.005; B-0.007; C-0.006; A X B-NS; AXC-NS; B X C-0.014; A X B X C -NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

4.1.2.3. *Fractions of carbon nitrogen (C:N) ratio*

Coarse particulate C:N ratio (CCN)

It was observed from the data (Table 40a) the treatment ART with 105 kg N ha^{-1} resulted a maximum C:N ratio of 15.83 in surface soil. The treatments, RHB with 35 and 70 kg N ha^{-1} showed values of 14.54 and 14.56 which were on par with the highest value. During mundakan season, RHB with 35 kg N ha^{-1} recorded the maximum (11.31). The same treatment with 70 kg N ha^{-1} also recorded a value of 11.04 and these two treatments were on par with each other. In general, the treatments where the organic sources were ART or RHB, recorded comparatively higher values than the other organic sources and also the ratios were higher during virippu season.

The highest and significant sub-surface soil CCN value (Table 40b) was observed in the treatment without any organic or inorganic source (15.35) followed by the treatment with 35 kg N ha^{-1}alone (12.97). During mundakan season, the above treatments recorded the highest values of 17.71 and 12.40 respectively.

Fine particulate C:N ratio (FCN)

The highest value of surface soil FCN, 8.49 was observed (Table 41a) for ART with 70 kg N ha^{-1}. The same organic source with 105 kg N ha^{-1} also showed value of 7.94 which was on par with each other. During mundakan season, ART with 105 kg N ha^{-1}showed significant maximum value of 8.95 followed by ART with 70 kg N ha^{-1}(7.76).

The sub-surface soil CN ratio ranged between 1.14 in 105 kg N ha^{-1} and 8.15 for the treatment RHB with 105 kg N ha^{-1} in virippu season (Table 41b). During mundakan season, the value was maximum for the same treatment with a value of 10.96.

Light fraction C:N ratio (LCN)

From the perusal of data in Table 42a, the surface soil CN ratio was found to be the highest in the treatment, RHB with 105kg N ha^{-1} (34.14). All the treatments

Table 40a. Effect of different organic sources on coarse particulate carbon nitrogen ratio of surface soil

Treatments	Coarse particulate C:N ratio									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	6.80	5.93	6.17	3.58	13.75	6.30	4.71	5.12	2.14	11.30
N_1	9.00	3.65	10.00	4.03	14.54	7.04	2.45	5.94	1.55	11.31
N_2	3.93	2.70	14.13	2.02	14.56	2.96	1.39	6.32	1.74	11.04
N_3	3.32	4.79	15.83	2.21	13.13	2.16	2.85	8.40	1.89	10.54

CD (0.05)- A-0.0284; B-0.0449; C-0.401; A X B - 0.635; AXC-0.568; B X C - 0.898; A X B X C - 1.269

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 40b. Effect of different organic sources on coarse particulate carbon nitrogen ratio of sub-surface soil

Treatments	Coarse particulate C:N ratio									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	15.35	1.56	1.76	0.50	1.70	17.71	1.16	1.54	0.37	1.70
N_1	12.97	0.75	1.64	5.52	0.83	12.40	0.48	1.56	3.93	0.63
N_2	4.92	2.07	1.50	3.56	2.01	5.32	1.93	1.68	2.76	1.65
N_3	2.34	1.57	1.50	1.08	2.27	2.37	1.09	1.22	0.75	2.10

CD (0.05)- A-NS; B-4.050; C-NS; A X B - 0.313; AXC-NS ; B X C - 0.442; A X B X C - 0.626

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 41a. Effect of different organic sources on fine particulate carbon nitrogen ratio of surface soil

Treatments	Fine particulate C:N ratio									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	5.52	4.57	3.93	7.03	4.17	5.70	4.04	3.58	6.64	3.73
N_1	3.33	5.95	3.65	4.96	6.27	2.22	5.38	3.48	3.24	5.79
N_2	6.05	4.16	8.49	3.72	3.87	5.41	3.77	7.76	3.01	3.97
N_3	4.38	4.25	7.94	3.24	2.68	3.72	3.26	8.95	2.93	2.74
CD (0.05)- A-0.186; B-0.294; C-0.263; A X B - 0.343; AXC-NS; B X C - 0.484; A X B X C - 0.685										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 41b. Effect of different organic sources on fine particulate carbon nitrogen ratio of sub-surface soil

Treatments	Fine particulate C:N ratio									
	Virippu					**Mundakan**				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	3.07	1.72	5.29	6.47	5.96	1.54	1.58	5.90	5.30	5.51
N_1	2.24	4.49	5.32	5.93	5.76	1.57	4.29	5.65	4.68	6.42
N_2	1.85	5.00	2.50	3.22	6.09	1.86	4.65	2.51	3.00	6.83
N_3	1.14	5.19	4.04	1.79	8.15	1.69	4.43	4.01	1.78	10.96
CD (0.05)- A-NS; B-0.467; C-0.418; A X B - 0.660; AXC-NS; B X C - 0.934; A X B X C - NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 42a. Effect of different organic sources on light fraction carbon nitrogen ratio of surface soil

Treatments	Light fraction C:N ratio									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	6.24	7.67	11.28	12.34	21.42	6.08	7.48	10.85	11.93	21.05
N_1	7.70	10.74	12.39	12.32	23.94	7.43	10.43	11.72	11.81	23.55
N_2	10.30	10.82	14.43	12.19	33.96	10.12	10.43	13.85	11.68	32.48
N_3	6.60	9.46	8.69	8.07	34.14	6.47	8.91	8.56	7.74	32.56
CD (0.05)- A-0.120; B-0.190; C-0.170 ; A X B - 0.241; AXC-NS; B X C - 0.380; A X B X C - NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 42b. Effect of different organic sources on light fraction carbon nitrogen ratio of sub-surface soil

Treatments	Light fraction C:N ratio									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	10.25	12.71	7.57	7.83	8.11	9.72	5.76	6.86	7.01	8.34
N_1	13.45	8.17	8.08	8.18	7.64	13.00	7.65	7.11	7.29	7.42
N_2	13.02	9.21	10.07	7.36	7.44	12.75	8.39	9.41	6.72	7.83
N_3	12.00	7.62	7.21	11.25	9.09	11.65	6.55	6.86	10.25	9.16
CD (0.05)- A-0.345; B-0.546; C-0.488; A X B - 0.772; AXC-0.690; B X C - 1.091; A X B X C - 1.543										

A- Cropping season ; B- Organic source ; C- Nitrogen level

with RHB showed very high values compared to other treatments. During mundakan season, the CN ratio was slightly reduced to a value of 32.56 for the same treatment. The treatments did not differ significantly with each other.

The sub-surface soil LCN value was significantly higher (Table 42b) for the treatment, no organic source with 35 kg N ha^{-1} with values of 13.45 and 13.00 in virippu and mundakan seasons respectively. The treatments with higher doses of nitrogen were on par.

Intra light fraction C:N ratio (iLCN)

The data regarding surface soil iLCN are given in Table 43a. The ratio was also maximum in RHB treatment (33.27) in virippu season and 32.44 in mundakan season. The treatments did not differ significantly with each other. Similar to the LCN, iLCN values were also higher for the RHB treatments.

Maximum value (Table 43b) of sub-surface soil iLCN was recorded in the treatment RHB without any N dose (27.82) in virippu season and 26.90 in mundakan season respectively.

Heavy fraction C:N ratio (HCN)

The Table 44a show that in surface soil, the maximum value was obtained for the treatment without any organic or inorganic source with values being 8.11 during virippu and 8.04 during mundakan seasons.

The highest sub-surface soil HCN value (Table 44b) was observed for the treatment 105 kg N ha^{-1} alone (14.75) in virippu season. Rice husk biochar without any N source also showed an on par value of 14.12. Similar trend was observed in mundakan season also with the highest value of 13.56 observed in the control treatment. The treatment with 105 kg N ha^{-1} alone also recorded value of 13.55 which was on par with the highest value.

Mineral associated C:N ratio (MCN)

The data on surface soil MCN indicated that the maximum (Table 45a) value was noticed in the control treatment (1.33) in virippu season and 2.17 in mundakan

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season. The highest sub-surface soil MCN value (Table 45b) was recorded in the treatment daincha + 105 kg N ha^{-1} showing values of 0.46 and 0.48 in virippu and mundakan seasons respectively. The treatments did not differ significantly with each other.

Table 43a. Effect of different organic sources on intra light fraction carbon nitrogen ratio of surface soil

Treatments	Intra light fraction C:N ratio									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	9.60	7.13	8.13	7.81	33.27	9.10	6.93	7.67	7.40	32.44
N_1	6.81	7.37	7.72	7.91	21.61	6.06	6.98	7.36	7.65	21.54
N_2	6.57	14.14	0.28	16.54	27.79	6.33	13.51	0.42	15.68	26.66
N_3	7.61	7.57	1.02	8.49	28.85	7.31	7.37	1.10	8.10	26.99
CD (0.05)-	**A-0.151; B-0.239; C-0.214; A X B - 0.338; AXC-NS; B X C - 0.477; A X B X C - NS**									

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 43b. Effect of different organic sources on intra light fraction carbon nitrogen ratio of sub-surface soil

Treatments	Intra light fraction C:N ratio									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	14.23	8.91	4.84	7.51	27.82	8.54	8.93	4.80	7.36	26.90
N_1	8.94	8.82	8.82	5.13	4.81	8.47	8.59	8.75	4.87	4.52
N_2	8.71	9.90	15.04	8.26	6.55	8.52	9.50	14.39	8.06	6.32
N_3	6.61	7.77	7.99	8.13	8.33	6.52	7.65	7.81	7.80	8.08
CD (0.05)-	**A-0.104; B-0.164; C-0.147; A X B - 0.232; AXC-0.207; B X C - 0.328; A X B X C - 0.464**									

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 44a. Effect of different organic sources on heavy fraction carbon nitrogen ratio of surface soil

Heavy fraction C:N ratio										
Treatments	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	8.11	5.15	5.75	6.41	7.45	8.04	5.03	5.87	5.97	6.96
N_1	4.21	6.23	4.90	5.90	6.88	3.94	4.77	4.39	5.82	6.75
N_2	4.35	6.70	6.57	6.16	6.79	4.19	7.50	6.29	5.76	6.38
N_3	4.49	5.59	6.28	5.92	7.48	4.14	4.81	6.03	5.73	7.01
CD (0.05)- A-0.054; B-0.085; C-0.076; A X B - NS; AXC-0.108; B X C - 0.171; A X B X C - 0.241										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 44b. Effect of different organic sources on heavy fraction carbon nitrogen ratio of sub-surface soil

Heavy fraction C:N ratio										
Treatments	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	11.42	4.96	6.97	7.26	14.12	13.56	4.61	6.58	7.04	12.96
N_1	2.94	7.11	9.16	7.04	6.69	2.79	6.59	9.36	4.34	5.92
N_2	6.83	6.60	4.97	7.46	4.74	6.10	6.00	4.75	6.71	3.97
N_3	14.75	6.39	3.22	7.86	6.26	13.55	6.08	2.87	7.01	5.60
CD (0.05)- A-0.152; B-0.240; C-0.214; A X B - 0.339; AXC-0.303; B X C - 0.479; A X B X C - 0.678										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 45a. Effect of different organic sources on mineral associated carbon nitrogen ratio of surface soil

Treatments	Mineral associated C:N ratio									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	1.33	0.28	0.39	0.29	0.22	2.17	0.31	0.43	0.38	0.35
N_1	0.67	0.41	0.17	0.19	0.41	0.83	0.44	0.24	0.25	0.49
N_2	0.58	0.16	0.23	0.19	0.45	1.08	0.19	0.30	0.31	0.53
N_3	0.85	0.30	0.26	0.24	0.14	1.22	0.34	0.36	0.30	0.26
CD (0.05)- A-0.032; B-0.050; C-0.045; A X B - 0.071; AXC-0.063; B X C - 0.100; A X B X C - 0.142										

A- Cropping season ; B- Organic source ; C- Nitrogen level

Table 45b. Effect of different organic sources on mineral associated carbon nitrogen ratio of sub-surface soil

Treatments	Mineral associated C:N ratio									
	Virippu					Mundakan				
	NOM	FYM	ART	DNC	RHB	NOM	FYM	ART	DNC	RHB
N_0	0.36	0.19	0.35	0.30	0.28	0.39	0.21	0.44	0.35	0.33
N_1	0.26	0.33	0.32	0.22	0.28	0.28	0.39	0.37	0.26	0.35
N_2	0.26	0.24	0.31	0.32	0.28	0.25	0.30	0.41	0.37	0.38
N_3	0.39	0.32	0.34	0.46	0.27	0.40	0.41	0.36	0.48	0.30
CD (0.05) - A-0.017; B-0.028; C-0.025; A X B - NS; AXC-NS; B X C – 0.055; A X B X C - NS										

A- Cropping season ; B- Organic source ; C- Nitrogen level

4.1.3. Plant nutrient characteristics

4.1.3.1. *Nutrient content in grain*

Nitrogen

The highest N content of 1.25 per cent was observed during virippu season in the treatment daincha with 35 and 70 kg N ha^{-1} (Table 46a) and FYM with 70 kg N ha^{-1}. Daincha+105 kg N ha^{-1} and FYM + 35 kg N ha^{-1} also recorded an on par value of 1.24 per cent.

Maximum value (Table 46b) in mundakan was obtained with FYM + 70 kg N ha^{-1} (1.29%). Daincha with various doses of nirtrogen and FYM with higher level of N were found to be on par with this value.

Phosphorus

Table 47a showed that maximum phosphorus content in virippu was in the treatment, daincha with 35 kg N ha^{-1} and FYM with 70 kg N ha^{-1} with a value of 0.19 per cent. Daincha with higher doses of N, FYM with 35 kg N ha^{-1} and RHB with 70 kg N ha^{-1} were on par with each other.

The highest value for the phosphorus content in mundakan (Table 47b) was observed in ART with 105 kg N ha^{-1} (0.31%). During this season, the treatment daincha without N showed a very close value of 0.30 per cent.

Potassium

The data in Table 48a revealed that maximum K content in virippu was for FYM with 70 kg N ha^{-1} (0.26%). The treatments, daincha and FYM with 35 kg N ha^{-1} showed same value of 0.25 per cent.

The highest content in mundakan (Table 48b) was obtained with FYM + 105 kg N ha^{-1} (0.27%) followed by FYM + 70 kg N ha^{-1} and daincha + 35/105kg N ha^{-1} which recorded a value of 0.26 per cent.

Table 46a. Effect of different organic sources on nitrogen content in rice grain in virippu season

Nitrogen (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	1.15	1.17	1.17	1.20
FYM	1.18	1.24	1.25	1.23
ART	1.16	1.17	1.20	1.19
DNC	1.20	1.25	1.25	1.24
RHB	1.16	1.17	1.21	1.20
CD(0.05) - A- 0.010; B -0.009 ; A X B- 0.020				

A- Organic source ; B- Nitrogen level

Table 46b. Effect of different organic sources on nitrogen content in rice grain inmundakan season

Nitrogen (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	1.16	1.18	1.21	1.22
FYM	1.21	1.23	1.29	1.26
ART	1.16	1.21	1.23	1.24
DNC	1.23	1.28	1.28	1.26
RHB	1.18	1.19	1.19	1.22
CD(0.05) - A- 0.016 l; B -0.015 ; A X B - 0.033				

A- Organic source ; B- Nitrogen level

Table 47a. Effect of different organic sources on phosphorus content in rice grain in virippu season

Phosphorus (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.14	0.17	0.16	0.17
FYM	0.16	0.18	0.19	0.16
ART	0.14	0.16	0.14	0.16
DNC	0.15	0.19	0.18	0.18
RHB	0.14	0.16	0.18	0.16
CD (0.05) - A- 0.008 ; B -0.007 ; A X B -0.016				

A- Organic source ; B- Nitrogen level

Table 47b. Effect of different organic sources on phosphorus content in rice grain in mundakan season

Phosphorus (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.18	0.18	0.20	0.24
FYM	0.23	0.24	0.24	0.21
ART.	0.19	0.20	0.25	0.31
DNC	0.30	0.25	0.24	0.23
RHB	0.19	0.22	0.26	0.26
CD(0.05) - A- 0.024 ; B- 0.021 ; A X B --0.047				

A- Organic source ; B- Nitrogen level

Table 48a. Effect of different organic sources on potassium content in rice grain in virippu season

Potassium (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.19	0.22	0.22	0.22
FYM	0.23	0.25	0.26	0.22
ART	0.20	0.20	0.23	0.22
DNC	0.23	0.25	0.23	0.23
RHB	0.19	0.19	0.22	0.18
CD(0.05) - A --0.016 ; B-- 0.014 ; A X B-- NS				

A- Organic source ; B- Nitrogen level

Table 48b. Effect of different organic sources on potassium content in rice grain in mundakan season

Potassium (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.21	0.23	0.24	0.24
FYM	0.24	0.25	0.26	0.27
ART	0.22	0.23	0.20	0.22
DNC	0.24	0.26	0.25	0.26
RHB	0.22	0.22	0.23	0.25
CD (0.05) - A- 0.009 ; B- 0.008 ; A X B --NS				

A- Organic source ; B- Nitrogen level

Calcium

It can be inferred from the Table 49a that in virippu season the treatment, FYM with 70 kg N ha^{-1} recorded a maximum value of 598.69 mg kg^{-1}. The treatments of same organic source with higher level of N daincha /RHB with 70kg N ha^{-1} also showed on par values.

In mundakan season the significant highest Ca content was shown in RHB + 35 kg N ha^{-1} (1986.38 mg kg^{-1}) followed by RHB + 70 kg N ha^{-1} and daincha + 70 kg N ha^{-1} with values 1367.51 mg kg^{-1} and 1362.22 mg kg^{-1} respectively (Table 49b).

Magnesium

The Mg content was significantly higher (Table 50a) in virippu in daincha with 105 kg N ha^{-1} with a value 1122.19 mg kg^{-1}. The treatment ART with 105 kg Nha^{-1} showed a value of 1044.57 mg kg^{-1} whereas other treatment combinations showed relatively lower values.

The maximum Mg content was seen in mundakan in RHB with 70 kg N ha^{-1} (1387.67 mg kg^{-1}). The same organic source with lesser dose of N and daincha with 70 kg N ha^{-1} were on par with the maximum value (Table 50b).

Sulphur

The data from Table 51a on sulphur content indicated that it was significantly maximum in virippu in the treatment FYM with 105 kg N ha^{-1} (414.58 mg kg^{-1}). The treatment FYM with 70 kg N ha^{-1} also showed a closer value of 400.89 mg kg^{-1}.

In mundakan season, the S content (Table 51b) was significantly maximum in FYM with 105 kg N ha^{-1} with a value 328.49 mg kg^{-1}. The treatment FYM + 70 kg N ha^{-1} and ART + 105 kg N ha^{-1} showed on par values of 325.50 and 325.56 mg kg^{-1} respectively.

Iron

Data in Table 52a showed that iron content in virippu season ranged from 302.51 to 612.48 mg kg^{-1} and was significantly maximum in daincha with 105 kg N ha^{-1} (612.48 mg kg^{-1}) followed by the control showing a value of 504.28 mg kg^{-1}.

Table 49a. Effect of different organic sources on calcium content in rice grain in virippu season

Calcium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	389.45	415.42	425.04	450.35
FYM	436.41	510.24	598.69	545.70
ART	420.26	435.49	505.21	517.01
DNC	335.41	531.05	560.19	520.93
RHB	510.35	520.80	556.01	535.07
CD(0.05) - A -32.284; B -28.875; A X B- 64.567				

A- Organic source ; B- Nitrogen level

Table 49b. Effect of different organic sources on calcium content in rice grain in mundakan season

Calcium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	387.55	406.43	436.93	467.12
FYM	512.24	528.50	425.39	477.51
ART	489.39	494.40	510.38	515.46
DNC	535.92	646.45	1362.22	1144.93
RHB	1147.13	1986.38	1367.51	534.01
CD(0.05)- A- 2.366 ; B- 2.116 ; A X B -4.732				

A- Organic source ; B- Nitrogen level

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Table 50a. Effect of different organic sources on magnesium content in rice grain in virippu season

Magnesium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	374.19	418.00	408.24	843.68
FYM	646.78	545.53	529.30	458.20
ART	389.08	613.78	994.10	1044.57
DNC	677.59	812.45	934.64	1122.19
RHB	489.20	610.35	672.47	659.04
CD(0.05) - A -18.982; B -16.978 ; A X B -37.964				

A- Organic source ; B- Nitrogen level

Table 50b. Effect of different organic sources on magnesium content in rice grain in mundakan season

Magnesium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	824.51	994.43	1024.48	1057.33
FYM	1044.05	1067.93	1145.31	1113.76
ART	1015.07	1024.44	1053.75	1074.65
DNC	1076.87	1267.13	1311.83	1278.38
RHB	1152.42	1371.13	1387.67	1181.67
CD - A -44.018; B- 39.371; A X B- 88.036				

A- Organic source ; B- Nitrogen level

Table 51a. Effect of different organic sources on sulphur content in rice grain in virippu season

Sulphur (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	344.61	347.07	348.45	351.87
FYM	347.46	378.22	400.89	414.58
ART	347.30	350.53	353.08	354.73
DNC	349.34	367.60	365.24	365.59
RHB	346.48	350.64	353.43	354.04
CD(0.05) - A- 0.932 ; B- 0.833; A X B -1.863				

A- Organic source ; B- Nitrogen level

Table 51b. Effect of different organic sources on sulphur content in rice grain in mundakan season

Sulphur (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	302.64	307.50	308.53	311.49
FYM	307.65	309.81	325.50	328.49
ART	308.57	310.49	312.53	325.56
DNC	309.36	313.43	318.17	321.28
RHB	312.35	313.46	311.54	311.66
CD(0.05)- A- 0.962 ; B- 0.861; A X B- 1.924				

A- Organic source ; B- Nitrogen level

Table 52a. Effect of different organic sources on iron content in rice grain in virippu season

Iron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	504.28	476.55	444.41	420.44
FYM	302.51	389.49	435.55	402.58
ART	305.55	376.91	398.91	323.60
DNC	348.49	410.45	467.50	612.48
RHB	303.60	375.71	343.61	465.25
CD(0.05) - A- 1.286; B- 1.150 ; A X B- 2.572				

A- Organic source ; B- Nitrogen level

Table 52b. Effect of different organic sources on iron content in rice grain in mundakan season

Iron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	3,390.89	3,692.76	3,829.76	4,736.63
FYM	3,466.05	3,702.39	3,260.99	3,453.24
ART	2,989.95	2,546.78	2,228.21	1,733.18
DNC	1,579.42	1,350.48	1,084.28	1,141.48
RHB	1,031.16	1,346.37	1,265.11	1,072.54
CD (0.05)- A- 24.305 B- 21.739 A X B -48.609				

A- Organic source ; B- Nitrogen level

In mundakan season, significantly maximum Fe content (Table 52b) was noted in the treatment with 105 kg N ha^{-1} alone with a value 4736.63 mg kg^{-1} followed by treatment with 70 kg N ha^{-1} (3829.76 mg kg^{-1}). The values ranged from 1031.16 to 4736.63 mg kg^{-1}.

Manganese

Maximum Mn content in virippu season was seen in daincha with 35 kg N ha^{-1} with a value 46.90 mg kg^{-1} (Table 53a) followed by 44.18 mg kg^{-1} recorded in the treatment using the same organic source with 105 kg N ha^{-1}.

The Mn content (Table 53b) in mundakan was significantly maximum in RHB with 70 kg N ha^{-1} (33.95 mg kg^{-1}). The treatments of the 105 kg N ha^{-1} alone showed an on par value of 33.56 mg kg^{-1}.

Zinc

It can be inferred from Table 54a that in virippu, the zinc content was significantly maximum in FYM with 105 kg N ha^{-1} (3.85 mg kg^{-1}). It was also seen that FYM with 70kg N ha^{-1} showed a closer value of 3.57 mg kg^{-1}. The data also showed that zinc content could not be detected in the treatments where organic source was not integrated, except the highest level of nitrogen dose applied.

In mundakan season the Zn content (Table 54b) was significantly maximum in FYM + 105 kg N ha^{-1} with a value 3.80 mg kg^{-1} followed by FYM with 70 kg N ha^{-1} which had a value of 3.58 mg kg^{-1}. The zinc content was below detectable level in the treatments where inorganic nitrogen alone was applied as in the case of virippu season.

Copper

A perusal of data in Table 55a showed that in virippu, copper content was significantly maximum in FYM with 105 kg N ha^{-1} (1.56 mg kg^{-1}). Farm yard manure with 70 kg N ha^{-1} showed an on par value of 1.52 mg kg^{-1}. The treatments where fertilizer alone was applied showed non detectable levels of copper.

Table 53a. Effect of different organic sources on manganese content in rice grain in virippu season

Manganese (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	17.39	21.41	23.31	18.18
FYM	21.56	36.76	35.28	25.86
ART	20.19	22.32	25.54	24.60
DNC	29.01	46.90	43.49	44.18
RHB	25.42	31.40	39.52	36.55
CD(0.05) - A- 0.622; B- 0.55 ; A X B- 1.244				

A- Organic source ; B- Nitrogen level

Table 53b. Effect of different organic sources on manganese content in rice grain in mundakan season

Manganese (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	24.82	27.03	29.44	33.56
FYM	28.38	30.95	28.68	31.22
ART	18.73	20.46	23.65	24.43
DNC	25.07	27.01	30.10	30.89
RHB	28.51	30.56	33.95	31.84
CD(0.05) - A- 0.815; B- 0.729; A X B- 1.631				

A- Organic source ; B- Nitrogen level

Table 54a. Effect of different organic sources on zinc content in rice grain in virippu season

Zinc (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	ND	ND	ND	1.84
FYM	2.58	3.45	3.57	3.85
ART	2.19	2.20	2.24	2.28
DNC	2.78	2.84	2.96	3.05
RHB	2.24	2.31	2.33	2.35
CD(0.05) - A-- 0.056; B-- 0.050; A X B-- 0.112				

ND - Not Detectable;

A- Organic source ; B- Nitrogen level

Table 54b. Effect of different organic sources on zinc content in rice grain in mundakan season

Zinc (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	ND	ND	ND	1.24
FYM	2.47	3.23	3.58	3.80
ART	2.81	2.20	2.26	2.28
DNC	2.66	2.81	2.95	3.04
RHB	2.54	2.33	2.35	2.36
CD (0.05)- A-- 0.321; B-- 0.287; A X B-- 0.642				

ND - Not Detectable

A- Organic source ; B- Nitrogen level

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Table 55a. Effect of different organic sources on copper content in rice grain in virippu season

	Copper (mg kg^{-1})			
Treatments	N_0	N_1	N_2	N_3
NOM	ND	ND	ND	ND
FYM	1.30	1.43	1.52	1.56
ART	1.01	1.00	1.05	1.10
DNC	1.10	1.12	1.15	1.20
RHB	1.10	1.10	1.13	1.15
CD(0.05) - A-- 0.038 ; B-- 0.034; A X B-- 0.076				

ND - Not Detectable

A- Organic source ; B- Nitrogen level

Table 55b. Effect of different organic sources on copper content in rice grain in mundakan season

	Copper (mg kg^{-1})			
Treatments	N_0	N_1	N_2	N_3
NOM	ND	ND	ND	ND
FYM	1.31	1.44	1.53	1.57
ART	1.00	1.00	1.06	1.20
DNC	1.13	1.14	1.15	1.17
RHB	1.12	1.13	1.13	1.14
CD (0.05)- A-- 0.028; B-- 0.025; A X B-- 0.05				

ND - Not Detectable

A- Organic source ; B- Nitrogen level

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In mundakan season, the Cu content was significantly maximum (Table 55b) in FYM + 105 kg N ha^{-1} with a value 1.57 mg kg^{-1}. Farmyard manure with 70 kg N ha^{-1} showed a slightly lower value of 1.53 mg kg^{-1}. The same trend of non-detectable levels were noticed here also.

Boron

The B content in virippu season ranged from 1.03 mg kg^{-1} in the control to 1.36 mg kg^{-1} in FYM with 105 kg N ha^{-1} (Table 56a). The treatments were found to be non significant with each other.

The B content in mundakan (Table 56b) was significantly maximum in daincha with 70 kg N ha^{-1} (1.30 mg kg^{-1}). The treatments of the same organic source with different levels of N and FYM + 70 kg N ha^{-1} showed on par values.

4.1.3.2. *Nutrient content in straw*

Nitrogen

The highest significant nitrogen content was observed (Table 57a) in virippu in the treatment, FYM with 105 kg N ha^{-1} (0.64%). The treatment, daincha with 35 kg N ha^{-1} and FYM with 70 kg N ha^{-1} recorded on par values of 0.61 and 0.60 per cent respectively.

The significant highest content of nitrogen with a value of 0.65 per cent was seen in FYM with 105 kg N ha^{-1} (Table 57b) in mundakan season. The treatment with same organic source and 70 kg N ha^{-1} also recorded an on par value of 0.63 per cent. Treatments, daincha and FYM with 35 kg N ha^{-1} were on par with each other with values of 0.60 and 0.59 per cent respectively.

Phosphorus

Data from Table 58a revealed that in virippu season, phosphorus content was the highest (1.18%) in daincha with 35 kg N ha^{-1}. Treatments with the same organic source with higher doses of N also recorded values above one per cent.

Plants which received the treatment, daincha with 105 kg N ha^{-1} showed maximum value of 0.20 per cent (Table 58b) for phosphorus in mundakan season.

Table 56a. Effect of different organic sources on boron content in rice grain in virippu season

Boron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	1.03	1.16	1.16	1.17
FYM	1.29	1.30	1.35	1.36
ART	1.14	1.22	1.32	1.33
DNC	1.25	1.32	1.33	1.33
RHB	1.18	1.20	1.22	1.23
CD (0.05) - A- 0.039; B- 0.034; A X B –NS				

A- Organic source ; B- Nitrogen level

Table 56b. Effect of different organic sources on boron content in rice grain in mundakan season

Boron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	0.93	1.05	1.08	1.21
FYM	1.22	1.17	1.25	1.24
ART	0.98	1.13	1.13	1.13
DNC	1.21	1.25	1.30	1.26
RHB	1.12	1.17	1.18	1.18
CD(0.05)- A- 0.040; B- 0.036; A X B- 0.079				

A- Organic source ; B- Nitrogen level

Table 57a. Effect of different organic sources on nitrogen content in rice straw in virippu season

Nitrogen (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.35	0.37	0.42	0.47
FYM	0.46	0.55	0.60	0.64
ART	0.40	0.43	0.46	0.50
DNC	0.47	0.61	0.55	0.50
RHB	0.42	0.45	0.47	0.48
CD (0.05)- A- 0.013;; B- 0.011; A X B- 0.025				

A- Organic source ; B- Nitrogen level

Table 57b. Effect of different organic sources on nitrogen content in rice straw in mundakan season

Nitrogen (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.40	0.42	0.44	0.46
FYM	0.46	0.59	0.63	0.65
ART	0.42	0.44	0.45	0.51
DNC	0.49	0.60	0.56	0.52
RHB	0.43	0.45	0.48	0.50
CD (0.05)- A -0.008; B -0.007; A X B- 0.016				

A- Organic source ; B- Nitrogen level

Table 58a. Effect of different organic sources on phosphorus content in rice straw in virippu season

Phosphorus (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.05	0.07	0.08	0.39
FYM	0.08	0.76	0.12	0.08
ART	0.06	0.07	0.39	0.08
DNC	0.08	1.18	1.11	1.10
RHB	0.06	0.08	0.44	0.42
CD (0.05)-	**A- 0.225;**	**B -0.201;**	**A X B- 0.449**	

A- Organic source ; B- Nitrogen level

Table 58b. Effect of different organic sources on phosphorus content in rice straw in mundakan season

Phosphorus (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.07	0.09	0.12	0.14
FYM	0.12	0.15	0.18	0.19
ART	0.13	0.13	0.15	0.17
DNC	0.12	0.18	0.19	0.20
RHB	0.13	0.14	0.16	0.17
CD (0.05)-	**A- 0.009;**	**B- 0.008;**	**A X B- 0.019**	

A- Organic source ; B- Nitrogen level

Daincha with lesser doses of N (35 kg N ha^{-1}) and also FYM + 105 kg N ha^{-1} also showed on par values of 0.18 and 0.19 per cent respectively.

Potassium

The K content was maximum in virippu for the treatment, daincha + 35 kg N ha^{-1} and control with a value of 1.24 per cent (Table 59a). Treatments with same organic source and higher levels of nitrogen and FYM with same levels of nitrogen were on par with each other.

The highest K content in mundakan (Table 59b) was seen in daincha with 105 kg N ha^{-1} (1.51%). The treatments, daincha + 70 kg N ha^{-1} and FYM +105 kg N ha^{-1} showed similar value (1.50 %).

Calcium

The significant highest Ca content in virippu was found to be in (Table 60a) daincha with 105 kg N ha^{-1} which recorded a value of 6954.06 mg kg^{-1}. Rice husk biochar with 35 kg N ha^{-1} also recorded a value of 5803.96 mg kg^{-1}.

During mundakan season, rice husk biochar with 35 kg N ha^{-1} recorded significant maximum content (Table 60b) of 5590.11 mg kg^{-1} followed by daincha with 105 kg N ha^{-1} with a value of 4946.73 mg kg^{-1}.

Magnesium

It can be seen from the Table 61a, in virippu the treatment daincha with 105 kg N ha^{-1} recorded significant maximum content of magnesium of 867.39 mg kg^{-1}. Farmyard manure with 105 kg N ha^{-1} showed a slightly lesser value of 853. 56 mg kg^{-1}.

Magnesium was significantly highest in mundakan (Table 61b) in daincha with 105 kg N ha^{-1} (1114.73 mg kg^{-1}). Farmyard manure with 105 kg N ha^{-1} recorded a closer value of 1009.55 mg kg^{-1}.

Sulphur

The highest content of 473.92 mg kg^{-1} in virippu was obtained for daincha with 70 kg N ha^{-1}(Table 62a). Treatment with same organic source and higher dose of

Table 59a. Effect of different organic sources on potassium content in rice straw in virippu season

Potassium (%)				
Treatments	N_0	N_1	N_2	N
NOM	0.95	1.12	1.17	1.24
FYM	1.19	1.22	1.23	1.23
ART	1.12	1.15	1.20	1.19
DNC	1.20	1.24	1.23	1.23
RHB	1.15	1.15	1.17	1.23
CD (0.05)- A -0.017; B- 0.015; A X B -0.034				

A- Organic source ; B- Nitrogen level

Table 59b. Effect of different organic sources on potassium content in rice straw in mundakan season

Potassium (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	1.18	1.25	1.35	1.42
FYM	1.36	1.41	1.48	1.50
ART	1.29	1.32	1.35	1.39
DNC	1.42	1.48	1.50	1.51
RHB	1.28	1.30	1.34	1.36
CD (0.05)- A- 0.011; B- 0.010; A X B- 0.022				

A- Organic source ; B- Nitrogen level

Table 60a. Effect of different organic sources on calcium content in rice straw in virippu season

Calcium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	2,536.36	3,114.47	4,605.45	3,535.79
FYM	3,353.56	3,547.82	3,559.57	3,409.77
ART	3,341.31	3,553.26	2,442.94	2,652.27
DNC	2,794.46	3,229.71	2,901.61	6,954.06
RHB	3,422.30	5,803.96	3,621.63	2,428.99
CD (0.05)- A-28.39; B-25.40; A X B-56.78				

A- Organic source ; B- Nitrogen level

Table 60b. Effect of different organic sources on calcium content in in rice straw in mundakan season

Calcium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	2,352.57	3,703.52	4,113.43	3,313.09
FYM	3,235.79	3,343.55	3,458.00	3,210.31
ART	3,166.39	3,636.40	3,114.73	4,027.78
DNC	4,136.27	4,080.88	2,573.54	4,946.73
RHB	2,627.92	5,590.11	3,419.77	2,131.83
CD(0.05) - A-22.34; B-19.98; A X B-44.68				

A- Organic source ; B- Nitrogen level

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Table 61a. Effect of different organic sources on magnesium content in rice straw in virippu season

Magnesium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	649.39	727.03	746.44	808.93
FYM	782.81	823.25	843.65	853.56
ART	708.61	763.34	627.68	714.05
DNC	610.29	648.16	687.51	867.39
RHB	713.60	713.81	768.32	784.98
CD(0.05) - A-- 2.514; B-- 2.248; A X B-- 5.027				

A- Organic source ; B- Nitrogen level

Table 61b. Effect of different organic sources on magnesium content in rice straw in mundakan season

Magnesium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	753.23	724.64	773.46	777.80
FYM	773.72	864.55	902.15	1009.55
ART	958.12	605.05	610.30	931.22
DNC	863.76	893.46	715.74	1114.73
RHB	744.39	729.41	805.58	851.20
CD (0.05)- A-2.88; B-2.58; A X B-5.76				

A- Organic source ; B- Nitrogen level

Table 62a. Effect of different organic sources on sulphur content in rice straw in virippu season

Sulphur (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	411.31	415.54	423.67	427.43
FYM	412.35	435.44	445.29	448.37
ART	411.26	422.46	426.20	436.50
DNC	420.37	445.89	473.92	472.30
RHB	421.30	427.37	435.73	444.81
CD(0.05)- A-1.14 ; B-1.02 ; A X B--2.28				

A- Organic source ; B- Nitrogen level

Table 62b. Effect of different organic sources on sulphur content in rice straw in mundakan season

Sulphur (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	414.72	422.51	425.96	429.46
FYM	417.03	445.34	457.46	457.85
ART	416.37	422.71	428.92	439.59
DNC	430.55	459.44	484.44	480.63
RHB	428.69	431.19	441.32	451.42
CD (0.05)- A- 1.531; B -1.370; A X B-- 3.063				

A- Organic source ; B- Nitrogen level

N also recorded an on par value of 472.30 mg kg^{-1}. Treatments, daincha with 35 kg N ha^{-1} and FYM with 70 kg N ha^{-1} also showed on par values.

During mundakan season also, the same treatment daincha with 70 kg N ha^{-1} recorded the highest content (Table 62b) of 484.44 mg kg^{-1} followed by an on par value of 480.63 mg kg^{-1} for the treatment with same organic source and inorganic N at 105 kg ha^{-1}.

Iron

Iron content in virippu was found to be significantly highest (Table 63a) in RHB with 105 kg N ha^{-1} with value 3219.10 mg kg^{-1}. The same organic source with 70 kg N ha^{-1} also recorded a closer value of 2167.00 mg kg^{-1}. In general, the treatments with RHB had distinctly higher content of Fe than other treatments.

The results showed that the same trend was repeated for the content of Fe in straw in mundakan season also and a significant higher Fe content (Table 63b) was seen with RHB with105 kg N ha^{-1} (5220.65 mg kg^{-1}) followed by the treatment, ART with 105 kg N ha^{-1} (3808.10 mg kg^{-1}).

Manganese

The significant maximum Mn content in straw in virippu season was seen (Table 64a) with ART+ 35 kg N ha^{-1} (345.84 mg kg^{-1}). Treatments with ART and RHB recorded higher values compared to other organic sources.

The treatment, ART without any added N recorded the highest Mn content of 837.15 mg kg^{-1} (Table 64b) in mundakan. With increasing level of added fertilizer, all the treatment combinations where FYM was the organic source showed an increase in Mn content.

Zinc

It was seen from Table 65a that in virippu the treatment ARTwith 35 kg N ha^{-1} recorded significant maximum zinc content of 50.50 mg kg^{-1}. The treatment ART with 70 kg N ha^{-1} showed a lower content of 45. 23 mg kg^{-1}. The treatments, FYM as well as RHB in combination with graded doses of N fertiliser showed relatively

Table 63a. Effect of different organic sources on iron content in rice straw in virippu season

Iron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	603.37	972.70	1051.16	1587.21
FYM	725.88	955.27	1207.95	840.69
ART	1019.66	1097.26	743.18	1357.21
DNC	1141.95	1316.56	1116.47	1323.51
RHB	1236.49	1713.60	2167.00	3219.10
CD (0.05) - A- 25.282; B- 22.613; A X B-- 50.564				

A- Organic source ; B- Nitrogen level

Table 63b. Effect of different organic sources on iron content in rice straw in mundakan season

Iron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	2,013.39	1,907.00	1,765.93	1,962.66
FYM	1,123.59	1,347.47	1,427.16	919.31
ART	1,242.91	1,537.68	1,235.79	3,808.10
DNC	1,242.88	1,536.15	1,430.87	1,181.82
RHB	1,350.71	2,294.26	3,543.70	5,220.65
CD (0.05)- A- 3.077; B -2.752 ; A X B --6.155				

A- Organic source ; B- Nitrogen level

Table 64a. Effect of different organic sources on manganese content in rice straw in virippu season

Manganese (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	168.89	150.56	208.77	229.29
FYM	167.05	189.87	201.90	237.38
ART	257.66	345.84	235.87	247.44
DNC	173.05	195.00	309.24	136.81
RHB	212.08	235.40	274.22	205.47
CD (0.05)- A- 3.430; B- 3.068; A X B-- 6.860				

A- Organic source ; B- Nitrogen level

Table 64b. Effect of different organic sources on manganese content in rice straw in mundakan season

Manganese (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	198.75	224.60	228.67	248.18
FYM	238.71	278.91	298.99	365.18
ART	837.15	211.32	193.54	226.79
DNC	255.95	268.33	200.84	303.75
RHB	252.40	258.15	223.84	180.16
CD (0.05)- A- NS; B- NS; A X B –NS				

A- Organic source ; B- Nitrogen level

Table 65a. Effect of different organic sources on zinc content in rice straw in virippu season

Zinc (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	5.57	5.80	5.90	6.10
FYM	25.50	27.45	30.23	30.34
ART	34.78	50.50	45.23	43.56
DNC	7.34	8.45	9.58	11.45
RHB	8.50	10.46	37.50	39.34
CD (0.05)- A-- 0.034; B-- 0.030; A X B-- 0.067				

A- Organic source ; B- Nitrogen level

Table 65b. Effect of different organic sources on zinc content in rice straw in mundakan Season

Zinc (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	3.45	3.57	3.50	3.70
FYM	23.34	25.13	27.06	28.00
ART	35.00	38.67	50.35	49.00
DNC	7.89	8.95	9.60	9.50
RHB	8.50	15.36	35.56	34.21
CD (0.05)- A --0.036; B-- 0.032; A X B --0.072				

A- Organic source ; B- Nitrogen level

higher values of Zn than those of daincha. Here with increase in the fertilizer doses, the content of zinc also increased.

The results (Table 65b) were found to follow the same pattern during mundakan season also. Zn was significantly higher in ART +70 kg N ha^{-1} (50.35 mg kg^{-1}). It was found that the treatmentART with 105 kg N ha^{-1} also recorded an on par value of 49.00 mg kg^{-1}. The treatment combinations, where daincha was the organic source, exhibited the lowest value for this nutrient among integrated treatment combinations.

Copper

The treatment, FYM with different doses of N fertiliser recorded higher values than all other treatments in virippu season. The significant highest Cu content was seen in the treatment (Table 66a) FYM with 105 kg N ha^{-1} which recorded 10.34 mg kg^{-1}. The treatment FYM with 70 kg N ha^{-1} recorded a value of 5.70 mg kg^{-1}. All the treatment combinations of other organic sources, exhibited values less than 1.00 mg kg^{-1} for copper.

Farmyard manure +105 kg N ha^{-1} recorded significant maximum content (Table 66b) of 11.25 mg kg^{-1}in mundakan season followed by the same organic source with 70 kg N ha^{-1} (5.83 mg kg^{-1}).

Boron

Data from Table 67a showed that in virippu, the B content was found to be stable with values ranging from 4.12 mg kg^{-1} for control treatment to 5.21 mg kg^{-1} for daincha treatment supplemented with 35 kg N ha^{-1}.

The control treatment and ART without any fertilizer showed the lowest values of 3.79 and 3.91 mg kg^{-1} (Table 67b) respectively in mundakan season. The content was maximum in the treatment with DNC + 35 kg N ha^{-1} (4.61) followed by the same organic source with 70 kg N ha^{-1} (4.60 mg kg^{-1}) which was on par with it.

Table 66a. Effect of different organic sources on copper content in rice straw in virippu season

Copper (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	ND	ND	ND	1.00
FYM	3.00	4.50	5.70	10.34
ART	0.56	0.50	0.50	0.52
DNC	0.54	0.59	0.51	0.64
RHB	0.50	0.50	0.50	0.50
CD (0.05)- A-- 0.061; B-- 0.054; A X B-- 0.121				

ND - Not Detectable

A- Organic source ; B- Nitrogen level

Table 66b. Effect of different organic sources on copper content in rice straw in mundakan season

Copper (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	ND	ND	ND	1.23
FYM	3.23	4.58	5.83	11.25
ART	0.78	0.89	0.95	1.00
DNC	0.60	0.75	1.00	0.87
RHB	0.60	0.55	0.48	0.20
CD (0.05)- A-- 0.039; B-- 0.035; A X B-- 0.077				

ND - Not Detectable

A- Organic source ; B- Nitrogen level

Table 67a. Effect of different organic sources on boron content in rice straw in virippu season

Boron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	4.12	4.36	4.48	4.69
FYM	4.42	4.66	4.90	4.82
ART	4.40	4.54	4.74	4.78
DNC	4.52	5.21	4.84	4.83
RHB	4.37	4.47	4.63	4.70
CD (0.05)-	**A -0.066;**	**B- 0.059;**	**A X B -0.132**	

A- organic source ; B- nitrogen level

Table 67b. Effect of different organic sources on boron content in rice straw in mundakan season

Boron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	3.79	4.03	4.12	4.23
FYM	4.13	4.32	4.51	4.52
ART.	3.91	4.08	4.10	4.20
DNC	4.22	4.61	4.60	4.50
RHB	4.10	4.20	4.30	4.40
CD (0.05)-	**A- 0.025;**	**B- 0.022 ;**	**A X B-- 0.049**	

A- organic source ; B- nitrogen level

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4.1.3.3. *Nutrient content in root*

Nitrogen

The treatment daincha with no added N (Table 68a) recorded maximum value of 0.97 per cent in virippu season. Daincha with 35 kg N ha^{-1} and FYM with different levels of N showed on par values.

In mundakan, daincha with 35 kg N ha^{-1} showed maximum N content (Table 68b) in the root (1.12%). Daincha with 105 kg N ha^{-1} also showed on par value of 1.09 per cent.

Phosphorus

The treatment FYM with 105 kg N ha^{-1} recorded (Table 69a) highest value of 0.19 per cent in virippu season followed by FYM with 70 kg N ha^{-1} with value of 0.18 per cent. The treatment daincha with lower and higher levels of N showed same value of 0.17 per cent which was on par with the highest value.

The P content of root in mundakan (Table 69b) was maximum in the treatemnt FYM with 105 kg N ha^{-1} (0.20%). Treatments, FYM with 70 kg N ha^{-1} and daincha with lower and higher doses of N showed on par values.

Potassium

The maximum K content of root was seen in virippu in FYM with 105 kg N ha^{-1} with a value 0.64 per cent (Table 70a). Daincha with 70 kg N ha^{-1} also showed 0.62 per cent which was on par with this value.

In mundakan season, the significantly highest value (Table 70b) of K was seen in the treatment, daincha with 105 kg N ha^{-1} and also FYM with 70 kg N ha^{-1} (0.62%).

Table 68a. Effect of different organic sources on nitrogen content in rice root in virippu season

Nitrogen (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.82	0.85	0.87	0.88
FYM	0.86	0.94	0.93	0.94
ART	0.83	0.83	0.86	0.93
DNC	0.97	0.94	0.85	0.84
RHB	0.82	0.85	0.88	0.88
CD (0.05)- A- 0.019; B- 0.017 ; A X B --0.038				

A- Organic source ; B- Nitrogen level

Table 68b. Effect of different organic sources on nitrogen content in rice root in mundakan season

Nitrogen (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.90	0.92	0.94	0.96
FYM	0.96	0.99	1.03	1.02
ART	0.93	0.94	0.95	1.00
DNC	1.03	1.12	1.06	1.09
RHB	0.94	0.95	0.98	1.00
CD (0.05)- A-- 0.014; B- 0.013; A X B- 0.029				

A- Organic source ; B- Nitrogen level

Table 69a. Effect of different organic sources on phosphorus content in rice root in virippu season

Phosphorus (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.09	0.10	0.11	0.12
FYM	0.11	0.14	0.18	0.19
ART.	0.10	0.13	0.14	0.15
DNC	0.14	0.17	0.17	0.17
RHB	0.11	0.12	0.14	0.14
CD (0.05)- A-- 0.006; B-- 0.006; A X B-- 0.012				

A- Organic source ; B- Nitrogen level

Table 69b. Effect of different organic sources on phosphorus content in rice root in mundakan season

Phosphorus (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.12	0.13	0.15	0.16
FYM	0.16	0.17	0.18	0.20
ART	0.14	0.15	0.16	0.16
DNC	0.15	0.19	0.18	0.18
RHB	0.14	0.14	0.15	0.17
CD(0.05) - A- 0.008; B-- 0.007; A X B --0.017				

A- Organic source ; B- Nitrogen level

Table 70a. Effect of different organic sources on potassium content in rice root in virippu season

Potassium (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.42	0.45	0.47	0.50
FYM	0.49	0.54	0.60	0.64
ART	0.44	0.46	0.48	0.51
DNC	0.50	0.56	0.62	0.59
RHB	0.46	0.47	0.48	0.49
CD (0.05)- A- 0.012; B- 0.011; A X B- 0.024				

A- Organic source ; B- Nitrogen level

Table 70b. Effect of different organic sources on potassium content in rice root in mundakan season

Potassium (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	0.46	0.48	0.48	0.50
FYM	0.50	0.58	0.62	0.56
ART	0.53	0.47	0.51	0.52
DNC	0.49	0.59	0.59	0.62
RHB	0.49	0.51	0.55	0.56
CD (0.05)- A -0.010; B- 0.009 ; A X B- 0.020				

A- Organic source ; B- Nitrogen level

Calcium

Maximum Ca content in virippu was seen (Table 71a) in FYM + 35 kg N ha^{-1} which recorded a value of 2508.92 mg kg^{-1}. In general, the treatments with FYM as organic source recorded higher values of Ca in the root followed by RHB.

The treatment without any added organic source but with 35 kg N ha^{-1} recorded maximum Ca content (Table 71b) in mundakan season (4817.24 mg kg^{-1}). The treatment with no added nitrogen and organic source showed a value of 2289.04 mg kg^{-1} during this season.

Magnesium

From a perusal of data shown in Table 72a, it was found that the Mg content was significantly the highest with RHB + 35 kg N ha^{-1} (819.87 mg kg^{-1}). The treatment consisting of same organic source with lower and higher doses of N showed on par values.

Magnesium content in mundakan (Table 72b) was found to be the highest and significant (881.25 mg kg^{-1}) in the treatment with ART and 105 kg N ha^{-1} followed by FYM without any N with a value of 863.76 mg kg^{-1}.

Sulphur

The maximum significant S content in virippu (Table 73a) was observed in the treatment, daincha with 70 kg N ha^{-1} with a value of 380.51 mg kg^{-1} followed by daincha with 105 kg N ha^{-1} (372.59 mg kg^{-1}). Farmyard manure either with 70 or with 105kg N ha^{-1} showed values of 354.20 and 354.07 mg kg^{-1} which were on par.

The S content in mundakan (Table 73b) was maximum in daincha with 70 kg N ha^{-1} with a value 383.78 mg kg^{-1} followed by the value of 375.95 mg kg^{-1} shown by daincha with higher dose of N. As in case of virippu, FYM with 70/105 kg N ha^{-1} were on par.

Table 71a. Effect of different organic sources on calcium content in rice root in virippu season

Calcium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	623.38	609.61	371.28	662.30
FYM	1044.31	2508.92	1446.36	920.28
ART	477.81	510.47	464.52	577.75
DNC	378.42	384.39	643.51	555.22
RHB	674.48	830.10	990.23	1315.68
CD (0.05)- A -7.477; B- 6.687; A X B --14.954				

A- Organic source ; B- Nitrogen level

Table 71b. Effect of different organic sources on calcium content in rice root in mundakan season

Calcium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	2289.04	4817.24	879.85	1513.71
FYM	1641.70	370.07	963.94	869.60
ART	662.39	779.23	3085.84	1643.18
DNC	962.59	1148.60	1353.50	664.63
RHB	693.05	1330.32	1870.81	585.03
CD (0.05)- A- 38.968; B- 34.854; A X B --77.936				

A- Organic source ; B- Nitrogen level

Table 72a. Effect of different organic sources on magnesium content in rice root in virippu season

Magnesium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	412.23	598.86	359.88	561.27
FYM	635.56	392.10	642.12	524.07
ART	514.10	625.65	516.64	424.17
DNC	402.90	405.35	524.61	712.47
RHB	794.65	819.87	787.27	664.42
CD (0.05)- A- 8.103; B- 7.248; A X B-- 16.207				

A- Organic source ; B- Nitrogen level

Table 72b. Effect of different organic sources on magnesium content in rice root in mundakan season

Magnesium (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	327.91	510.25	675.34	589.77
FYM	863.76	350.24	551.94	578.87
ART	538.34	597.78	569.74	881.25
DNC	567.25	588.18	621.79	498.33
RHB	540.35	483.52	844.94	451.37
CD (0.05)- A-- 11.997; B-- 10.730 ; A X B-- 23.993				

A- Organic source ; B- Nitrogen level

Table 73a. Effect of different organic sources on sulphur content in rice root in virippu season

Sulphur (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	311.12	319.41	321.98	325.24
FYM	313.37	341.68	354.20	354.07
ART	313.24	316.97	322.95	333.95
DNC	327.66	355.14	380.51	372.59
RHB	332.14	328.36	334.29	347.15
CD (0.05)- A- 3.434; B- 3.071; A X B-- 6.867				

A- Organic source ; B- Nitrogen level

Table 73b. Effect of different organic sources on sulphur content in rice root in mundakan season

Sulphur (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	313.36	321.49	323.63	327.06
FYM	315.55	344.72	356.19	357.31
ART	315.85	319.29	328.60	339.11
DNC	329.53	358.88	383.78	375.95
RHB	334.42	331.15	338.01	350.63
CD (0.05)- A- 3.203; B - 2.865; A X B -- 6.406				

A- Organic source ; B- Nitrogen level

Iron

Table 74a showed that Fe content in virippu was significantly maximum in the treatment with RHB applied alone as organic source (28692.67 mg kg^{-1}) followed by daincha with 105 kg N ha^{-1} with a value 26939.00 mg kg^{-1}. The treatments, FYM without N, with 70 kg N ha^{-1} and also 105 kg N ha^{-1} inorganic source were on par showing values of 25766.00 and 25348.00 mg kg^{-1} respectively.

In mundakan season, the Fe content (Table 74b) was significantly maximum in RHB with 35 kg N ha^{-1} (39536.33 mg kg^{-1}). The treatment ART with 35 kg N ha^{-1} showed a closer value of 38725.67 mg kg^{-1} followed by ART with 105 kg N ha^{-1} (37445.00 mg kg^{-1}).

Manganese

The content of Mn in virippu was significantly higher (Table 75a) in FYM alone (46.29 mg kg^{-1}). Rice husk biochar without any N and FYM with 70 kg N ha^{-1} showed on par values of 42.22 mg kg^{-1} and 42.18 mg kg^{-1} respectively.

During mundakan season, Mn content was maximum (Table 75b) in RHB with 70 kg N ha^{-1} (77.58 mg kg^{-1}) with an on par value of 76.88 mg kg^{-1} from the control treatment.

Zinc

Zn content in virippu was significantly the highest (Table 76a) for RHB with 105 kg N ha^{-1} (25.00 mg kg^{-1}). Rice husk biochar with lesser doses of N showed on par values of 24.50 and 24.60 mg kg^{-1} respectively. In control and treatments with only graded doses of N fertilizers, the zinc content could not be traced.

During mundakan season, Zn content was maximum (Table 76b) in RHB with 105 kg N ha^{-1} (26.70 mg kg^{-1}) with an on par value of 26.12 mg kg^{-1} from the lower N dose (70 kg N ha^{-1}).

Table 74a. Effect of different organic sources on iron content in rice root in virippu season

Iron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	19,749.67	23,938.67	23,624.67	25,715.33
FYM	25,766.00	17,081.00	25,348.00	23,801.33
ART	22,266.00	22,850.33	18,697.67	19,317.33
DNC	15,159.00	16,517.33	20,447.67	26,939.00
RHB	28,692.67	17,962.33	15,457.00	17,798.00
CD (0.05)- A -885.078 ; B- 885.078 ; A X B ---1,770.155				

A- Organic source ; B- Nitrogen level

Table 74b. Effect of different organic sources on iron content in rice root in mundakan season

Iron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	22,722.00	20,175.00	37,249.00	17,524.00
FYM	33,526.00	21,332.67	25,011.00	22,548.33
ART	32,442.33	38,725.67	28,169.00	37,445.00
DNC	33,888.00	34,559.00	35,619.00	22,904.67
RHB	28,325.33	39,536.33	30,652.67	33,230.67
CD (0.05)- A- 119.709 ; B- 107.071 ; A X B --239.419				

A- Organic source ; B- Nitrogen level

Table 75a. Effect of different organic sources on manganese content in rice root in virippu season

Manganese (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	35.84	33.73	24.90	37.59
FYM	46.29	18.29	42.18	43.50
ART	35.38	35.68	33.88	31.17
DNC	20.80	21.52	0.81	33.22
RHB	42.22	34.01	37.34	25.37
CD (0.05)- A- 1.228; B-1.099; A X B --2.457				

A- Organic source ; B- Nitrogen level

Table 75b. Effect of different organic sources on manganese content in rice root in mundakan season

Manganese (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	76.88	33.06	54.88	26.85
FYM	55.07	46.12	31.73	27.33
ART	45.52	54.00	52.08	55.42
DNC	58.76	36.09	46.33	33.03
RHB	45.92	47.59	77.58	64.41
CD (0.05)- A -2.052 ; B -1.836; A X B- 4.105				

A- Organic source ; B- Nitrogen level

Table 76a. Effect of different organic sources on zinc content in rice root in virippu season

Zinc (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	ND	ND	ND	ND
FYM	11.50	11.70	12.40	12.80
ART	1.00	1.45	1.78	2.00
DNC	12.00	12.30	12.34	12.54
RHB	24.00	24.50	24.60	25.00
CD (0.05)- A-- 0.040 ; B-- 0.035; A X B-- 0.079				

ND - Not Detectable

A- Organic source ; B- Nitrogen level

Table 76b. Effect of different organic sources on zinc content in rice root in mundakan season

Zinc (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	ND	ND	ND	ND
FYM	10.39	10.90	8.56	8.85
ART	2.45	2.57	2.98	3.00
DNC	13.40	13.45	14.37	14.65
RHB	25.00	25.56	26.12	26.70
CD (0.05)- A --0.034; B-- 0.030; A X B -- 0.068				

ND - Not Detectable

A-Organic source ; B- Nitrogen level

Copper

The maximum significant Cu content in virippu (Table 77a) was observed in RHB applied with no added inorganic N (23.67 mg kg^{-1}) followed by ART alone with an on par value of 21.49 mg kg^{-1}.

The Cu content in mundakan (Table 77b) was maximum in ART + 0 kg N ha^{-1} with a value 25.31 mg kg^{-1} followed by the value of 22.45 mg kg^{-1} shown by FYM with higher dose of N. The two treatments were found to be on par with each other.

Boron

The maximum B content in virippu was observed (Table 78a) in 105 kg N ha^{-1} alone was applied, which showed a value 5.62 mg kg^{-1}. The treatments, daincha with 70 kg N ha^{-1} and FYM with 105 kg N ha^{-1} showed the same value of 5.59 mg kg^{-1} and this was on par with the highest value.

During mundakan season B content (Table 78b) was significantly maximum for daincha with 105 kg N ha^{-1} (5.60 mg kg^{-1}). Treatments daincha and FYM with 70 kg N ha^{-1} showed same value of 5.40 mg kg^{-1}.

4.1.4. *Growth and yield attributes of rice*

Plant height at panicle initiation (PI) stage

The data are presented in Table 79a. The differential response of rice to five different organic sources in combination with four levels of inorganic nitrogen was explicitly seen. The maximum plant height of 76.95 cm in virippu was achieved when daincha was supplied with 70 kg N ha^{-1}. Under the same nitrogen regime, FYM application gave a non-significant response of 76.83 cm. Both these sources of organic manure were effective in producing an on par plant height even at a lower level of nitrogen supply @ 35 kg ha^{-1}. But a very high dose of nitrogen @105 kg ha^{-1} significantly decreased the plant height.

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Table 77a. Effect of different organic sources on copper content in rice root in virippu season

Copper (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	12.00	18.00	10.00	12.17
FYM	20.67	10.00	20.17	16.00
ART	21.49	17.67	14.17	14.00
DNC	17.14	17.50	16.00	20.67
RHB	23.67	18.83	16.00	11.83
CD (0.05)- A-- 0.955; B-- 0.854; A X B --1.910				

A- Organic source ; B- Nitrogen level

Table 77b. Effect of different organic sources on copper content in rice root in mundakan season

Copper (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	13.17	15.00	20.00	4.73
FYM	15.00	16.20	14.73	22.45
ART	25.31	18.21	21.16	16.77
DNC	10.98	13.42	15.31	12.71
RHB	12.77	13.11	9.50	7.47
CD (0.05)- A-- 1.779; B- 1.592; A X B-- 3.559				

A- Organic source ; B- Nitrogen level

Table 78a. Effect of different organic sources on boron content in rice root in viripp season

Boron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	5.40	5.47	5.54	5.62
FYM	5.40	5.41	5.50	5.59
ART	5.01	5.20	5.30	5.30
DNC	5.31	5.50	5.59	5.51
RHB	5.03	5.12	5.20	5.21
CD (0.05)- A- 0.025 ; B -0.023; A X B --0.050				

A- Organic source ; B- Nitrogen level

Table 78b. Effect of different organic sources on boron content in rice root in mundakan season

Boron (mg kg^{-1})				
Treatments	N_0	N_1	N_2	N_3
NOM	5.12	5.03	5.10	5.30
FYM	5.20	5.31	5.40	5.50
ART.	4.73	4.82	4.88	4.99
DNC	5.20	5.31	5.40	5.60
RHB	4.80	4.90	4.90	4.90
CD (0.05)- A- 0.020; B- 0.018; A X B --0.040				

A- Organic source ; B- Nitrogen level

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Table 79a. Effect of different organic sources on plant height at panicle initiation stage in virippu season

Plant height (cm)				
Treatments	N_0	N_1	N_2	N_3
NOM	66.71	68.78	70.39	74.05
FYM	72.39	75.28	76.83	74.55
ART	69.11	69.34	72.34	72.28
DNC	74.89	76.16	76.95	73.78
RHB	70.28	72.00	73.28	73.11
CD (0.05)- A - 1.09; B- 0.98; AxB- 2.19				

A- Organic source ; B- Nitrogen level

Table 79b. Effect of different organic sources on plant height at panicle initiation stage in mundakan season

Plant height (cm)				
Treatments	N_0	N_1	N_2	N_3
NOM	69.49	70.28	70.69	71.46
FYM	70.41	72.57	73.89	72.34
ART	69.46	70.66	70.88	71.06
DNC	70.59	72.57	73.68	72.94
RHB	69.23	69.53	70.49	70.79
CD (0.05)- A- 0.079; B- 0.070; AxB- 0.157				

A- Organic source ; B- Nitrogen level

Maximum plant height of 73.89 cm in mundakan was attained (Table 79b) when FYM was amended with 70 kg N ha^{-1} and was significantly superior to all other treatments. A slightly less plant height of 73.68 cm, which was not significant was recorded with daincha + 70 kg N ha^{-1}.

Plant height at harvest

During virippu the maximum plant height of 106.65 cm was achieved (Table 80a) when FYM was supplied with 105 kg N ha^{-1} and was significantly superior to all other treatment combinations. When FYM was applied with 70 kg N ha^{-1}, a significantly reduced plant height of 105.94 cm was attained followed by daincha applied with 70 kg N ha^{-1} (105.51cm).

In mundakan, the maximum plant height of 106.53 cm (Table 80b) could be attained with the application of FYM along with 105 kg N ha^{-1}. A slightly reduced dose of 70 kg N ha^{-1} along with the organic source daincha also resulted in a much closer value of 106.47 cm.

Leaf area index (LAI)

The data on LAI at panicle initiation stage in virippu is presented in Table 81a. Application of daincha with 35 kg N ha^{-1} resulted in LAI of 6.65. There was no differential response to the treatments where organic manures were applied in combination with augmented nitrogen supply.

Maximum LAI of 6.77 (Table 81b) was recorded in mundakan with application of daincha along with 70 kg N ha^{-1} and was significantly different from the rest of the treatments.

Root biomass

Application of daincha with 70 kg N ha^{-1} could produce a root biomass of 136.95 g m^{-2} (Table 82a) in virippu which was significantly different from all other treatments. When the application of N was increased, slight reduction in root biomass was observed and the value was 136.29 g m^{-2}.

Table 80a. Effect of different organic sources on plant height at harvest in virippu season

Plant height (cm)				
Treatments	N_0	N_1	N_2	N_3
NOM	98.42	99.42	100.47	101.31
FYM	101.70	103.30	105.94	106.65
ART	99.29	101.53	104.41	104.62
DNC	100.89	103.68	105.51	104.81
RHB	99.37	101.78	103.33	103.65
CD (0.05)-	**A-0.110;**	**B- 0.098;**	**AxB-0.220**	

A- Organic source ; B- Nitrogen level

Table 80a. Effect of different organic sources on plant height at harvest in mundakan season

Plant height (cm)				
Treatments	N_0	N_1	N_2	N_3
NOM	100.48	101.55	102.32	102.71
FYM	100.45	103.68	105.60	106.53
ART	99.26	102.78	103.37	104.65
DNC	100.60	104.51	106.47	105.45
RHB	100.41	101.71	104.14	103.66
CD (0.05)-	**A- 0.158;**	**B- 0.142;**	**AxB-0.317**	

A- Organic source ; B- Nitrogen level

Table 81a. Effect of different organic sources on leaf area index at panicle initiation stage in virippu season

	Leaf area index (LAI)			
Treatments	N_0	N_1	N_2	N_3
NOM	6.43	6.47	6.50	6.52
FYM	6.50	6.52	6.56	6.55
ART	6.48	6.51	6.54	6.54
DNC	6.59	6.65	6.63	6.63
RHB	6.50	6.42	6.56	6.57
CD (0.05)- A- 0.036; B- 0.032; AxB- NS				

A- Organic source ; B- Nitrogen level

Table 81b. Effect of different organic sources on leaf area index at panicle initiation stage in mundakan season

	Leaf area index (LAI)			
Treatments	N_0	N_1	N_2	N_3
NOM	6.51	6.54	6.58	6.60
FYM	6.54	6.57	6.61	6.59
ART	6.54	6.57	6.58	6.57
DNC	6.72	6.75	6.77	6.73
RHB	6.55	6.59	6.62	6.64
CD (0.05)- A- 0.007; B-0.006; AxB- 0.014				

A- Organic source ; B- Nitrogen level

Table 82a. Effect of different organic sources on root biomass in virippu season

	Root biomass(g m^{-2})			
Treatments	N_0	N_1	N_2	N_3
NOM	125.57	127.44	127.88	130.77
FYM	130.18	133.72	135.55	135.04
ART	126.08	128.28	130.85	132.46
DNC	130.66	135.68	136.95	136.29
RHB	127.57	129.07	130.64	132.48
CD (0.05)- A-0.069; B-0.062; AxB- 0.138				

A- Organic source ; B- Nitrogen level

Table 82b. Effect of different organic sources on root biomass in mundakan season

	Root biomass(g m^{-2})			
Treatments	N_0	N_1	N_2	N_3
NOM	126.43	128.67	129.43	132.02
FYM	132.98	135.46	137.01	136.67
ART	128.45	129.70	131.69	132.60
DNC	133.74	135.75	137.80	136.62
RHB	128.68	129.62	130.83	133.15
CD (0.05)- A-0.270; B- 0.242; AxB- 0.541				

A- Organic source ; B- Nitrogen level

A significantly high root biomass of 137.80 g m^{-2} (Table 82b) was obtained for daincha with 70 kg N ha^{-1} in mundakan season. The treatment, FYM with the same dose of nitrogen produced a root biomass of 137.01 g m^{-2}. Root biomass of 136.67 g m^{-2} for FYM with 105 kg N ha^{-1} and 136.62 g m^{-2} for daincha with 105 kg N ha^{-1} were found to be on par.

Number of productive tillers

The data on number of productive tillers in virippu season are given in Table 83a. The highest number (6.50) was obtained for the treatment, daincha with 35 kg N ha^{-1}. The number of productive tillers formed under the application of daincha (6.39) and FYM (6.33) treatments receiving 70 kg N ha^{-1} were on par.

During mundakan season, the maximum number of productive tillers (6.50) was obtained with FYM with 70 kg N ha^{-1} (Table 83b).

Percentage of filled grains

The data on the percentage of filled grains per panicle in virippu is presented in table 84a. During this season, there was no significant response between treatments for the various doses of N. On an average, the filled grain percentage was 76.13.

The highest value of 82.60 per cent was achieved in mundakan with FYM and 70 kg N ha^{-1} during mundakan season (Table 84b). Here also the lowest value was noticed for the control treatment (71.08%).

Thousand grain weight

Application of FYM with 70 kg N ha^{-1} recorded highest thousand grain weight of 27.86 g (Table 85a) in virippu. Increased application of nitrogen could not attain a better yield except for fertilizer N alone applied treatments.

In mundakan, thousand grain weight of 28.10 g (Table 85b) was obtained under the application of FYM with 70 kg N ha^{-1} and it was significantly superior with respect to the application of any other organic source supplemented with N fertilizer.

Table 83a. Effect of different organic sources on number of productive tillers per hill in virippu season

Number of productive tillers per hill				
Treatments	N_0	N_1	N_2	N_3
NOM	4.36	4.55	4.60	4.59
FYM	4.78	5.28	6.33	5.78
ART	4.39	4.83	4.89	5.22
DNC	5.39	6.50	6.39	5.50
RHB	4.72	5.22	5.67	5.83
CD (0.05)- A- 0.228; B - 0.204; AxB- 0.456				

A- Organic source ; B- Nitrogen level

Table 83b. Effect of different organic sources on number of productive tillers per hill in mundakan season

Number of productive tillers per hill				
Treatments	N_0	N_1	N_2	N_3
NOM	4.84	5.16	5.69	5.29
FYM	5.56	5.57	6.50	5.94
ART	4.94	5.18	5.50	5.63
DNC	5.48	6.37	6.39	5.66
RHB	5.27	5.33	5.67	5.68
CD (0.05)- A- 0.193; B- 0.172 ; AxB- 0.385				

A- Organic source ; B- Nitrogen level

Table 84a. Effect of different organic sources on percentage of filled grains in virippu season

Flled grains (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	67.16	69.06	73.72	75.89
FYM	77.22	80.67	80.56	79.11
ART	73.61	74.45	75.83	76.33
DNC	77.67	80.39	82.11	78.10
RHB	74.06	74.50	75.95	76.17
CD (0.05)-	**A- 1.987;**	**B- 1.778 ;**		**AxB- NS**

A- Organic source ; B- Nitrogen level

Table 84b. Effect of different organic sources on percentage of filled grains in mundakan season

Filled grains (%)				
Treatments	N_0	N_1	N_2	N_3
NOM	71.08	73.82	73.72	74.56
FYM	79.38	80.21	82.60	82.06
ART	73.74	74.45	75.83	76.33
DNC	76.18	80.19	81.31	77.88
RHB	74.41	74.69	75.95	76.09
CD (0.05)-	**A-0.821;**	**B- 0.734;**	**AxB- 1.642**	

A- Organic source ; B- Nitrogen level

Table 85a. Effect of different organic sources on thousand grain weight in virippu season

1000 grain weight (g)				
Treatments	N_0	N_1	N_2	N_3
NOM	21.86	23.37	23.40	24.30
FYM	24.81	24.95	27.86	27.17
ART	23.10	24.08	25.31	25.16
DNC	24.35	25.54	26.96	26.26
RHB	24.76	25.15	25.06	24.50
CD (0.05)- A- 0.440; B -0.393; AxB- 0.879				

A- Organic source ; B- Nitrogen level

Table 85b. Effect of different organic sources on thousand grain weight in mundakan season

1000 grain weight (g)				
Treatments	N_0	N_1	N_2	N_3
NOM	23.37	23.40	23.69	24.36
FYM	25.01	25.21	28.10	27.27
ART	23.59	24.53	25.47	25.78
DNC	24.71	26.82	27.17	26.70
RHB	25.53	25.62	25.53	25.58
CD (0.05)- A- 0.363; B- 0.325; AxB- 0.726				

A- Organic source ; B- Nitrogen level

Grain yield

The treatment, daincha with 35 kg N ha^{-1} yielded 3780.33 kg ha^{-1} (Table 86a) in virippu. The treatment with same organic source at higher doses of N and FYM with 70 kg N ha^{-1} produced yields which were on par with this treatment.

Maximum significant yield of 3940.33 kg ha^{-1} (Table 86b) was attainable with the treatment daincha in combination with 35 kg N ha^{-1} in mundakan season. The data clearly showed that the treatment, FYM with 70 kg N ha^{-1} could only produce 3894 kg ha^{-1} grain yield during this season. In general, the yields were higher during mundakan season as was seen from the data.

Straw yield

In contrast to grain yield, the treatment with organic source, RHB supplemented with 105 kg N ha^{-1} recorded the highest straw yield of 4861. 33 kg ha^{-1} in virippu season. The data pertaining to this is given in Table 87a. The treatments with daincha as organic source supplemented with inorganic N yielded more straw in comparison with others and they were on par.

The treatment with organic source RHB in combination with nitrogen at 105 kg ha^{-1} produced maximum straw yield (4879 kg ha^{-1}) in mundakan. In general, the crop treated with RHB as organic source recorded higher straw yields (Table 87b).

Harvest index (HI)

Maximum value of HI (47.75) was obtained in virippu in daincha and 70 kg N ha^{-1} and is shown in table 88a. The treatment with same organic source and higher level of nitrogen and FYM with 70 kg N ha^{-1} could also result in HI values of 46.95 and 47.62 respectively. These were on par with the maximum value.

Harvest index in mundakan was the highest (47.45) in FYM along with 70 kg N ha^{-1}. The treatment FYM with higher dose of nitrogen and daincha with 35 kg N ha^{-1} were on par with each other (Table 88b).

Table 86a. Effect of different organic sources on grain yield in virippu season

Grain yield (kg ha $^{-1}$)				
Treatments	N_0	N_1	N_2	N_3
NOM	3,272.67	3,528.00	3,591.67	3,616.67
FYM	3,583.00	3,674.67	3,760.00	3,721.67
ART	3,362.67	3,466.00	3,515.33	3,585.67
DNC	3,643.67	3,780.33	3,773.67	3,766.33
RHB	3,489.67	3,546.33	3,639.00	3,728.67
CD (0.05)- A- 12.139 ; B- 10.857; AxB- 24.277				

A- Organic source ; B- Nitrogen level

Table 86b. Effect of different organic sources on grain yield in mundakan season

Grain yield (kg ha $^{-1}$)				
Treatments	N_0	N_1	N_2	N_3
NOM	3,339.33	3,489.00	3,529.33	3,562.33
FYM	3,542.33	3,771.67	3,894.00	3,831.67
ART	3,450.33	3,536.00	3,576.67	3,662.33
DNC	3,728.33	3,940.33	3,866.67	3,813.33
RHB	3,609.67	3,699.67	3,767.00	3,791.00
CD (0.05)- A- 14.304; B - 12.794; AxB- 28.608				

A- Organic source ; B- Nitrogen level

Table 87a. Effect of different organic sources on straw yield in virippu season

	Straw yield (kg ha $^{-1}$)			
Treatments	N_0	N_1	N_2	N_3
NOM	4,485.33	4,674.00	4,666.33	4,695.00
FYM	4,124.00	4,192.00	4,135.33	3,914.33
ART	4,261.00	4,298.00	4,385.67	4,543.33
DNC	4,601.33	4,314.33	4,130.33	4,256.00
RHB	4,463.00	4,456.00	4,472.00	4,861.33
CD (0.05)- A- 147.009; B- NS; AxB- 294.017				

A- Organic source ; B- Nitrogen level

Table 87b. Effect of different organic sources on straw yield in mundakan season

	Straw yield (kg ha $^{-1}$)			
Treatments	N_0	N_1	N_2	N_3
NOM	4,604.67	4,722.33	4,606.00	4,582.00
FYM	4,457.33	4,374.67	4,477.33	4,294.33
ART	4,322.67	4,360.00	4,431.67	4,590.00
DNC	4,616.67	4,416.67	4,496.00	4,445.67
RHB	4,561.33	4,651.67	4,689.33	4,879.00
CD (0.05)- A- 67.570; B- NS; AxB- 135.140				

A- Organic source ; B- Nitrogen level

Table 88a. Effect of different organic sources on harvest index in virippu season

	Harvest index			
Treatments	N_0	N_1	N_2	N_3
NOM	42.19	43.01	43.49	43.51
FYM	46.49	46.71	47.62	46.70
ART	44.11	44.64	44.49	44.11
DNC	44.20	46.70	47.75	46.95
RHB	43.37	44.08	44.87	43.42
CD (0.05)- A- 0.432; B- 0.386; AxB- 0.864				

A- Organic source ; B- Nitrogen level

Table 88b. Effect of different organic sources on harvest index in mundakan season

	Harvest index			
Treatments	N_0	N_1	N_2	N_3
NOM	42.03	42.49	43.38	43.74
FYM	44.28	46.30	47.45	47.15
ART	44.39	44.78	44.66	44.38
DNC	44.68	47.15	46.24	46.18
RHB	44.18	44.30	44.55	43.73
CD (0.05)- A- 0.252; B- 0.225; AxB- 0.504				

A- Organic source ; B- Nitrogen level

4.1.5. *Correlations of surface soil properties and yield*

Correlation analysis of physico-chemical properties in surface soil and yield

The correlation matrix presented in Table 89a shows the correlation coefficients between different soil properties and yield. It was found that soil pH had significant positive correlation with OC (0.73**) and WHC (0.73**) and significant negative correlation with BD (-0.67**). Electrical conductivity had positive correlation with OC (0.06), BD (0.15) and significant negative correlation with WHC (-0.20*). Organic carbon and CEC were significantly positively correlated with WHC (0.53** and 0.27**). Bulk density had significant negative correlation with WHC (-0.74**) while the latter was significantly and positively correlated with yield.

Table 89a. Correlation coefficients between physico-chemical properties of surface soil and yield of rice crop

Physico- chemical properties							
Treatments	pH	EC	OC	CEC	BD	WHC	Yield
pH	1	-	0.73**	-	-0.67**	0.73**	-
EC		1	0.06	-	0.15	-0.20*	0.03
OC			1	0.03	-0.49**	0.53**	0.07
CEC				1	-	0.27**	0.76**
BD					1	-0.74**	-
WHC						1	0.34**
Yield							1

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

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

Correlation analysis of soil available nutrients in surface soil and yield

Correlation between different soil nutrients with the surface layer of soil and yield were worked out and they are presented in Table 89b. An analysis of the data showed that soil nutrients except available calcium, sulphur, iron, manganese and

Table 89b. Correlation coefficients between available nutrients of surface soil and yield of rice crop

	Available nutrients											
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Yield
N	1	.1	.49**	.35**	.28**	.42**	.27**	.07	.25**	.13	.62**	.67**
P		1	-	.04	.32**	-	-	-.22*	.16	-	.13	.29**
K			1	.67**	.49**	.70**	.59**	.56**	.46**	.35**	.58**	.33**
Ca				1	.58**	.88**	.84**	.66**	.21*	.24**	.49**	.03
Mg					1	.45**	.50**	.51**	.27**	.30**	.38**	.32**
S						1	.84**	.71**	.09	.37**	.54**	.03
Fe							1	.67**	.11	.43**	.46**	-
Mn								1	.08	.63*	.19*	-
Zn									1	.28**	.32**	.41**
Cu										1	.17	.03
B											1	.64**
Yield												1

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

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

copper had positive and significant correlation with yield. Significant positive correlations were obtained for available nitrogen with potassium, calcium, magnesium, sulphur, iron, zinc and boron. Available phosphorus had significant positive correlation with available magnesium (0.32**) and significant negative correlation with available manganese (-0.22*).

Secondary and micronutrients had significant positive correlation with each other while it was found that available iron and available manganese had no correlation with yield.

Correlation analysis of biological properties in surface soil and yield

Significant positive correlations were obtained for the biological properties such as MBC, phosphatase (0.91**) and dehydrogenase activity (0.79**) with yield (Table 89c).

Table 89c. Correlation coefficients between biological properties of surface soil and yield of rice crop

Biological properties				
Treatments	MBC	Phosphatase	Dehydrogenase	Yield
MBC	1	0.91**	0.79**	0.59**
Phosphatase		1	0.82**	0.59**
Dehydrogenase			1	0.68*
Yield				1

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

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

4.1.6. *Correlations of sub-surface soil properties and yield*

Correlation analysis of physico-chemical properties in sub-surface soil and yield

It was found that soil pH had significant positive correlation (Table 90 a) with EC (0.61**) and WHC (0.36**) and negative correlation with BD (-0.45**). Organic carbon (0.10), CEC (0.16) and yield (0.16) are only positive correlated with pH. Electrical conductivity also had significant positive correlation with yield (0.24**). Cation exchange capacity had significant positive correlation with WHC (0.34**) and yield (0.75**) while BD had significant negative correlation with WHC (-0.53**).

Table 90a. Correlation coefficients between physico-chemical properties of sub-surface soil and yield of rice crop

Physico- chemical properties							
	pH	EC	OC	CEC	BD	WHC	Yield
pH	1	0.61**	0.10	0.16	-0.45**	0.36**	0.16
EC		1	-	0.14	-0.22	0.06	0.24**
OC			1	-	-	0.07	0.07
CEC				1	-	0.34**	0.75**
BD					1	-0.53**	-
WHC						1	0.34**
Yield							1

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

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

Correlation analysis of soil available nutrients in sub-surface soil and yield

Analysis of correlation coefficients of available nutrients in the sub-surface soil showed that they were positively correlated with yield (Table 90b). Available nitrogen, phosphorus, sulphur, zinc, copper and boron were found to have significant positive correlation with yield.

Table 90b. Correlation coefficients between available nutrients of sub-surface soil and yield of rice crop

Available nutrients												
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Yield
N	1	.47**	.29**	.01	.13	.34**	-	-	.11	.15	.61**	.80**
P		1	-	-	-	-.19*	-37**	-.25**	-	-	.21*	.46**
K			1	.43**	.28**	.67**	.51**	.60**	.36**	.37**	.36**	.11
Ca				1	.66**	.57**	.41**	.38**	.13	.32**	.27**	.04
Mg					1	.59**	.40**	.36**	.37**	.46**	.30**	.17
S						1	.69**	.77**	.17	.59**	.44**	.23*
Fe							1	.77**	.12	.51**	.06	-
Mn								1	.06	.60**	.10	-
Zn									1	2	30**	.19*
Cu										1	.42**	.19*
B											1	.69**
Yield												1

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

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

Correlation analysis of biological properties in sub-surface soil and yield

As seen in the surface soil, significant positive correlations were obtained for the biological properties such as MBC, phosphatase activity and dehydrogenase activity with yield (Table 90c) showing values of 0.64 **, 0.88** and 0.90** respectively.

Table 90c. Correlation coefficients between biological properties of sub-surface soil and yield of rice crop

Biological properties				
Treatments	MBC	Phosphatase	Dehydrogenase	Yield
MBC	1	0.88**	0.90**	0.64**
Phosphatase		1	0.91**	0.48**
Dehydrogenase			1	0.53**
Yield				1

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

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

4.2. ESTIMATION OF GREENHOUSE GAS (GHG) FLUX FROM CULTIVATED AND FALLOW WETLANDS

The gas samples from the treatment plots of organic sources with nitrogen fertilizer at various levels (N_1, N_2 and N_3) were collected using closed chamber method and the quantity of GHG contents present were compared with that of fallow wetland.

4.2.1. Measurement of GHG flux, soil temperature and moisture

The GHG gas samples from the experimental plots were collected during mundakan season at three different stages of rice crop *viz*., active tillering, panicle initiation and near harvest. The samples were analysed for CH_4 and CO_2 content using gas chromatograph and the results obtained were as follows.

4.2.1.1 *Analysis of carbon di oxide flux*

Active tillering stage

The data presented in the Table 91a shows that the highest emission of carbon-di-oxide was recorded in the treatment, RHB with 35 kg N ha^{-1} with a value

104.52 mg m^{-2} hr^{-1} whereas other treatments of the same organic source and lower nitrogen levels showed very low values (52.48 and 49.58 mg m^{-2} hr^{-1}). The carbon di oxide gas emission from the fallow plot was 15.14 mg m^{-2} hr^{-1}. The treatment, nitrogen fertilizer alone with 105 kg N ha^{-1} had a value of 61.17 mg m^{-2} hr^{-1}. The least emission was noticed in the treatment FYM with 105 kg N ha^{-1} (26.47 mg m^{-2} hr^{-1}). Comparing the effect of FYM and daincha, FYM recorded lesser emission of CO_2.

Panicle initiation stage

A perusal of data (Table 91b) clearly stated that the emission was maximum in daincha with 105 kg N ha^{-1} (129.93 mg m^{-2} hr^{-1}). This was followed by RHB with 105 kg N ha^{-1} (56.03 mg m^{-2} hr^{-1}) while that from the fallow plot was 21.27 mg m^{-2} hr^{-1}. The treatments with organic sources recorded higher emission with increase in quantity of N fertilizer and the reverse was with inorganic fertiliser alone. The organic sources daincha, RHB and *Artocarpus* with the highest nitrogen level showed values more than 50 mg m^{-2} hr^{-1}. FYM with 105 kg N ha^{-1} recorded minimum value of 29.03 mg m^{-2} hr^{-1}.

Near harvest

The treatment with daincha and 35 kg N ha^{-1} recorded the maximum significant value of 86.20 mg m^{-2} hr^{-1} (Table 91c) and the minimum value was recorded in the treatment with inorganic nitrogen alone at 35 kg N ha^{-1} (37.30 mg m^{-2} hr^{-1}). The emission rate followed the order: daincha > FYM >ART > no organic manure > RHB. The rate of emission increased as the amount of N fertilizer increased in the treatments *viz.*, inorganic fertiliser alone and FYM. The increase was nearly double in the former compared to the latter. However in treatments with other organic sources, the emission pattern followed first a decrease with increase in N fertiliser and after that an increase was noticed. The treatment with FYM showed an increase in emission at all the nitrogen levels compared to other stages of rice crop. The emission from fallow plot was 29.74 mg m^{-2} hr^{-1}.

Table 91a. Effect of different organic sources on carbon di oxide emission at active tillering stage

Carbon di oxide (mg m^{-2} hr^{-1})				
Treatments	N_1	N_2	N_3	**Mean**
NOM	47.34	52.79	61.17	53.77
FYM	50.58	44.88	26.47	40.64
ART	43.54	43.11	43.79	43.48
DNC	44.58	45.43	48.88	46.30
RHB	104.52	49.58	52.48	68.86
Mean	47.70	47.16	56.97	
CD(0.05) -- 0.013				

Table 91b. Effect of different organic sources on carbon di oxide emission at panicle initiation stage

Carbon di oxide (mg m^{-2} hr^{-1})				
Treatments	N_1	N_2	N_3	**Mean**
NOM	45.29	44.91	39.64	43.28
FYM	44.44	46.63	29.03	40.03
ART	44.22	49.01	54.17	49.13
DNC	46.17	48.27	129.93	74.79
RHB	45.93	44.00	56.03	48.65
Mean	45.21	46.56	61.76	
CD (0.05) -- 0.013				

Table 91c. Effect of different organic sources on carbon di oxide emission at near harvest stage

Carbon di oxide (mg m^{-2} hr^{-1})				
Treatments	N_1	N_2	N_3	**Mean**
NOM	37.30	60.05	61.42	52.92
FYM	54.64	56.89	77.45	62.99
ART	57.25	40.67	77.22	58.38
DNC	86.20	66.73	81.07	78.00
RHB	55.21	40.96	56.98	51.05
Mean	58.12	53.06	70.83	
CD(0.05) -- 0.014				

4.2.1.2. *Analysis of methane flux*

Active tillering stage

Methane emission was the highest in the treatment (Table 92a) with FYM and 35 kg N ha^{-1} (15.30 mg m^{-2} hr^{-1}) while that from the same organic source and 105 kg N ha^{-1} recorded the least value (0.86 mg m^{-2} hr^{-1}). The emission from fallow plot was 1.36 mg m^{-2} hr$^{-1.}$ The emission rate of methane from the treatments was in the following order: FYM > daincha > no organic manure > *Artocarpus* > RHB. The value was higher when the organic sources were amended with lower levels of N. When the amount of fertilizer was the highest, the rates of emission from the treatments with *artocarpus* and daincha were reduced to half but in RHB the reduction was meagre.

Panicle initiation stage

It was observed that the methane emission was the highest (Table 92b) in the treatment with FYM and 35 kg N ha^{-1} (19.89 mg m^{-2} hr^{-1}) and was the lowest in

Table 92a. Effect of different organic sources on methane emission at active tillering stage

Methane (mg m^{-2} hr^{-1})				
Treatments	N_1	N_2	N_3	**Mean**
NOM	7.47	5.76	6.46	6.56
FYM	15.30	12.86	0.86	9.67
ART	6.63	8.41	3.95	6.33
DNC	9.57	5.06	4.43	6.35
RHB	3.74	3.68	3.63	3.68
Mean	8.54	7.15	3.87	
CD (0.05) -- 0.014				

Table 92b. Effect of different organic sources on methane emission at panicle initiation stage

Methane (mg m^{-2} hr^{-1})				
Treatments	N_1	N_2	N_3	**Mean**
NOM	10.40	13.38	4.88	9.55
FYM	19.89	17.32	1.23	12.81
ART	15.19	13.01	12.10	13.43
DNC	12.03	18.21	0.11	10.12
RHB	13.77	12.10	10.36	12.08
Mean	14.26	14.80	5.74	
CD (0.05) -- 0.014				

daincha +105 kg N ha^{-1} (0.11 mg m^{-2} hr^{-1}). In the case of treatments involving combined application of the organic sources treatments like FYM, daincha as well as with inorganic fertilizer alone, the rate of emission decreased when the quantity of N fertilizer was the highest. Treatments with *Artocarpus*/RHB recorded values ranging from 10-15 mg m^{-2} hr^{-1}. The fallow plot recorded an emission value of 2.97 mg m^{-2} hr^{-1}).

Near harvest

The methane emission was very meagre in this stage of rice crop compared to other two stages (Table 92c). Maximum emission was noted in the treatment with inorganic nitrogen fertiliser @35 kg N ha^{-1} (2.21 mg m^{-2} hr^{-1}) and it was minimum in the treatment with daincha and 105 kg N ha^{-1} (0.12 mg m^{-2} hr^{-1}). Among the treatments with organic sources, RHB with 70 kg N ha^{-1} recorded highest value of 1.15 mg m^{-2} hr^{-1} followed by daincha with 35 kg N ha^{-1} (1.1 mg m^{-2} hr^{-1}). The emission values of all other treatments were found to be less than one. When the treatments were amended with 70 kg N ha^{-1} the rate of emission was increased except in daincha and without organic source.

Table 92c. Effect of different organic sources on methane emission at near harvest stage

Methane (mg m^{-2} hr^{-1})				
Treatments	N_1	N_2	N_3	**Mean**
NOM	2.21	0.14	0.12	0.82
FYM	0.15	0.94	0.13	0.41
ART	0.13	0.87	0.14	0.38
DNC	1.10	0.16	0.12	0.46
RHB	0.18	1.15	0.23	0.52
Mean	0.75	0.65	0.15	
CD (0.05) -- 0.012				

As the quantity of N was further increased, the emission value reduced to the initial value. The emission from the fallow plot was found to be 0.14 mg m^{-2} $hr^{-1.}$

4.2.2. *Comparison between GHG flux, soil temperature and moisture*

A regression analysis was done between GHG gases like carbon di oxide and methane with soil temperature and soil moisture at the above mentioned crop stages in mundakan season (fig. 87a, 87b and 87c to 90a, 90b and 90c). The R^2 value was found to be very poor to fit.

4.3. SOIL CHARACTERISATION OF CULTIVATED AND FALLOW WETLANDS

The soils of this series are deep to very deep, moderately well drained, moderately coarse to moderately fine textured, brownish or greyish and acidic. These soils are found to occur on narrow and broad valleys with 1-5% slope located in between undulating laterite plains along the central region of Thrissur district. The climate is humid tropical with a mean annual rainfall of 3091.6 mm and a mean annual temperature of 27. 590C. It comes in taxonomic class- **Fine loany mixed, isohyperthermic, aquic ustifluvents**. The description of profile is given below:

Horizon	**Depth (cm)**	**Description**
Ap	0-16	Light greyish brown (10YR 6/2 M) sandy loam; weak medium sub angular blocky; friable; slightly sticky and slightly plastic; abundant fine roots; moderate permeability; faint brownish yellow (10YR 6/6 M); strongly acid (pH 5.5); clear wavy boundary
A2	16-32	Brown (10YR 5/3 M) sandy loam; weak medium sub angular blocky; friable, slightly-sticky and non- plastic; common fine roots; rapid permeability; many coarse faint grey mottling (10YR 6/1 M); neutral (pH 7.0); clear smooth boundary
AC1	32-47	Greyish brown (10 YR 5/2 M) sandy loam; weak fine sub angular blocky; slightly sticky and slightly plastic; common fine roots, moderate permeability, common coarse prominent brownish yellow mottles (10YR 6/6); very slightly alkaline (pH 7.4); clear wavy boundary
AC2	47-68	Greyish brown (10YR 5/2 M)sandy clay loam; weak medium sub-angular blocky; friable slightly sticky and slightly plastic; few coarse roots; moderate permeability; medium faint brownish grey mottles (10 YR 6/2); neurtral (pH 6.7); gradual smooth boundary
AC3	68-120	Grey (10YR 5/1 M) clay; moderate medium sub-angular blocky; sticky and plastic; common distinct mottles; many fine brownish yellow (10YR 6/1) and yellowish red mottlings (5YR 5/8); neutral (pH 7.0); gradual diffuse boundary
AC4	120-160	Grey (10YR 5/1)sandy clay; moderate medium sub angular blocky; sticky and plastic; many fine distinct brownish yellow (10YR 6/6 M) red (2.5 YR 4/8) mottlings; neutral (pH 6.9); gradual diffuse boundary
C	160-200	Grey (10YR 6/1)sandy clay; moderate medium sub angular blocky; sticky and plastic; many fine distinct brownish yellow (10YR 6/6 M) mottlings; neutral (pH 7.3)

Range in characteristics

The thickness of the solum is more than 150cm. The MAST is 28.590C. The texture of the A horizon ranges from sandy loam to sandy clay loam and clour ranges from pale brown to grey in hue 10YR , value 5to 6 and chroma 1to 3. The colour of B horizon ranges from grey to light brownish grey in hue 10 YR, value 5 to 6 and chroma 1to 2. Texture ranges from sandy loam to sandy clay and weathered gneiss are noticed in the profile. The soils are moderately well drained with moderately rapid permeability. Paddy is the main crop grown in these soils. The general fertility status for primary nutrients is low to medium. The soils come under land capability sub classes IIw, IIIw and land irrigability class 2d and 3d.

Soil profiles of cultivated (Plate 10) and fallow lands were taken after harvest of the second crop and their morphological as well as physico-chemical characteristics were studied and are detailed below.

4.3.1. Soil characteristics

Soil profile in the fallow land had a depth of 115 cm and five horizons were delineated in it. A soil profile depth of more than 70 cm with six horizons was noticed in the cultivated land. The horizon wise description regarding depth, colour, texture, structure etc are given below in table.

4.3.1.1. *Morphological characteristics*

Fallow land

Horizon	Depth (cm)	Description
Ap	0-14	Dark yellowish brown (10YR 4/4 M) sandy clay loam; weak fine sub angular blocky; friable; slightly sticky and slightly plastic; many fine roots; moderate permeability; very strongly acid (pH 4.6); clear smooth boundary
AC1	14-35	Brown (10YR 4/3 M) sandy clay loam; weak fine sub angular blocky; friable non-sticky and non- plastic; common fine roots; moderate permeability; very strongly acid (pH 4.7); clear wavy boundary
AC2	48-70	Yellowish brown (10 YR 5/4 M) sandy loam; weak sub angular blocky; slightly sticky and slightly plastic; commonfine roots, medium faint mottles (10YR 5/8); moderate permeability, very strongly acid (pH 4.6); clear wavy boundary
AC3	38-53	Yellowish brown (10YR 5/4 M)sandy clay; weak sub-angular blocky; sticky and plastic; few coarse roots; medium faint mottles (10 YR 5/6);moderate permeability; very strongly acid pH 4.8; gradual smooth boundary
AC4	70-115	Greyish brown (10YR 5/2 M) sandy clay; moderate medium sub-angular blocky; sticky and plastic; common distinct mottles; dark yellowish brown; (10YR 4/4) and red mottling(2.5YR 5/6) 60% coarse fragments; strongly acid- pH 5.2
C	115+	Stone and laterite bed

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Cultivated land

Horizon	Depth (cm)	Description
Ap	0-8	Greyish brown (10YR 5/2 M) sandy clay loam; weak fine sub-angular blocky; friable; slightly sticky and slightly plastic; abundant fine roots; moderate permeability; strongly acid (pH 5.28); clear smooth boundary
A2	8-16	Brown (10YR 5/3M) sandy clay loam; weak medium sub angular blocky; friable; slightly sticky and non plastic; few fine roots; rapid permeability; crotovinas present; strongly acid (pH 5.29); clear smooth boundary
AC1	16-25	Grey (10YR 5/1) sandy clay; moderate medium sub angular blocky; many coarse faint red (2.5 YR 4/6) mottles; firm sticky and plastic moderately slow permeability; strongly acid (pH 5.32); gradual diffuse boundary
AC2	25- 37	Grey (10YR 5/1) sandy clay; moderate medium sub angular blocky; firm sticky and plastic; many fine distinct grey and red (2.5 YR 3/0) mottles; moderately slow permeability; strongly acid (pH 5.30); clear smooth boundary
AC3	37-53	Brownish yellow (10YR 6/6) sandy clay; moderate medium sub angular blocky; firm sticky and plastic; many fine distinct red (2.5YR 4/8) and very dark grey (2.5YR 3/0) mottles; very strongly acid (pH 4.8); gradual diffuse boundary
AC4	53-70+	Grey (10YR 5/1 M) clay; moderate medium sub angular blocky; firm sticky and plastic; many fine faint prominent grey (2.5YR 3/0) mottles; moderately slow permeability; very strongly acid (pH 5.2).
AC5	70+	Water saturated layer

4.3.1.2. *Physico- chemicalcharacteristics*

The parameters like organic carbon, water holding capacity, pH, electrical conductivity, cation exchange capacity and nutrient contents in soil were studied and they are as follows:

Fallow land

The data in Table 93a shows that in the fallow land, there had been a decrease in all parameters as the depth of the profile increased except electrical conductivity. The ranges of values for organic carbon, water holding capacity, pH, cation exchange capacity were 0.84 to 1.05 per cent, 46.26 to 48.47 per cent, 4.60 to 5.20 and 5.80 to 6.02 c mol kg^{-1} respectively. The value for electrical conductivity was 0.01 dS m^{-1}.

An analysis of the available nutrient contents in soil indicated that the nutrient contents in the fallow land was lesser than that of the cultivated land and they are presented in table 93b. Further it was found that the values decreased as the depth increased in the profile.

Table 93a. Physico-chemical characteristics of soil profile of fallow land

Horizons	OC (%)	WHC (%)	pH	EC (dS m^{-1})	CEC (c mol kg^{-1})
Ap	1.05	48.47	4.60	0.01	6.02
AC1	1.00	48.03	4.70	0.01	6.00
AC2	0.95	47.65	4.60	0.01	6.20
AC3	0.87	47.34	4.80	0.01	6.00
AC4	0.84	46.26	5.20	0.01	5.80

Table 93b. Available nutrient contents of soil profile of fallow land

	Macro nutrients (kg ha^{-1})			Secondary nutrients (mg kg^{-1})			Micro nutrients (mg kg^{-1})				
Horizons	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
Ap	401.76	18.46	87.34	300.42	31.25	5.89	235.73	5.43	2.84	6.87	0.27
AC1	360.43	17.74	84.14	268.36	26.56	5.04	213.45	4.36	2.44	6.39	0.23
AC2	342.56	17.56	83.23	265.41	24.35	5.00	210.47	4.32	2.24	6.31	0.22
AC3	327.84	17.34	81.24	264.89	24.17	4.57	205.78	4.27	2.20	6.23	0.20
AC4	313.58	15.45	80.45	264.12	22.56	4.34	205.57	4.20	2.12	6.20	0.18

Cultivated land

The maximum organic carbon, water holding capacity, pH, electrical conductivity, cation exchange capacity in the cultivated land (Table 94a) were 2.05 per cent, 54.66 per cent, 5.28, 0.04 dS m^{-1} and 6.37 c mol kg^{-1} respectively. The values of the parameters were found to be high in the surface and they decreased as we moved down the profile. The available nutrient content (Table 94b) also had the same trend like that of other physico- chemical properties.

Table 94a. Physico-chemical characteristics of soil profile of cultivated land

Horizons	OC (%)	WHC (%)	pH	EC (dS m^{-1})	CEC (c mol kg^{1})
Ap	2.05	54.66	5.28	0.04	6.37
A2	2.03	54.56	5.29	0.03	6.37
AC1	1.07	51.23	5.32	0.03	6.36
AC2	1.00	50.23	5.30	0.02	6.32
AC3	0.98	48.23	4.80	0.05	5.84
AC4	0.95	48.06	5.20	0.05	5.36

Table 94b. Available nutrient contents of soil profile of cultivated land

Horizons	Macro nutrients (kg ha^{-1})			Secondary nutrients (mg kg^{-1})			Micro nutrients (mg kg^{-1})				
	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
Ap	454.18	50.35	80.55	302.14	42.27	5.96	193.12	4.74	3.21	5.37	0.25
A2	453.02	50.25	80.50	302.00	42.13	5.76	193.04	4.02	3.03	5.14	0.24
AC1	380.45	32.65	55.43	133.67	15.97	3.78	111.77	2.67	1.80	5.42	0.24
AC2	365.34	30.45	52.36	127.43	14.37	2.45	110.45	2.63	1.54	5.32	0.20
AC3	354.26	27.43	50.56	125.37	13.46	2.25	110.24	2.62	1.45	5.25	0.18
AC4	321.45	27.37	50.24	124.67	13.21	2.13	110.00	2.62	1.36	5.18	0.17

DISCUSSION

5. DISCUSSION

The results of the various experiments conducted in "Carbon sequestration and soil health under different organic sources in wetland rice" were studied and presented in chapter 4. The details pertaining to the various findings are discussed below:

5.1. EFFECT OF COMBINED ORGANIC AND INORGANIC SOURCES ON CARBON STOCK AND SOIL HEALTH

5.1.1. Soil physical characteristics

The effect of organic sources in combination with inorganics on physical attributes of soil was presented in section 4.1 and it was clearly seen that the treatments had significant effect on the soil properties.

Bulk density (BD)

The study revealed that there existed a significant effect of organic and inorganic sources on the surface layer bulk density. Bulk density decreased from 1.39 Mg m^{-3} to 1.06 Mg m^{-3} in the surface layer and from 1.39 Mg m^{-3} to 1.15 Mg m^{-3} in the subsurface layer (Tables 6a and 6b). Among the different treatments, bulkdensity was found to be comparatively lower in the treatments amended with rice husk biochar/*Artocarpus* which might be due to increased pore space. A significant decrease in the surface layer bulk density of the manured fields was also reported by Shirani *et al.,* 2002. Application of organic amendments such as composts, manures, crop residues and bio-solids had been often shown to decrease soil bulk density which is attributed to the increase in pore space (Tian *et al.,* 2009). Therefore, the lower BD in soil may be contributed to input of organic material in this system.

The effect of organic amendments on BD was more pronounced in the surface layer (0-15 cm) than lower depth (15-30 cm) and it increased with depth (Fig.3a and 3b). The increase of BD with depth was largely because of decreasing organic matter content and reduced aggregation with depth.

Water holding capacity (WHC)

The results revealed that the treatments which received addition of organic sources either alone or in combination with inorganic fertilizers had higher WHC, while treatments in which inorganic fertilizers alone were applied recorded the lowest values. The values ranged from 44.76 per cent to 51.66 per cent in the surface soil and from 43.37 per cent to 49.66 per cent in the subsurface soil (Fig. 4a and 4b). The improvement in moisture retention characteristics of soil by organic matter addition has been suggested by several workers (Manickam and Venkitaramanan, 1972; Tadesse *et al.*, 2013) particularly in the top soil, where the organic matter content is greater. Increase in the moisture retention of the soil and improvement in dissolution of nutrients particularly phosphorus could be due to the high amount of organic matter in the manures (Choudhary *et al.*, 2013). The highest WHC in the RHB amended plot showed macro-aggregates formation in the rice soil as a result of biochar addition which increased total porosity and soil water retention (Sharma and Uehara, 1986).

5.1.2. Chemical characteristics of soil

pH

The data on pH of the samples revealed that the soil exhibited strong acidic reaction (Tables 8a and 8b). The soil pH ranged between 4.58 and 5.28 in the top 15 cm of the soil, while the soil from 15-30 cm had the pH range between 4.62 and 5.32 (Fig. 5a and 5b). The highest pH value found in the treatment with biochar was due to neutralizing effect on the acidic soil. This is related to the liming value of the biochar (Arocena and Opio, 2003), which is preferable for the soils of Kerala. Biochar had alkaline properties with a pH of 9.1(Table 3) which is higher than all other organic sources.The preferable variation in pH due to the application of biochar was generally attributed to the presence of ash residues that contain alkali and alkaline earth metals, amounts of silica, heavy metals, sesquioxides, phosphates and small amounts of organic and inorganic N (Raison, 1979). The organic materials application in acidic

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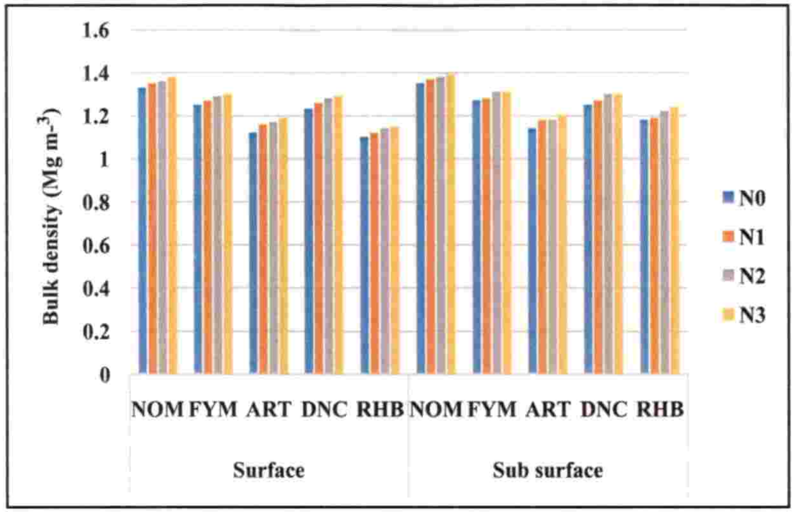

Fig. 3a. Effect of different organic sources on bulk density of soil in virippu season

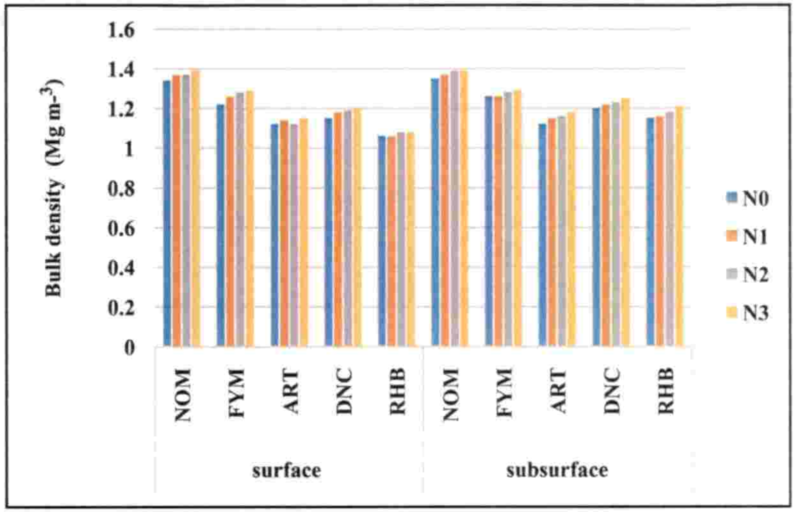

Fig. 3b. Effect of different organic sources on bulk density of soil in mundakan season

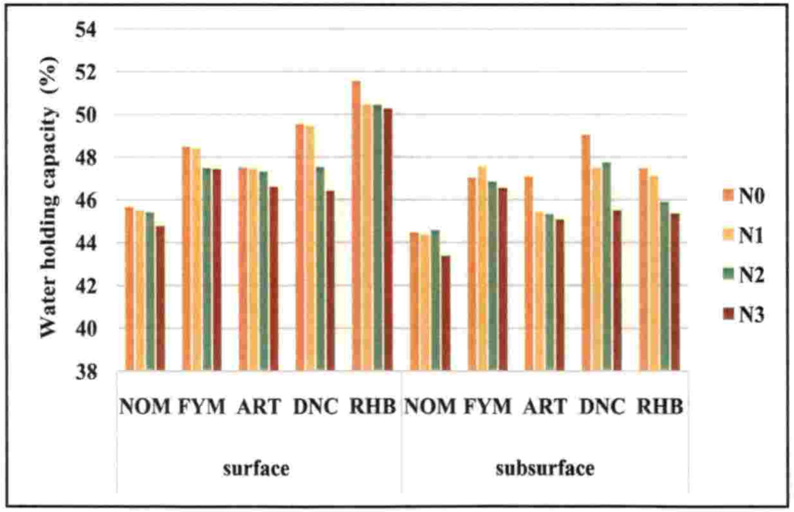

Fig. 4a. Effect of different organic sources on water holding capacity of soil in virippu season

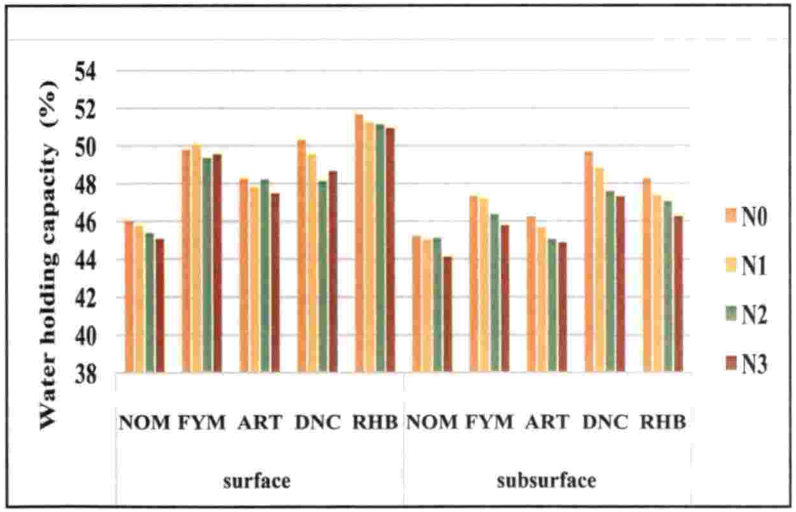

Fig. 4b. Effect of different organic sources on water holding capacity of soil in mundakan season

soils, in addition to increasing the soil pH due to its liming effect also increases the SOC content (Haynes and Mokolobate, 2001).

Electrical conductivity (EC)

Significant variation in EC of the soil was depicted by the estimated values of EC of the soils (Fig.6a and 6b). It ranged between 0.038 dS m^{-1} and 0.144 dS m^{-1} in the top 15 cm of the soil while the soil from 15 cm to 30 cm showed the values of EC ranging from 0.015 dS m^{-1} to 0.252 dS m^{-1} (Tables 9a and 9b). Generally, the EC values decreased over a period of time (mundakan) and also with increase in soil depth which is possibly due to the leaching of salts of various ions during NE monsoon and to slow mobility towards lower horizons.

Cation exchange capacity (CEC)

The values varied from 6.16 cmol (p+) kg^{-1} recorded by control treatment to 6.58 cmol (p+) kg^{-1} in the treatment with daincha and 35 kg N ha^{-1}(Fig.7a and 7b). Increase in CEC of rice soil due to application of organic sources is probably due to the negative charges arising from the carboxyl groups of the organic matter (Kaur *et al.*, 2008). Organic matter addition had shown increase in CEC and pH of soil (Bot and Benites, 2005). In addition to the presence of higher amount of humus, presence of sandy clay loam soil hadalso helped in boosting the cation exchange capacity. Jien and Wang (2013) had also reported that organic amendments such as biochar added to soil improved the soil structure, especially by the formation of macroaggregates and CEC and base saturation percentage.

Organic carbon (OC)

The perusal of data in Fig. 8a and 8b showed that organic manureapplication increased the OC content of soil. The organic carbon content of soil was influenced significantly due to treatments in the surface layer and it was the highest in treatment with biochar (Fig. 8a and 8b). The positive effect of biochar on SOC levels was due to its high carbon content (43.70%). The highest values of organic carbon in biochar treated soils indicated the presence of recalcitrant organic

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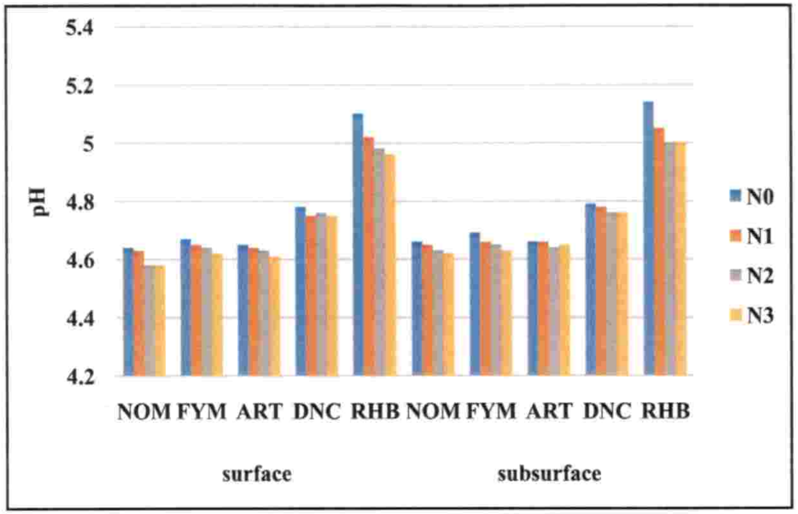

Fig. 5a. Effect of different organic sources on pH of soil in virippu season

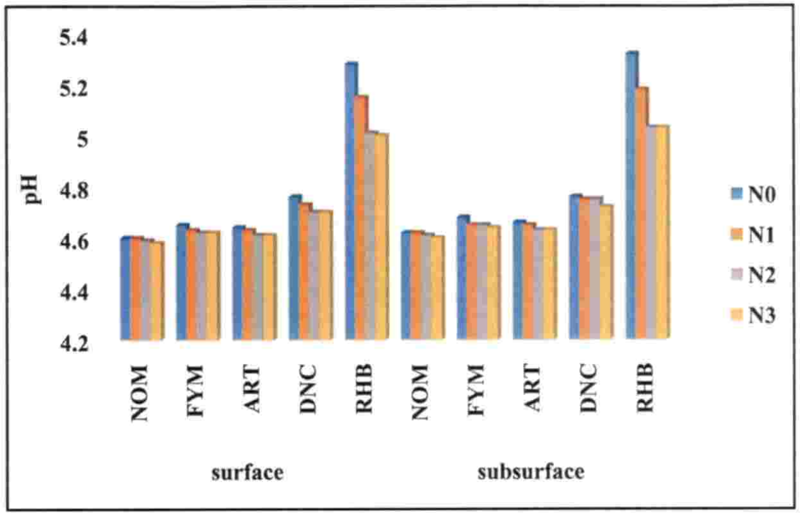

Fig. 5b. Effect of different organic sources on pH of soil in mundakan season

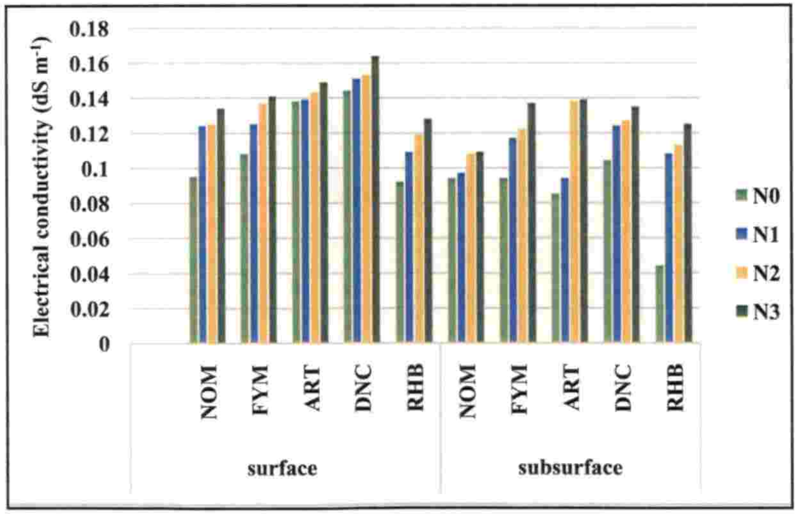

Fig. 6a. Effect of different organic sources on electrical conductivity of soil in virippu season

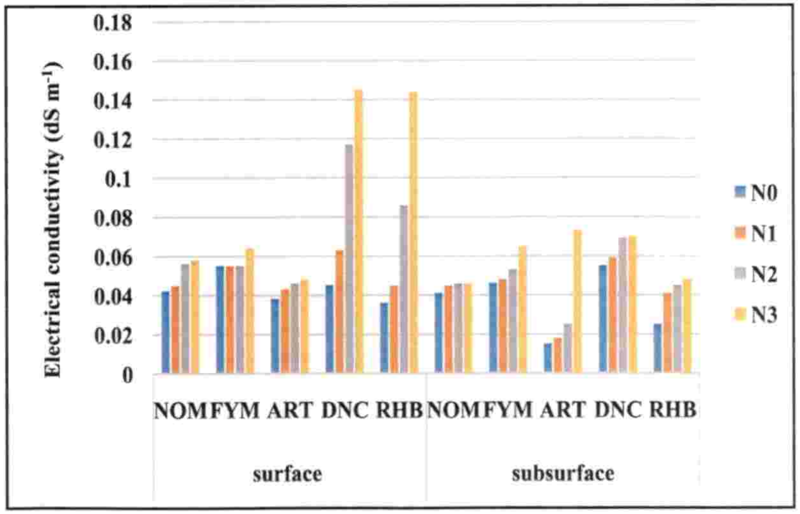

Fig. 6b. Effect of different organic sources on electrical conductivity of soil in mundakan season

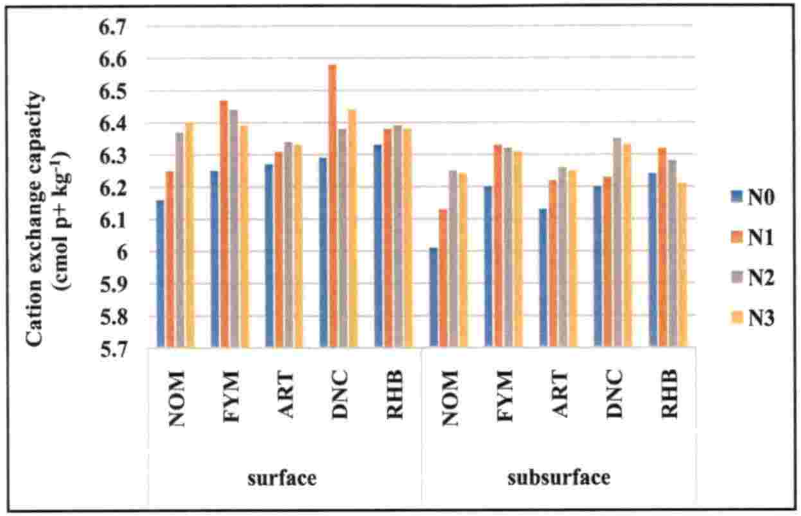

Fig. 7a. Effect of different organic sources on cation exchange capacity of soil in virippu season

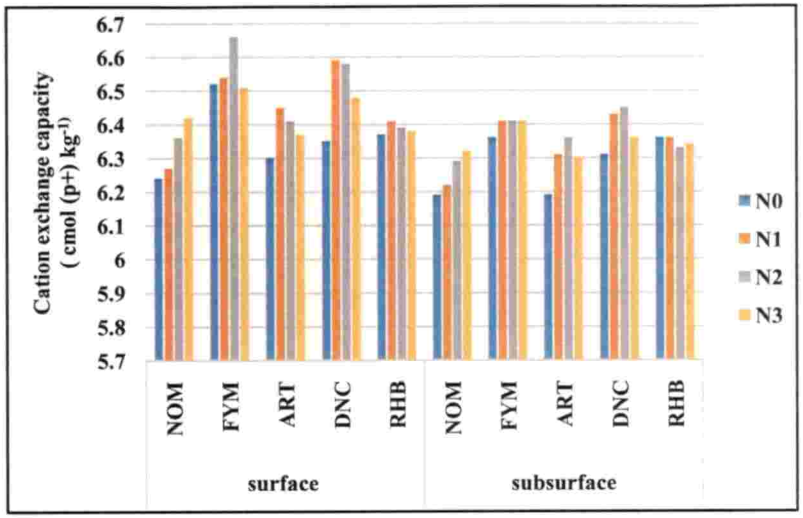

Fig. 7b. Effect of different organic sources on cation exchange capacity of soil in mundakan season

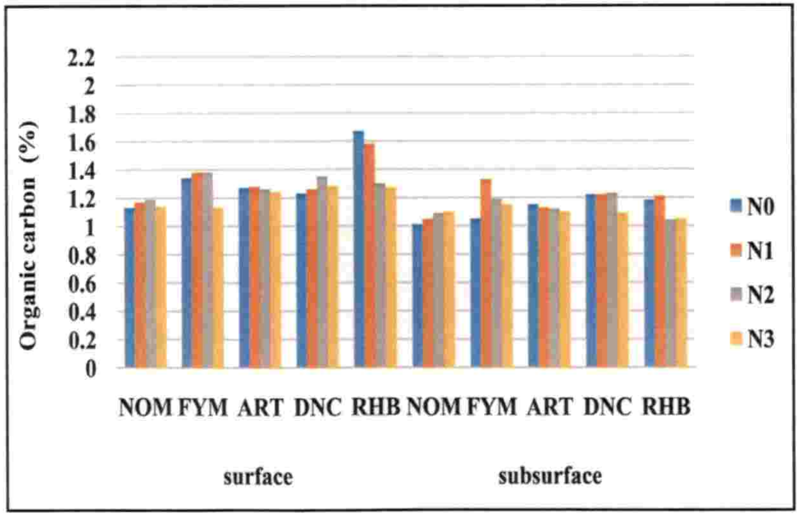

Fig. 8a. Effect of different organic sources on organic carbon of soil in virippu season

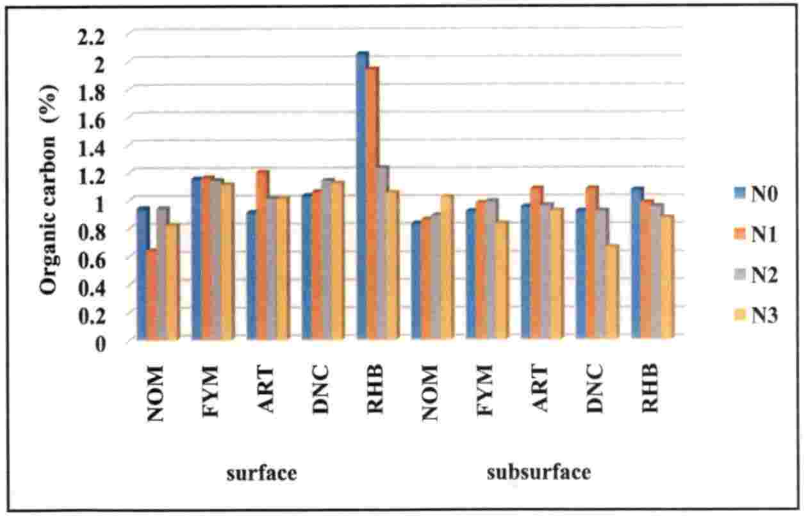

Fig. 8b. Effect of different organic sources on organic carbon of soil in mundakan season

carbon in biochar (Nigussie *et al.*, 2012). The treatments, daincha (DNC) + NPK and daincha (DNC) alone had recorded comparatively lower organic carbon content. This can be attributed to the rapid decomposition of fresh daincha leaves. The subsurface soil samples from RHB applied plots recorded lower OC content compared to other organic sources and it might be due to the low density of the material which might have led to lesser downward movement.

The OC values decreased after virippu season and it ranged between 0.64 and 2.05 per cent. The inability of organic manures to enhance the organic carbon content of soil considerably in spite of their application at same doses is mainly due to the effect of continuous cropping and tropical conditions of high rainfall and temperature prevailing in the region. This might have resulted in higher rate of decomposition of organic matter. Under water logged anaerobic conditions prevailing in the field, the rate of degradation of organic matter is low compared to upland aerobic situation. But towards the end of second cropping season in January 2015, the increase in temperature might have resulted in oxidation of accumulated humus in the soil thereby decreasing the OC content. This result is in lieu with the findings of Fang and Moncrieff, 2001.

5.1.2.1. *Available nutrients*

Nutrient contents in soil varied significantly with soil depth. Nutrient contents were higher in the treatments with organic sources and inorganic fertilizers than the ones without organics in both virippu and mundakan seasons. The amount of nutrients decreased with increasing soil depth. Top soil gained a higher amount of nutrients due to surface application of organic amendments.

Available nitrogen

Higher available soil N was noticed in soil profile from 0-15 cm depth, i.e., 411.75 - 596.38 kg ha^{-1} (Table 12a). This could be attributed to the higher available N in soil due to the application of nitrogenous fertilizer continuously over a period of time which became more pronounced when applied with P and K. The soil N content

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decreased with depth as seen from the value for lower horizon (Table 12b). Available N was the highest where application of daincha (*Sesbania aculeata*)was adopted along with fertilizer application (Fig. 9a and 9b). The values were found to be 521.78 and 596.38 kg ha^{-1} during virippu and mundakan seasons respectively. Chaphale *et al.* (2000) found that green manuring combined withfertilizer application increased the available N content in soil. Green manuring significantly reduced both leaching and gaseous loss of fertilizer N as reported by Bhattacharyya and Mandal (1996). Further it can be seen from the tables that the soil nitrogen content in the treatments with organic sources increased in the second cropping season. Eghball *et al.* (2004) pointed out that only certain portion of the N and some elements from organic manures become available for plants in initial period and this could have resulted in an increase in the N content in mundakan season.

Available phosphorus

Data on available P content in soil (Fig.10a and 10b) clearly revealed that application of P through fertilizers along with organics resulted in increase in available P. There wasincrease in available P with the combined use of organic sources along with inorganic fertilizers and the highest values were 55.62 and 60.38 kg ha^{-1} in FYM and RHB treated plots in virippu and mundakan seasons respectively. The increased release of P can be ascribed to the fact that organic anions competed with the phosphate ions for binding sites on soil colloids thereby reducing the P fixation (Paneerselvam *et al.,* 2000). Tejeda*et al.* (2009) showed that soils amended with composts originating from leguminous residues had an optimum balanced C/N ratio (10-12), where organic matter mineralization overcomes immobilization. The buildup of P status is very low in the soil where only inorganic fertilizers was applied due to fixation of P as Al or Fe phosphate.

During mundakan season, the treatment with RHB (rice husk biochar) /ART (*Artocarpus*) resulted in an increase in the content compared to other organic sources. Availability of phosphorus depends on soil pH, which is a function of organic anions

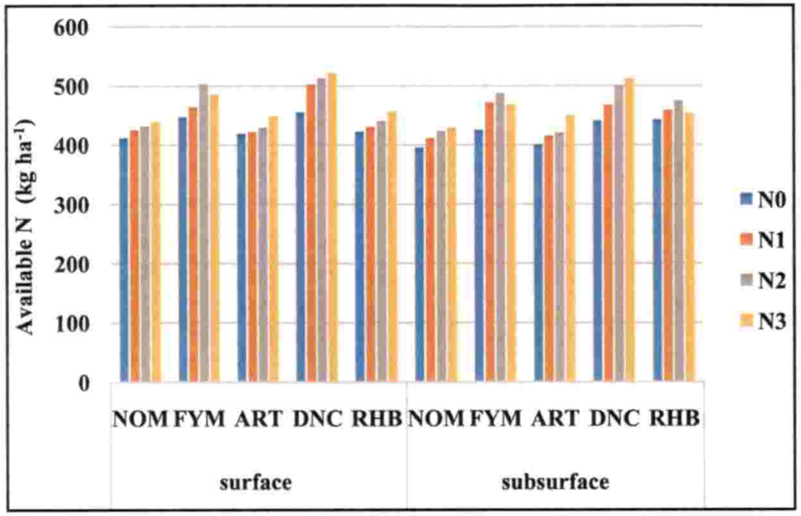

Fig. 9a. Effect of different organic sources on available nitrogen of soil in virippu season

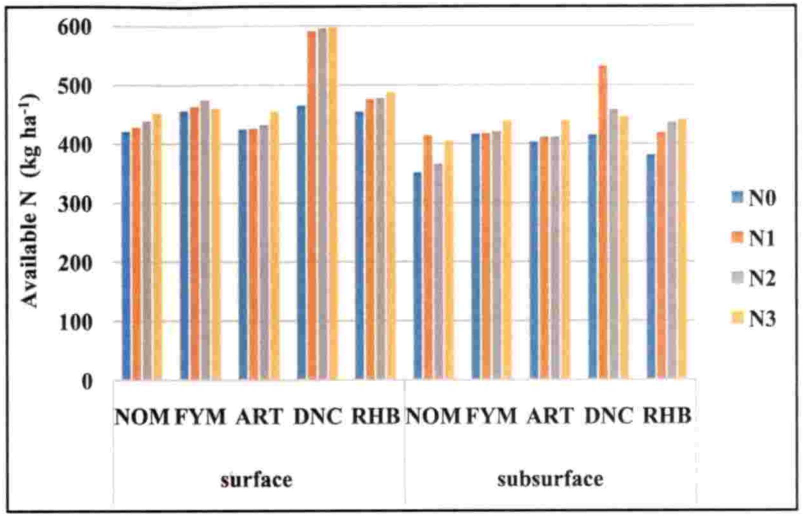

Fig. 9b. Effect of different organic sources on available nitrogen of soil in mundakan season

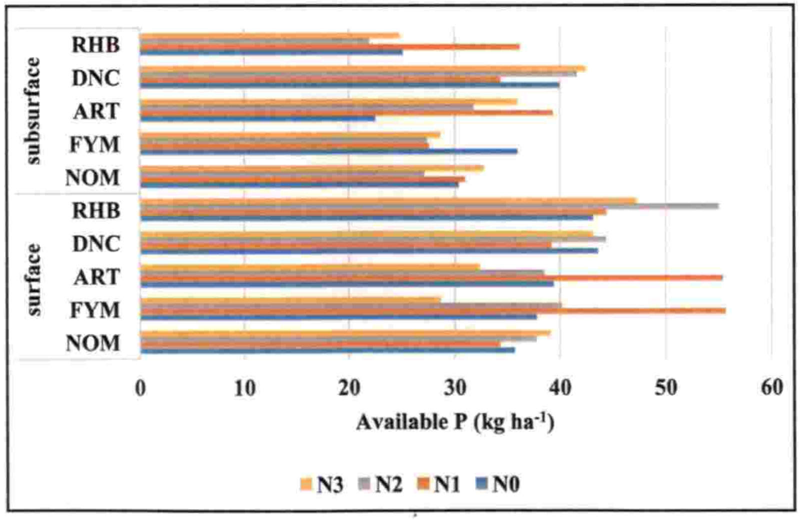

Fig. 10a. Effect of different organic sources on available phosphorus of soil in virippu season

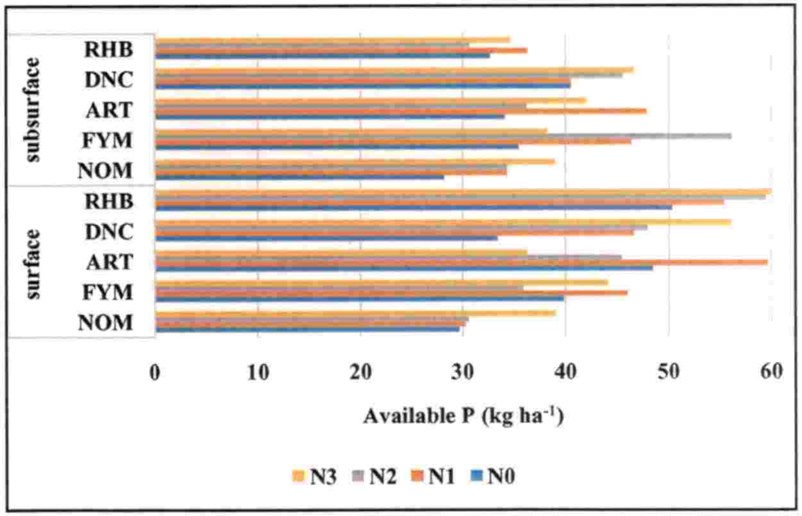

Fig. 10b. Effect of different organic sources on available phosphorus of soil in mundakan season

in soil (Nye, 1981 and Haynes, 1990). Increased retention of P with biochar addition was also observed by Prabha *et al.*, 2013. Organic acids derived from roots and microorganisms helped in increasing the labile P in soil. Further deficiency of P in soil stimulates root exudation of organic acids in rhizosphere. Results summarized above, with respect to available phosphorus are closely in consonance with findings reported earlier by Chang *et al.*(2004) in rice.

Available potassium

Analysis of Fig. 11a and 11b showed that the values of available potassium increased in virippu season (174.28 kg ha^{-1}) and then decreased during mundakan season (120.35 kg ha^{-1}). The increase might be attributed to the greater capacity of organic colloids to hold K^+ on the exchange sites. The higher values of K obtained through the addition of daincha (174.28 kg ha^{-1}) can also be due to the decomposition of organic matter which helped to release appreciable quantities of $CO_2$and this ondissolving in water, forms carbonic acid, which is capable of decomposing certain primary minerals resulting in release of nutrients. The decreased availability of K in absolute control treatments (96.45 and 76.21 kg ha^{-1}) may be attributed to the nutrient mining from the already impoverished soils of control plots coupled with its higher uptake by crops. Similar results were also reported by Elangovan (1984) from his study at Coimbatore.

Available calcium and magnesium

It can be inferred from the result (Fig. 12 and 13) that the organic sources in combination with inorganics had significant effect on exchangeable calcium and magnesium content in soil. Available Ca and Mg were higher in treatments receiving combinations of organic manures and fertilizers. The positive effect on Ca and Mg content in soil was owing to the release of these nutrients during the decomposition of organic manures. This is in conformity with the results reported by Kurumthottical, 1982. Application of daincha as organic source had the highest positive effect (444.73 and 39.67 mg kg^{-1}) on soil available calcium and magnesium

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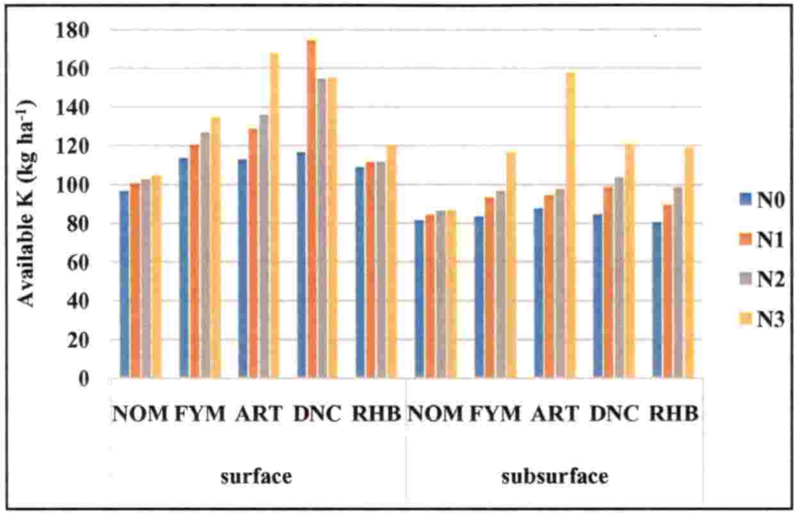

Fig. 11a. Effect of different organic sources on available potassium of soil in virippu season

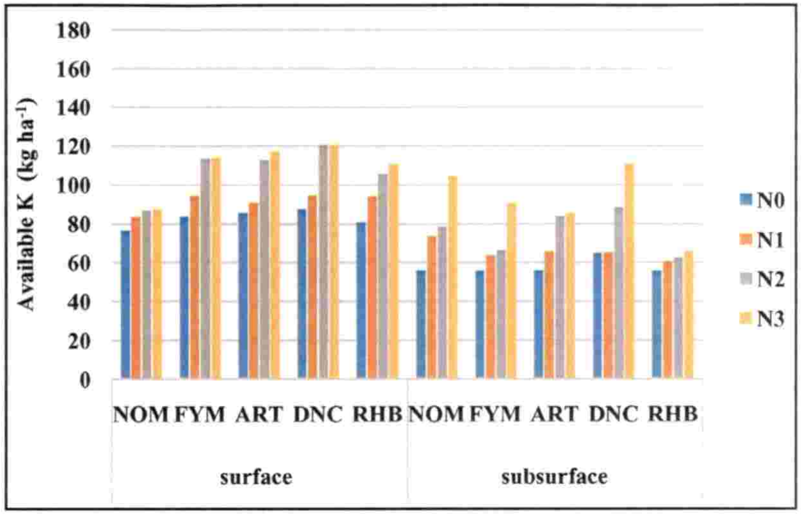

Fig. 11b. Effect of different organic sources on available potassium of soil in mundakan season

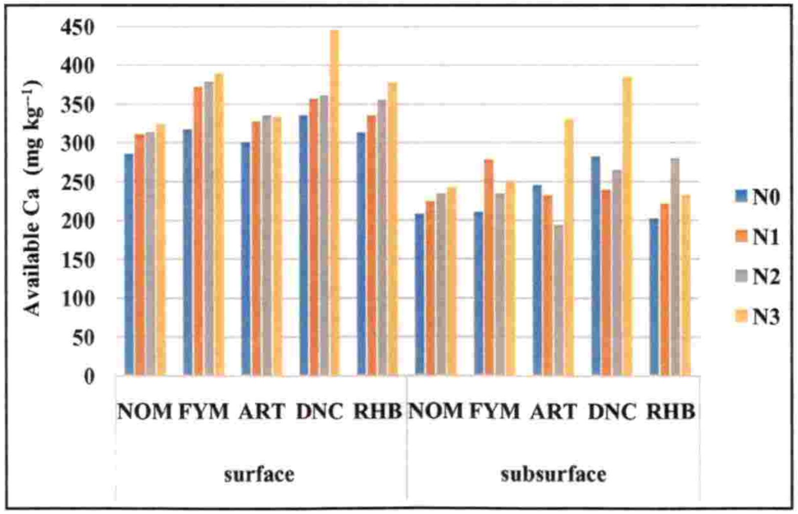

Fig. 12a. Effect of different organic sources on available calcium of soil in virippu season

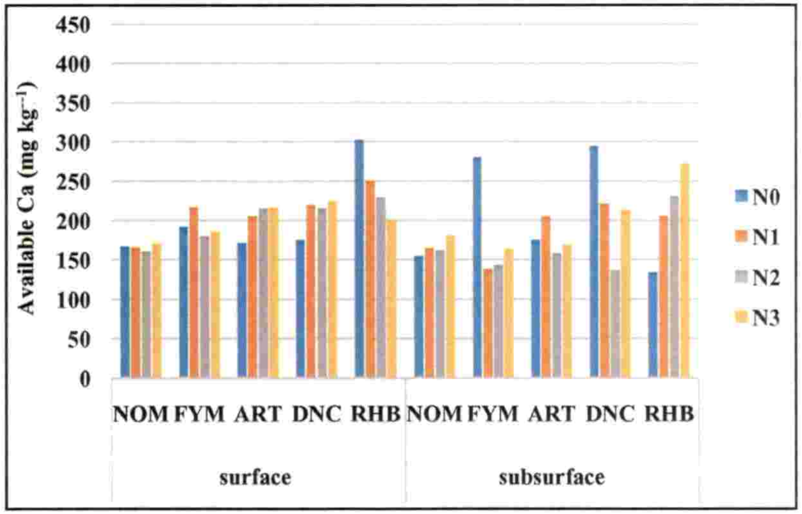

Fig. 12b. Effect of different organic sources on available calcium of soil in mundakan season

content in virippu season, while in mundakan season the effect of RHB was prominent. Significant variations between the treatments in available Ca and Mg content of soils might be ascribed to the variation of nutrient content in organics and their interaction with inorganics applied in the experimental plots. Further it was seen that a reduction occurred in available calcium and magnesium contents to nearly half the amount in the mundakan season. High and intense rainfall events mighthave increased leaching of basic cations which is a characteristic of low CEC of soil; thus, increasing soil acidity.

Available sulphur

The highest sulphur content of 8.46 mg kg^{-1} was obtained for daincha with 70 kg N ha^{-1} and the same trend was observed in mundakan season also with a value of 6.74 mg kg^{-1} for the same treatment (Table 18a). The treatments had significant effect with respect to available sulphur (Fig.14 b) in subsurface soil only and its content decreased considerably in mundakan season and with increased depth. During mundakan season, maximum value was observed for daincha with 105 kg N ha^{-1} (4.73 mg kg^{-1}). When compared to the initial sulphur content (Table 2) though a slight increase had occurred in virippu and mundakan seasons in the surface layer, the contents were very less in the subsurface layer. The reasons for this difference can be attributed to the contribution from organic sources and crop uptake respectively.

Available micronutrients

The available micronutrients were lower in the soil treated with N fertilizer alone and in control and higher in the treatments with organic sources (Fig. 15a and 15b to 19a and 19b). The increase in the soil available form of micronutrients due to organic manure application may be attributed to the formation of water-soluble complexes called chelates which prevents the reaction with the other soil constituents. Chelating action of FYM during decomposition of organic manures increased the availability of nutrient cations. Moreover, organic manures protected the cations thus rendering unavailable for fixation. Singh *et al.* (1999) also reported increased

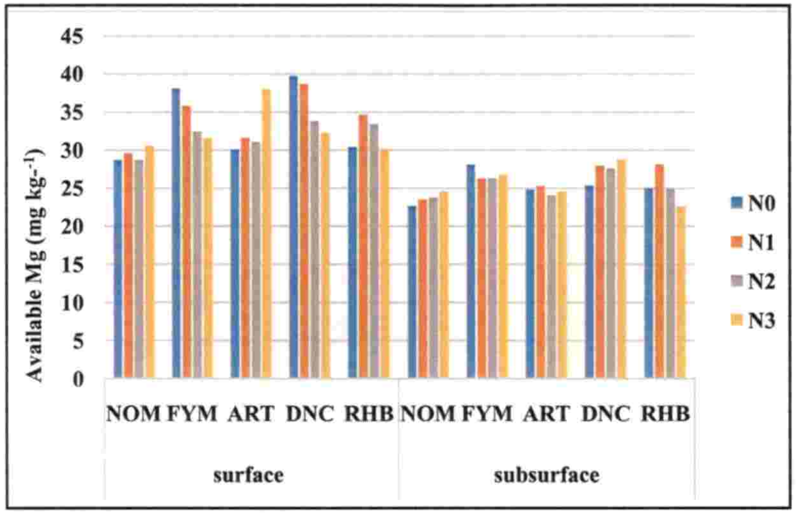

Fig. 13a.Effect of different organic sources on available magnesium of soil in virippu season

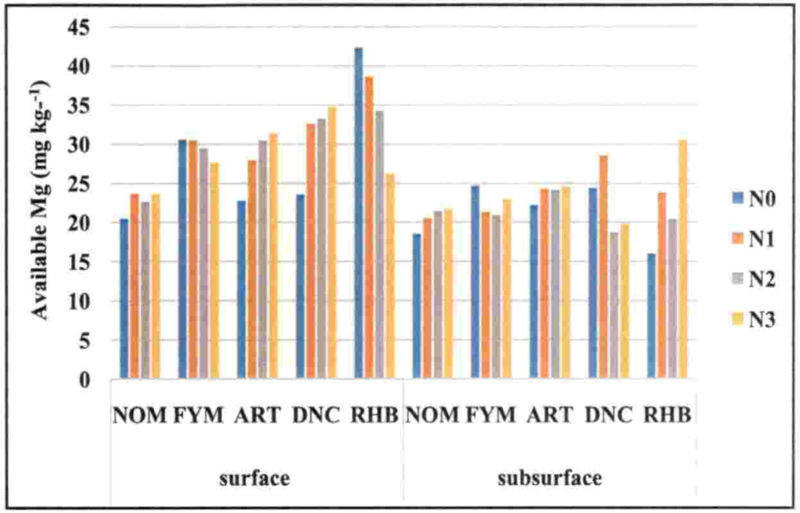

Fig. 13b. Effect of different organic sources on available magnesium of soil in mundakan season

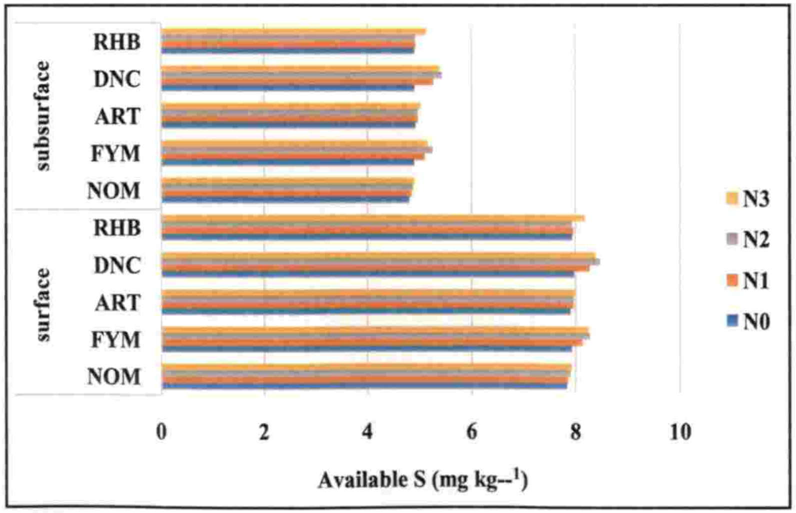

Fig. 14a. Effect of different organic sources on available sulphur of soil in virippu season

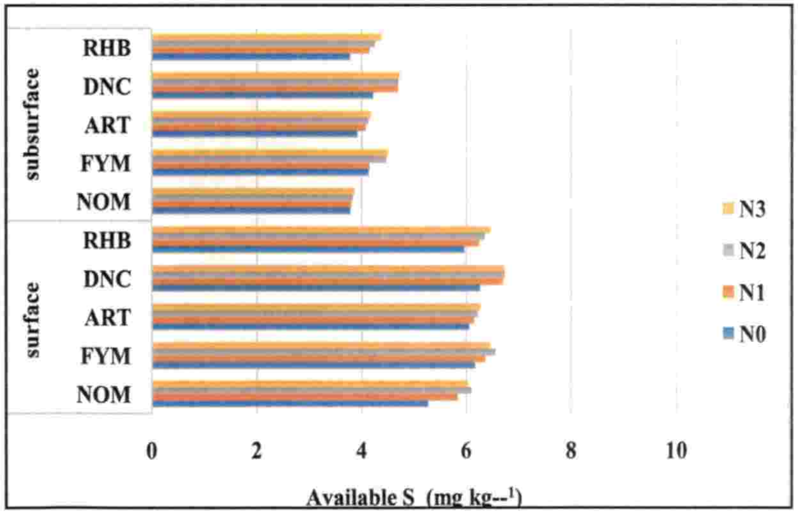

Fig. 14b. Effect of different organic sources on available sulphur of soil in mundakan season

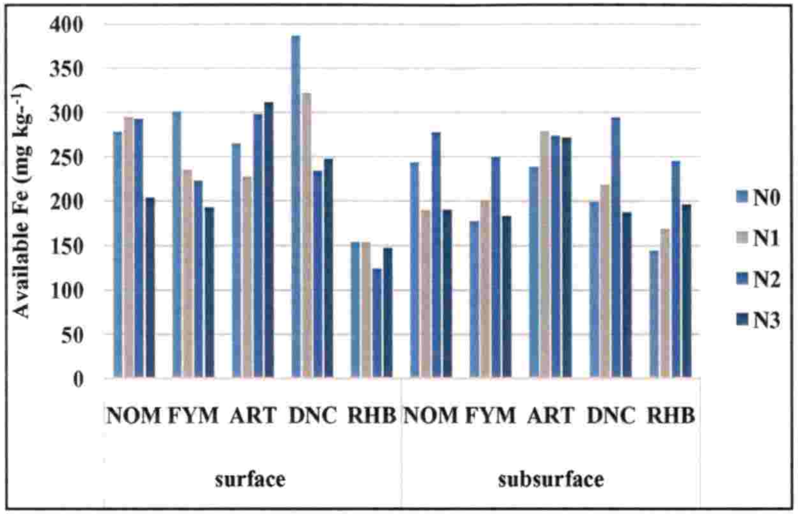

Fig. 15a. Effect of different organic sources on available iron of soil in virippu season

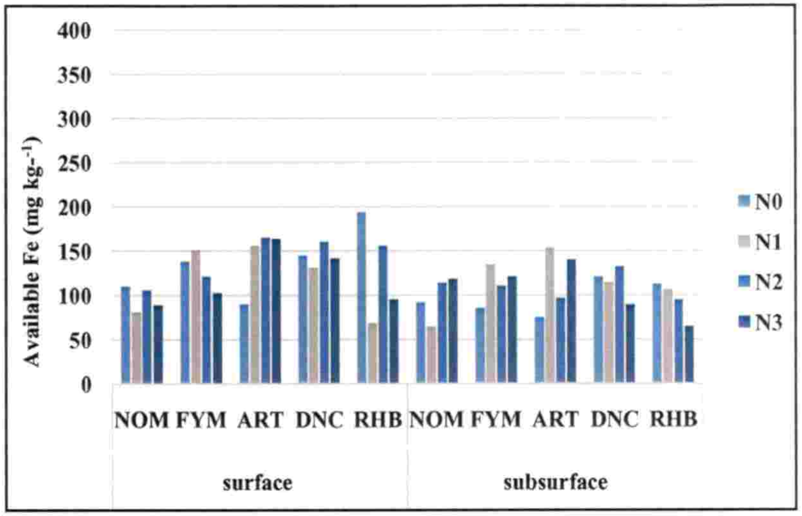

Fig. 15b. Effect of different organic sources on available iron of soil in mundakan season

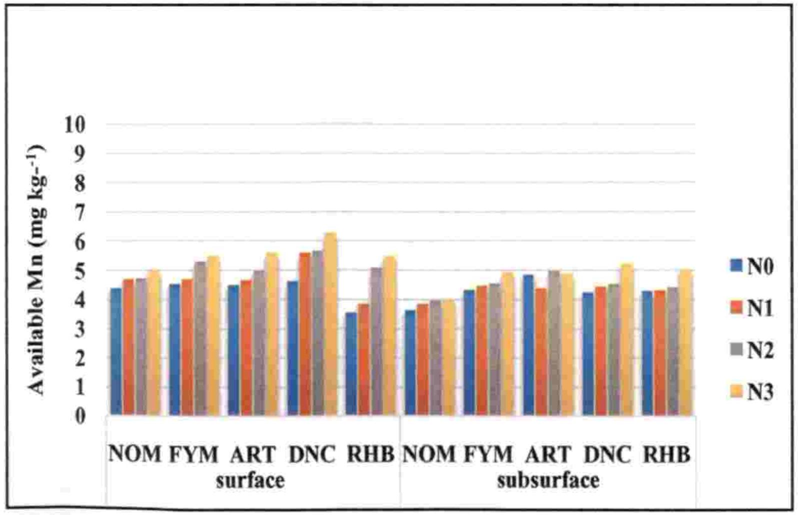

Fig. 16a. Effect of different organic sources on available manganese of soil in virippu Season

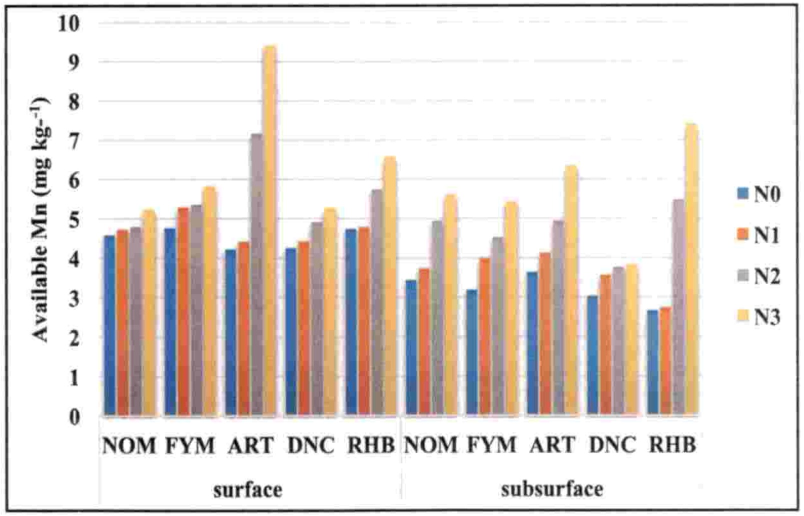

Fig. 16b. Effect of different organic sources on available manganese of soil in mundakan season

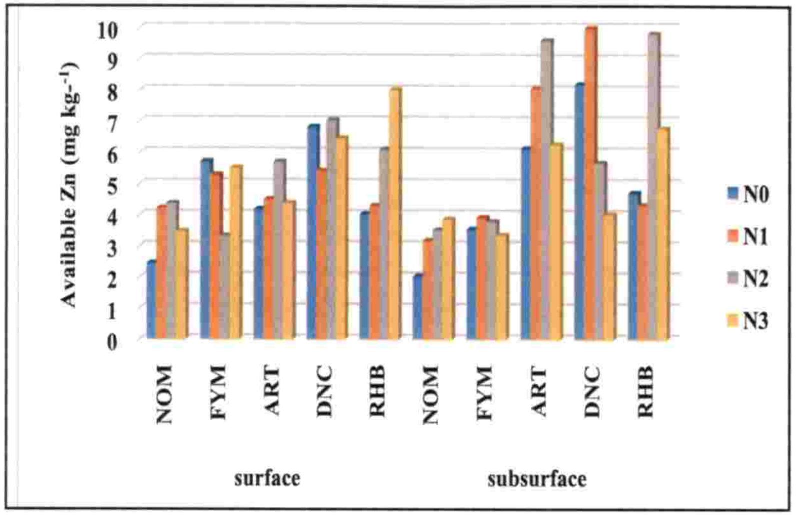

Fig. 17a Effect of different organic sources on available zinc of soil in virippu season

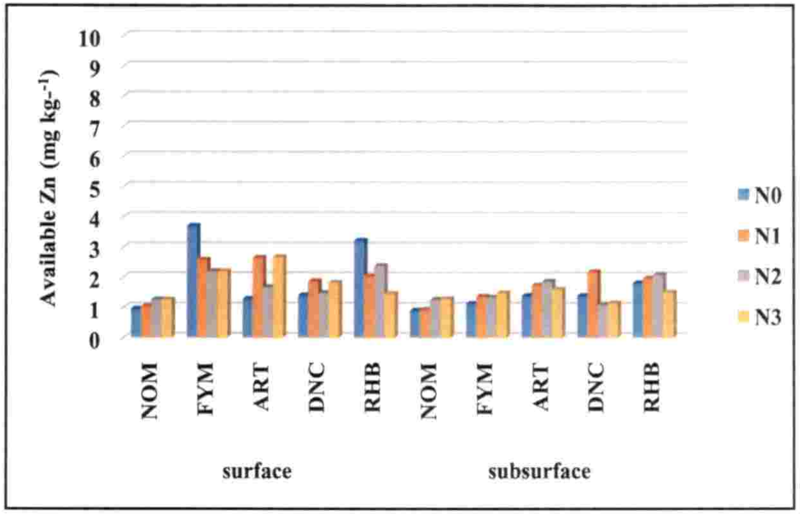

Fig. 17 b. Effect of different organic sources on available zinc of soil in mundakan season

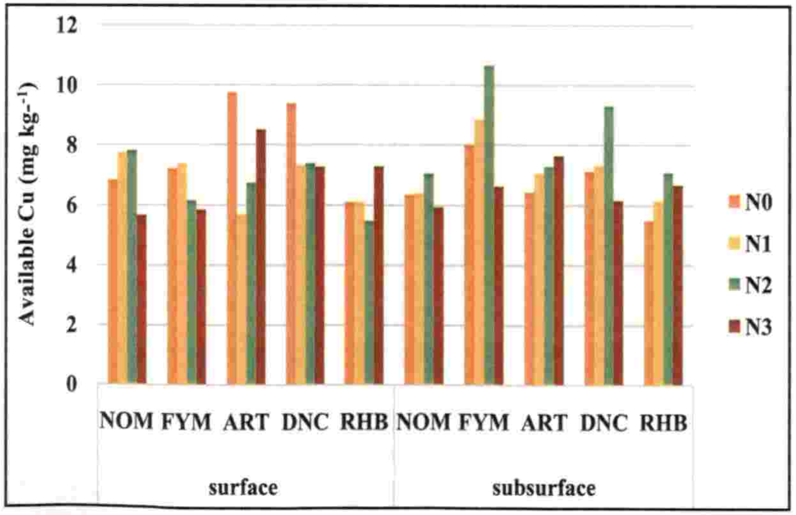

Fig. 18a. Effect of different organic sources on available copper in virippu season

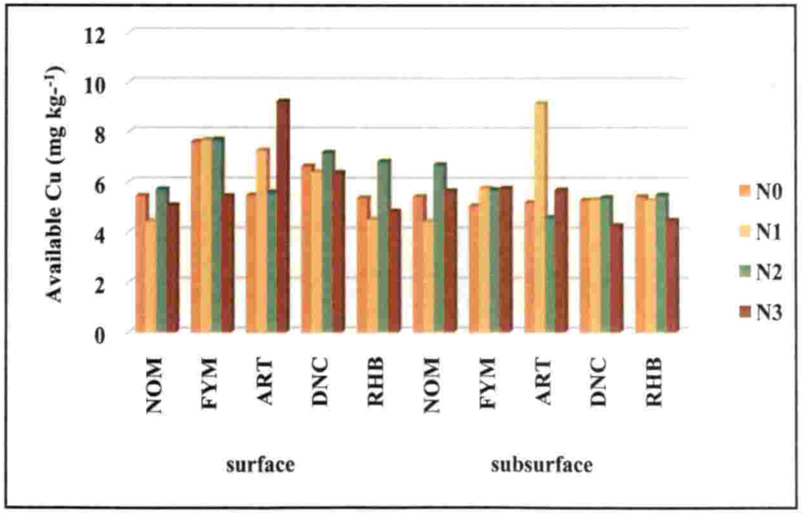

Fig. 18b. Effect of different organic sources on available copper in mundakan season

micronutrient content in balanced fertilization over control. The data revealed that the effects of the treatments were not significant in the available boron content in the soil.

In general, organic fertilizer application and/or INM system significantly increased availability of nutrients when compared to control or inorganic fertilizer applications. The available nutrients were found to be maximum in the treatments with daincha / RHB. The effect of RHB was more pronounced during the second season. The availability of nutrients in the biochar-added soil may also be due to the greater surface area of biochar material providing more adsorption sites.Biochar application can reduce nutrient leaching from soil with resulting increase in fertilizer use efficiency. Moreover, the increase in the water holding retention of biochar-added soils may improve nutrient retention in the topsoil. Increased nutrient retention may also due to attachment of organic matter or minerals with sorbed nutrients (aggregation) and biochar (Prabha *et al.*, 2013).

5.1.3. Biological characteristics of soil

The analyzed enzyme activities showed improved soil quality in treatments consisting of organic sources compared to treatments with mineral fertilizers and the increase was more in the surface soil than the subsurface. Kaiyong *et al.* (2011) reported that with increasing soil depth, there existed a consistent decrease in SOC and enzymatic activity. The soil biota increased when large amounts of energy were released increasing enzyme activity during straw decomposition. (Steenwerth and Belina, 2008).

Microbial biomass carbon

It was seen that (Tables 23a and 23b) various organic sources along with inorganic fertilizers improved (NPK) MBC than inorganic alone and control. This proved that soil management practices strongly affected the size of the microbial biomass pool (Fig. 20a and 20b). The control and inorganic fertilizer treatments showed less MBC while there was significant increase with organic manure application. The readily available C and N in organic sources along with root

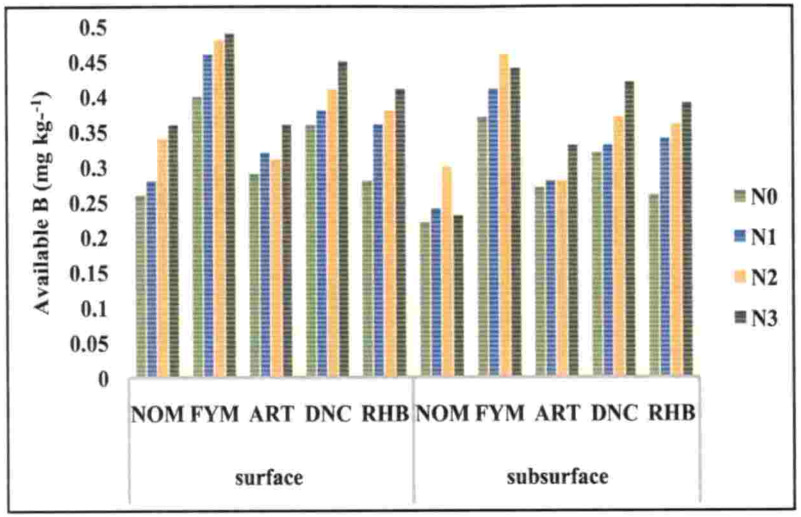

Fig. 19a. Effect of different organic sources on available boron in virippu season

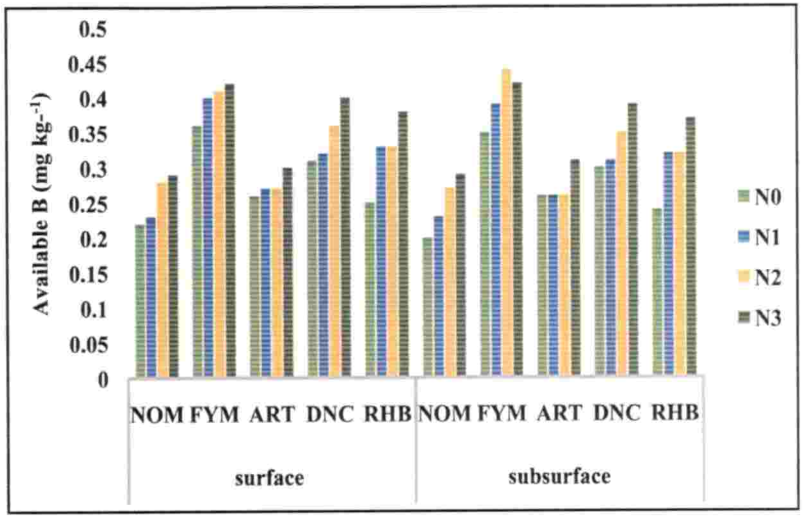

Fig. 19b. Effect of different organic sources on available boron in mundakan season

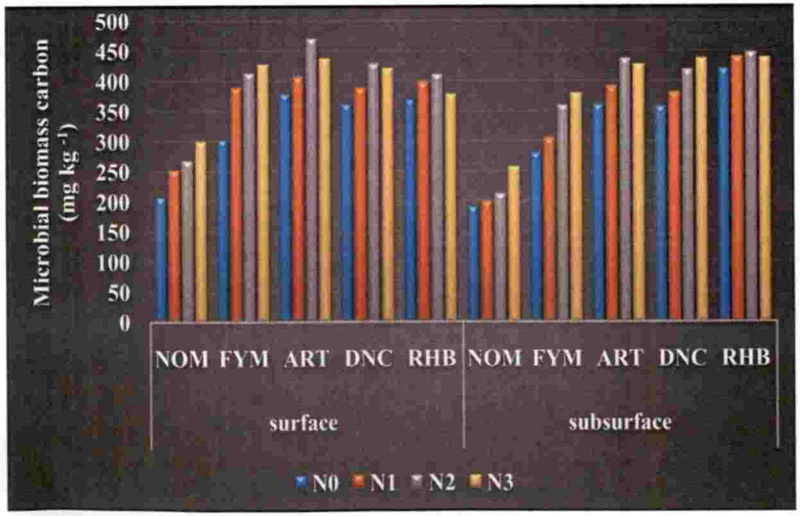

Fig. 20a. Effect of different organic sources on microbial biomass carbon in virippu season

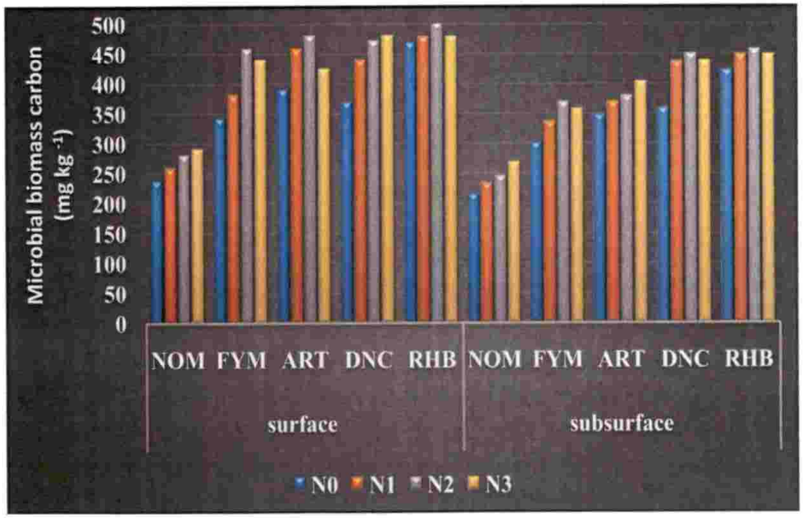

Fig. 20b. Effect of different organic sources on microbial biomass carbon in mundakan season

exudates might have led to increased crop growth and microbial biomass carbon. Ladha *et al.* (2011) pointed that even application of N fertilizers alone enhanced plant biomasswhich resulted in higher SOM and MBC.

When organic matter was added to the soil in the form of organic sources, the microbial biomass increased in size. In the surface soil (0–15 cm depth), organic materials contained higher MBC concentrations (ranged between 300.66 - 500.72 mg kg^{-1}) than the inorganics (Fig. 20a and 20b). The MBC concentrations declined with increasing soil depth but to various levels. However, the integrated approach including organic sources resulted in significantly higher MBC concentrations than the chemical fertilizers in 15–30 cm depth. The biomass in the treatment plots was mainly confined to the surface layers because of the accumulation of SOC near the soil surface resulting from mineralization and limited macrofaunal mixing (Hopkins *et al.*, 1996). Application of organic sources increased the MBC to higher values as compared to the control and NPK alone in the surface soil since exogenous organic amendments served as a substrate for microorganisms.

Tu *etal.* (2006) indicated that the quality of organic inputs is one of the most important factors affecting microbial biomass. This might be due to varying composition of organic materials which in turn affect utilization of C and nutrients by microbes. The porous structure of biochar, its high internal surface area and its ability to adsorb soluble inorganic matter, gases and inorganic nutrients might have provided a highly suitable habitat for microbes to colonize, grow and reproduce, particularly for bacteria (Lehmann*et al.*, 2003).

Phosphatase activity

The data in tables 24a and 24b revealed that the phosphatase activity was higher in organic treated plots in comparison with inorganic fertilizer alone and it was the highest in daincha with 105 kg N ha^{-1} (467.62 µg PNP h^{-1} g^{-1}). It could also be seen that the activity of enzymes increased with increase in inorganic fertilisers (Fig.21a and 21b). Theenhancement in dehydrogenase and phosphatase activities with increasing dose of chemical fertilizers as well as organic amendments is reflection of organic matter build up which leads to increase in microbial activities. This is in line with the findings of (Pascual *et al.,* 2002).Aparna (2000) also reported the same behaviour of enzymatic activity in soil.This might be due to complexation of clay and humus in SOM, being substrate of enzymes.

Dehydrogenase activity

As in the case of MBC, dehydrogenase activity was also significantly affected by the treatments and the response was more in the surface soil than in the subsurface soil (Fig. 22a and 22b). The maximum value of dehydrogenase activity was obtained for the treatment RHB with 105 kg N ha^{-1} (214.64μg TPF day^{-1} kg^{-1}). Dehydrogenase activity is a measure of overall microbial activity (Masciandaro *et al*., 2001) which is an intracellular enzyme in heterotrophic microorganisms having oxidative phosphorylation processes (Trevors, 1984). Organic application enhanced the soil microbial activity which could be correlated to dehydrogenase activity, as evidenced from increased soil polysaccharide content.

5.1.4. Soil carbon characteristics

Total organic carbon (TOC)

The total carbon contentin various treatments varied from 1.72 per cent to 4.06 per cent in surface soil and from 1.11 per cent to 3.98 per cent in subsurface soil (Fig. 23 a and 23 b). Addition of organic materials alone or along with fertilizer NPK significantly resulted in an increase in TOC in the 0–15 and 15–30 cm soil depths due to external C input to soil. The treatment with FYM alone recorded the significant and highest value of 4.04 per cent in virippu season followed by the RHB as organic source alone treatment with a value of 3.45 per cent (Table 26a). The increase in TOC concentration was much larger with cattle manure and RHB than with *Artocarpus* as well as daincha in the 0-15 cm depth, compared to the treatment NPK alone. The organic residue mainly resulted in accumulation of TOC in the surface soil, while organic C input into the subsoil was derived from dissolved organic

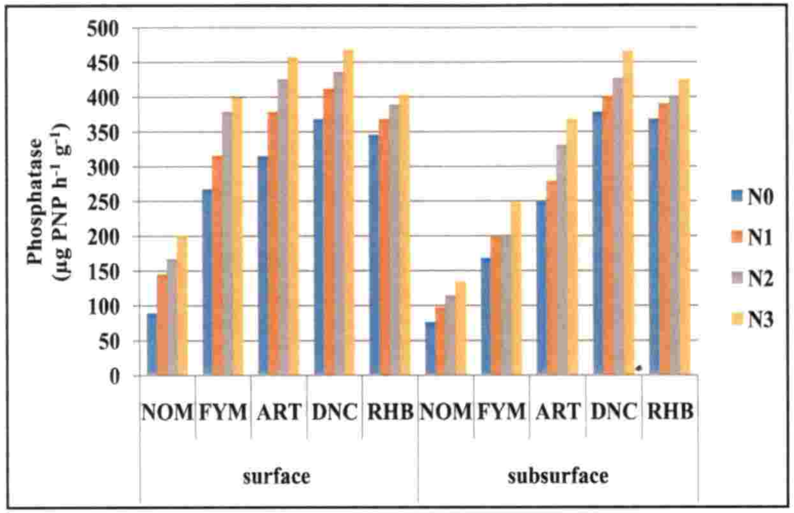

Fig. 21a. Effect of different organic sources on phosphatase activity in virippu season

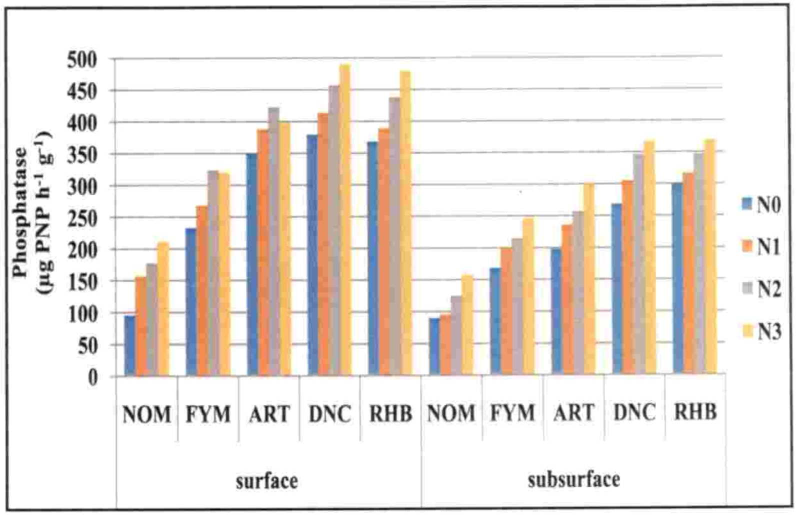

Fig. 21b. Effect of different organic sources on phosphatase activity in mundakan season

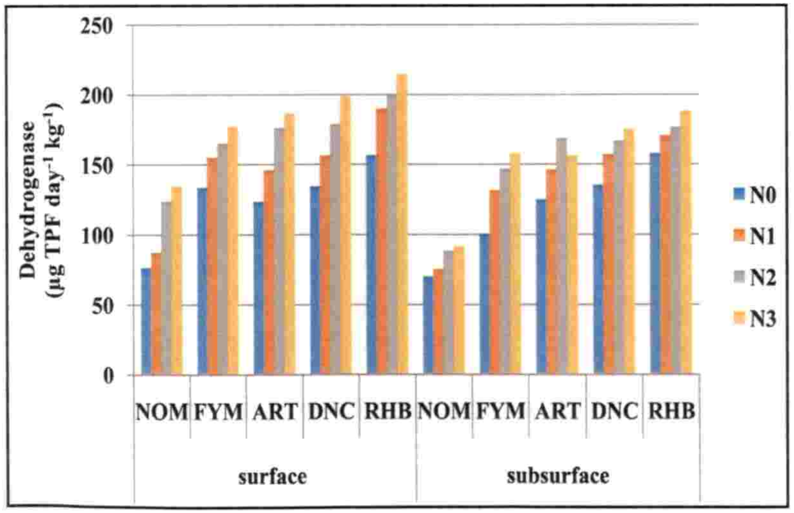

Fig. 22a. Effect of different organic sources on dehydrogenase activity in virippu season

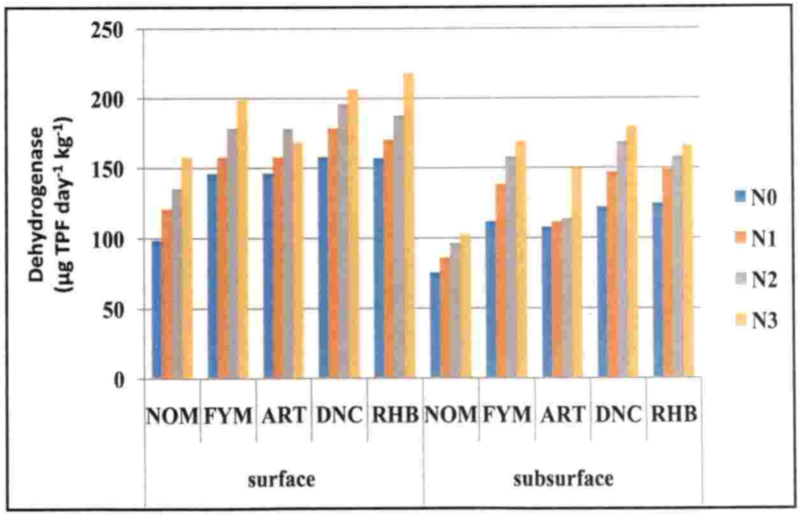

Fig. 22b. Effect of different organic sources on dehydrogenase activity in mundakan season

matter, plant roots and root exudate. The increase of TOC content on addition of chemical fertilizer was attributed to greater inputs of rhizo-deposited organic matter, root biomass and crop stubble. On the other hand, Zhao *et al.*(2014) had pointed that extraneous C input from manure was more effective in soil organic carbon sequestration.

The current experiment was carried out without ameliorating soil acidity. This was because on liming, increase in soil respiration decreases the SOC stock (Moore *et al.*, 2012). This can be ascribed to the fact that when lime is applied in an acid soil, it would react with active acidity (H^+, Al^{3+} and CO_2) in the soil solution and reserve acidity (exchange sites on soil colloid surfaces) releasing CO_2. The dissolution of carbonate minerals could act as either a net source or sink of CO_2 (Hamilton *et al.*, 2007). He pointed out that when the soil pH is <5, if H^+ comes in contact with HCO_3^-, it will be consumed and CO_2 will be produced. During nitrification of NH_4^+ to NO_3^- strong acids such as HNO_3 may be present, and the dissolution of carbonaceous minerals act as a CO_2 source.

$CaMg\,(CO_3)_2 + 4\,HNO_3$ ---- $Ca^{2+} + Mg^{2+} + 4\,NO_3 + 2\,CO_2 + 2\,H_2O$

This negative feedback of the SOC turnover involved in C cycling is again dependent on climate change such as C input level and temperature.

Soil organic carbon (SOC) stock

Figure 24 showed the increase insoil organic carbon, as a result of application of several organic sources. Soil organic carbon, a key determinant in soil quality is built up in soil in a slow process due to change in management practices (Malhi *et al.*, 2008). The results in table 27 also revealed that the stock of SOC was higher when the soil was amended with organic manures and inorganic fertilizers rather than organic fertilizers alone. The possible reasons for this decrease in SOC on adding exclusively organic sources might be ascribed due to the following mechanisms.

The addition of organic sources in soils not only increased the SOC content, but also has the potential to increase the soil pH in acidic soils due to its liming effect

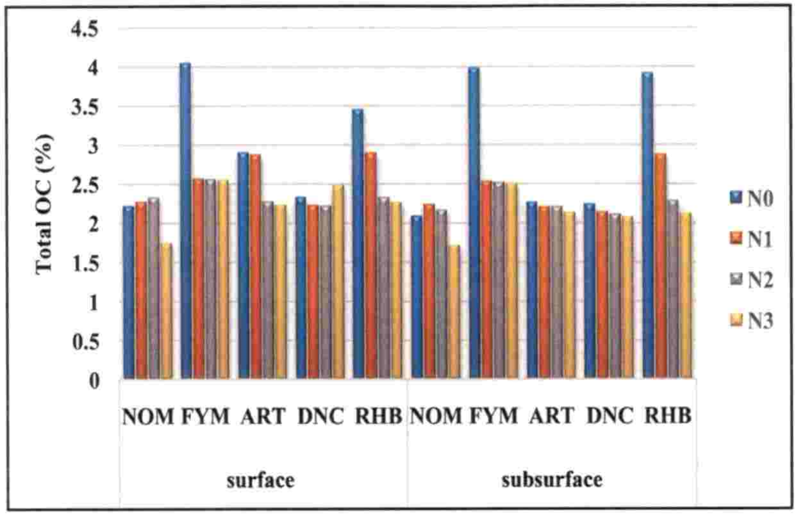

Fig. 23a. Effect of different organic sources on total organic carbon in virippu season

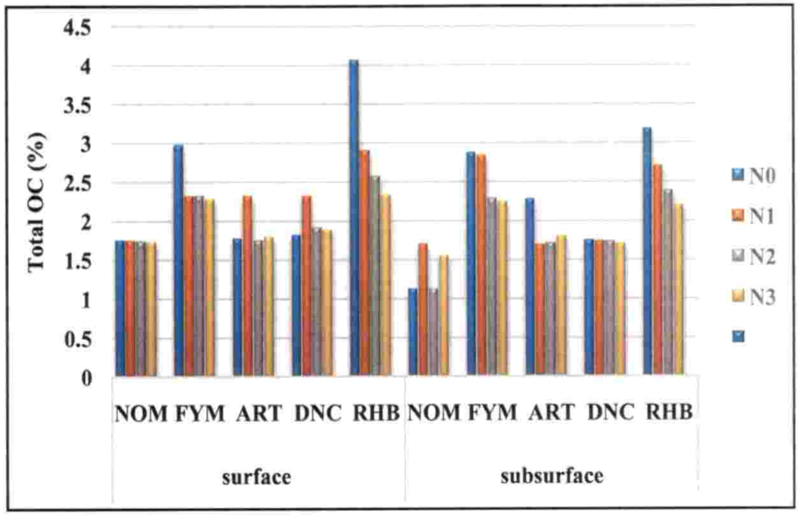

Fig. 23b. Effect of different organic sources on total organic carbon in mundakan season

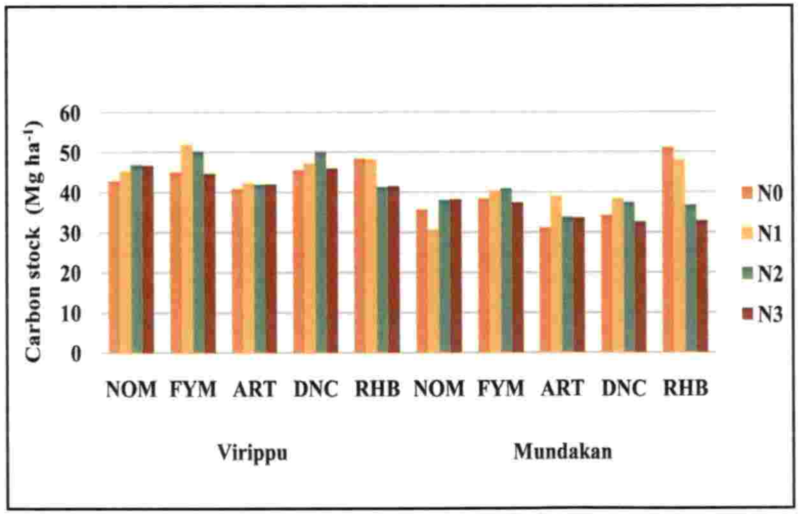

Fig. 24. Effect of different organic sources on soil carbon stock

(Haynes and Mokolobate, 2001). This pH rise reducedthe adsorption of SOC by minerals (Curtin *et al.*, 1998; Haynes, 2005; Mayer and Xing, 2001) and increased the chances for decomposition. In addition, enhanced soil water retentioncould aggravate the SOC decomposition (Rawls *et al.*, 2003). Further the increase in soil pH also enhanced the microbial activity in acidic soils (Andersson and Nilsson, 2001; Fuentes *et al.*, 2006). Finally, dark colors, usually associated with high SOC contents (Schulze *et al.*, 1993), would absorb more heat and subsequently strengthen the SOC decomposition resulting in a decrease in carbon sequestration.

The soil conditions would influence the stock of OC associated with the minerals and that the extent of surface loading in acid soils depends on pH (Mayer and Xing, 2001). Differences in the soil's hydrologic conditions can change shifts of both soil pH and redox conditions, which would result in the alteration of the reactive soil minerals, like Fe/Al oxides (Berhe and Kleber, 2013). The higher concentrations of SOC in biochar applied soil ranging from 48.20 Mg ha^{-1} to 51.11 Mg ha^{-1} might be due to the potential of biochar to increase the recalcitrant pool of soil carbon which would persist in the soil environment much longer than carbon added in the form of residues or biogenic soil organic matter (Jeffrey *et al.*, 2009). Shenbagavalli and Mahimairaja (2012) reported that application of biochar significantly increase the SOC content and would probably add to the decadal soil carbon pool.

Glaser *et al.* (2000) found that iron and aluminum oxide plaques on mineral surfaces embedded a large portion of black carbon.These oxides occur in many acidic soils and are characterized by surfaces that are inhabited by single coordinated hydroxyl groups (Keogel- Knabner *et al.*, 2008). Qian and Chen (2014) studied the interactions of aluminum with black carbon and found that carboxylic functional groups on black carbon surfaces could serve as binding sites for Al^{3+}. Energetically strong adsorption mechanisms lies betweenthe aromatic p-systems of organic compounds and the sorption sites at the mineral surfaces (Keiluweit and Kleber, 2009). Mineral-SOC complexes can be combined with other inorganic and/or organic materials to form aggregates of SOC, protected by adsorption to minerals which would be further occluded by aggregation. Hence, these two operations, namely, sorption to minerals and occlusion within aggregates, co-operate or interact.

The results also showed that the carbon stock decreased after virippu season (Table 27). This may be ascribed to the overall soil carbon turnover rates variation according to location, meteorological conditions, soil characteristics and land use (Franzluebbers, 1999). In addition to that, soil fertility was closely related to soil texture and this would have affected the turnover times and maximum C retention capacity of the soil. Post and Kwon (2000) reported that conversion from nearly all other land uses to cropping or monoculture could result in losses of SOC. Carbon loss can occur through tillage due to short term bursts of mineralization of organic C substrates. At all events, eventually, most of the carbon will be re-respired to the atmosphere as CO_2, potentially leading to reduction in soil C content.

5.1.5. Fractions of soil organic matter

5.1.5.1. *Fractions of soil organic carbon*

Particle size fractions and density fractionsin physical fractions of soil organic matterclearlydescribethe nature of soil minerals in SOM stabilization and turn over (Christensen, 1992).

Particle size fractions

Labile organic C is one of the important fraction of TOC. Particulate organic C (POC), a major labile component represents a small proportion of TOC, is characterized by rapid turnover times and responds more quickly to changes than TOC (Blair *et al.*, 1995; Needelman *et al.*, 1999). Hence, this fraction serves as an early indicator of changes in soil organic C.

Particulate organic carbon (POC)

Labile soil organic carbon fraction such as particulate organic carbon is an important indicator of soil C dynamics, which is affected by different management practices. It comprises of both coarse particulate organic carbon (CPOC) as well as fine particulate organic carbon (FPOC). From the perusal of data (Tables 28a and 28b), it can be inferred that RHB contributed more CPOC in the surface soil ranging from 14.60g kg^{-1} to 23.60g kg^{-1} in virippu and 13.50g kg^{-1} to 20.70g kg^{-1} in mundakan seasons. High POC content in the biochar treatments represented the accumulation of the dominant form of organic carbon normally noted under more conservative management practices of organic farming. The major contribution of POC especially CPOC to SOC detected in the biochar trial shows the ability of biochar-amended soil to stabilize and retain C in lower fractions of clay and silt. Studies suggest that biochar sequestered approximately 50 per cent of the carbon available within the biomass feedstock being pyrolyzed, depending upon the feedstock type (Lehmann *et al.*, 2006).

Particulate organic C consisted of decomposing plant residues, animal and microbial residues (Feller and Beare, 1997). In this study, all organic materials were incorporated in the soil which increased the concentration of POC under treatments with organic sources and was the highest in the 0–15 cm depth, declining with increasing soil depth (Fig.25 and 26). Increase in SOC as well as particulate organic C were closely associated with macro aggregates, indicating Ca^{2+} formed cationic bridges between kaolinitic clay and SOC in the Oxisol(Briedis *et al.*, 2012). Similarly, Rudrappa *et al.* (2006) reported that POC accumulation in the subsurface soil would be only half compared to upper soil layers, probably because the greatest proportion of organic substances remains in the surface soil layers. Cattle manure/green manure addition resulted in significantly higher concentrations of POC than RHB /*Artocarpus* in the subsurface soil. This may be explained by the lower C/N ratio in the cattle or green manure, causing rapid decomposition than that of the other two organic sources and its downward movement. Previous studies also pointed that soil labile organic C especially POC could reflect in higher management impacts on soil quality than total organic C. Continuous cropping decreases the amount of CPOC in soil. The SOC pool at 0-15 cm depth was also more in the treatment with

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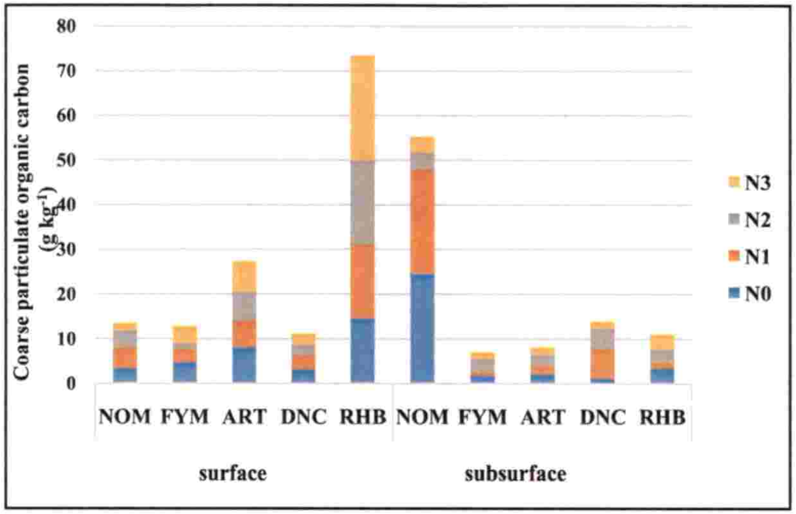

Fig. 25a. Effect of different organic sources on coarse particulate organic carbon of soil in virippu season

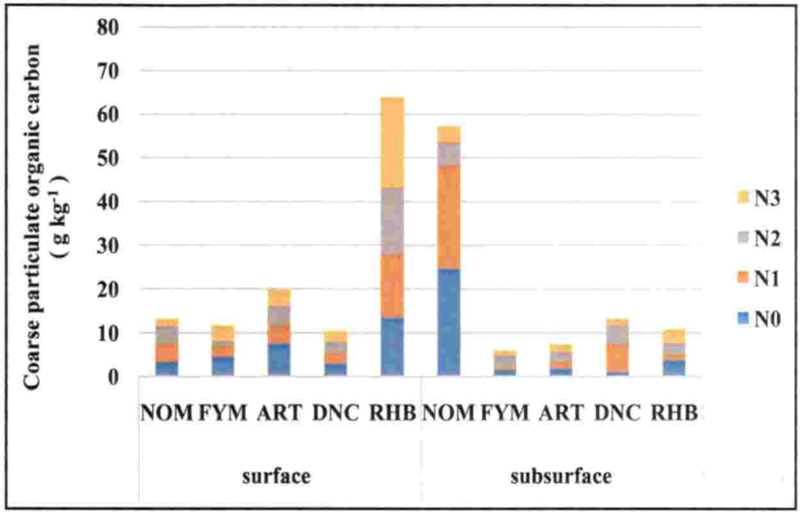

Fig. 25b. Effect of different organic sources on coarse particulate organic carbon of soil in mundakan season

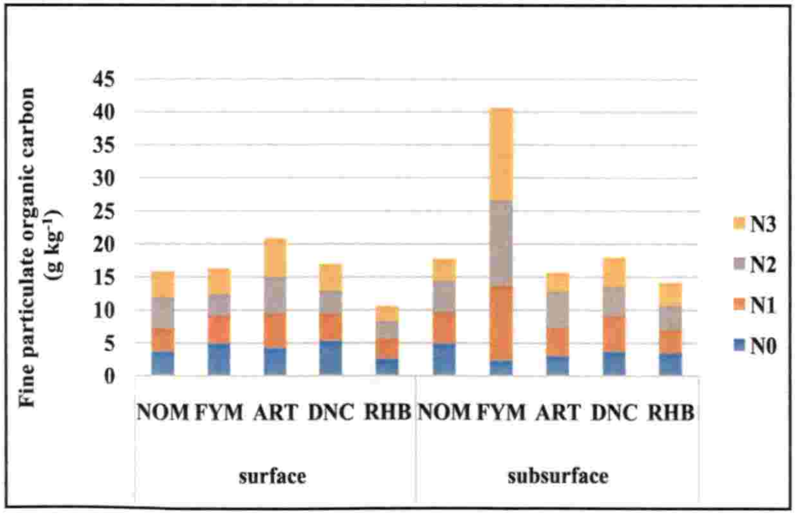

Fig. 26a. Effect of different organic sources on fine particulate organic carbon of soil in virippu season

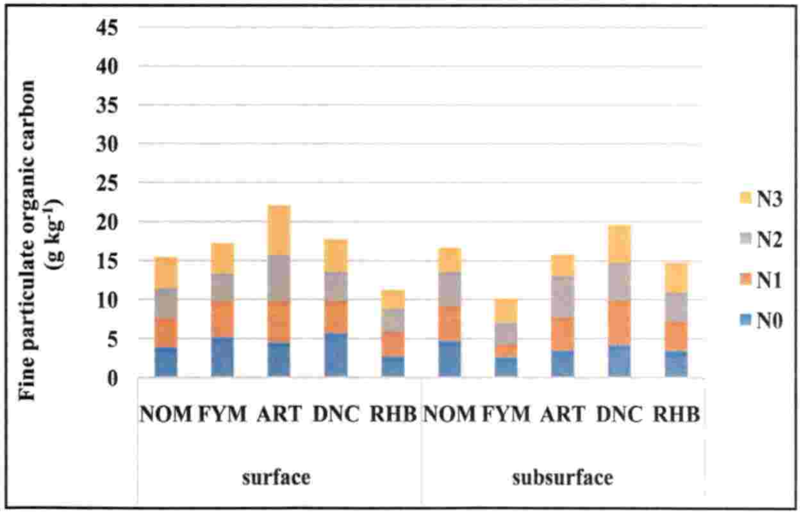

Fig. 26b. Effect of different organic sources on fine particulate organic carbon of soil in mundakan season

Artocarpus, though the difference was not statistically significant. However, calculation of the total pool below 15 cm depth revealed that carbon pool under control treatment was more or less similar to other treatments.

Density fractions

Soil carbon fractions as affected by different nutrient management practices are given in Fig. 27a and 27b to 30a and 30b). All the carbon pools were higher in the plots where integrated nutrient management practice was followed than chemical fertilizers alone. Yang *et al.* (2005) found on combined application of chemical fertilisers and manures, LFOC, POC in TOC increased in paddy soil followed by alternate wetting and drying of soil.

In this study, more significant variations in soil organic carbon fractions of LFOC as well as POC were observed than in soil total organic C among the different nutrient treatments. More POM in the soil means that carbon and other nutrients are stored in the intermediately available pool and are not lost, yet are available when needed. This was achieved by the use of RHB in soil. In the surface soil, LFOC had the highest C concentration (36.20-171.30 g kg^{-1}) followed by iLFOC, HFOC and MinOC. Application of organic amendments significantly increased the LFOC concentration as compared to inorganic fertilizers (Table 25). Compared to the integrated treatments comprising of FYM, artocarpus and daincha, the treatment with RHB enlarged the LFOC pool by 150 per cent, ILFOC pool by 175 per cent (Fig. 27a and 28a). The RHB application did not influence HFOC and Min OC significantly but they were improved by other organic sources. Organic residues in various stages of decomposition, also containing appreciable amounts of microbial debris made up largely light fraction organic matter (Gregorich and Janzen, 1996). It was characterized by rapid mineralization due to labile nature of its constituents and to the lack of protection by soil colloids (Turchenek and Oades, 1979).

Addition of daincha in the soil had only little effect on LFOC and iLFOC fractions. Fronning *et al.* (2008) reported that the addition of plant residues or other

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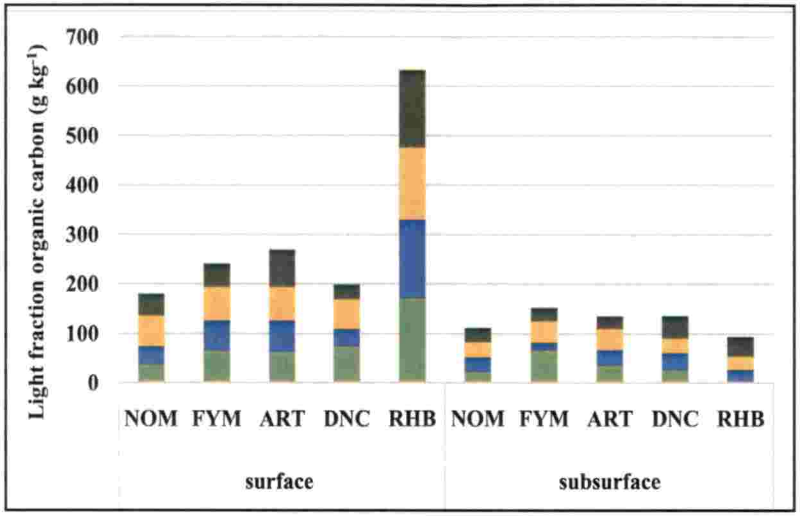

Fig. 27a. Effect of different organic sources on light fraction organic carbon of soil in virippu season

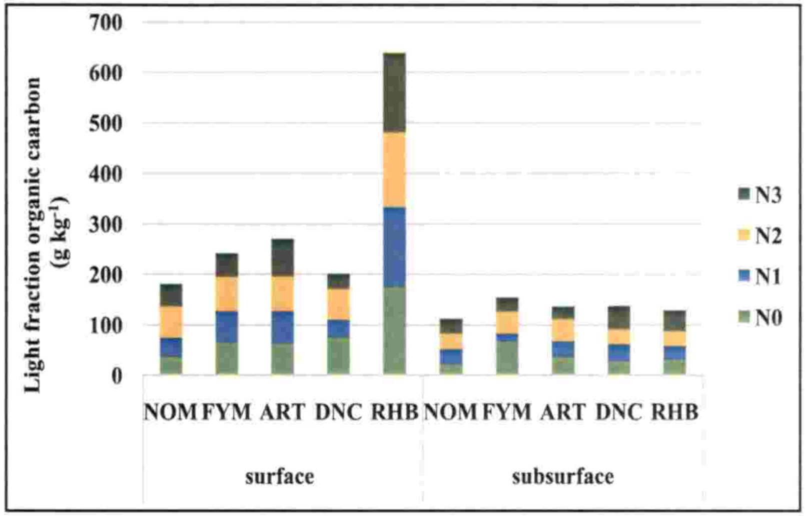

Fig. 27b. Effect of different organic sources on light fraction organic carbon of soil in mundakan season

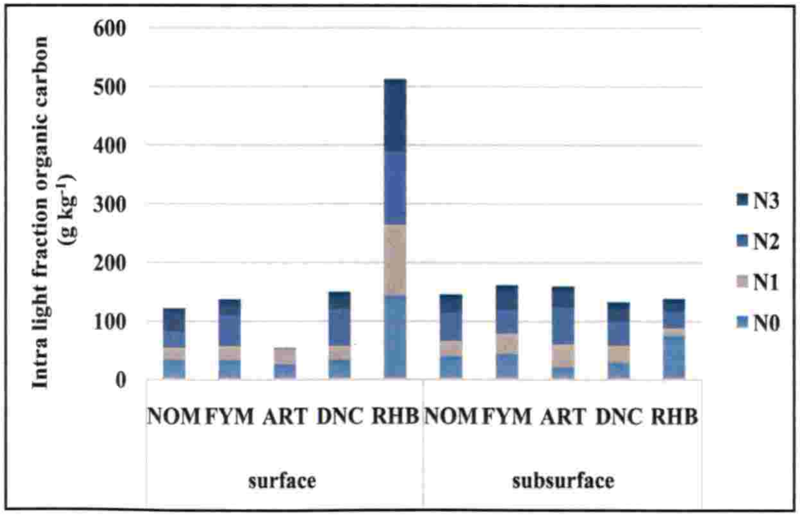

Fig. 28a. Effect of different organic sources on intra light fraction organic carbon of soil in virippu season

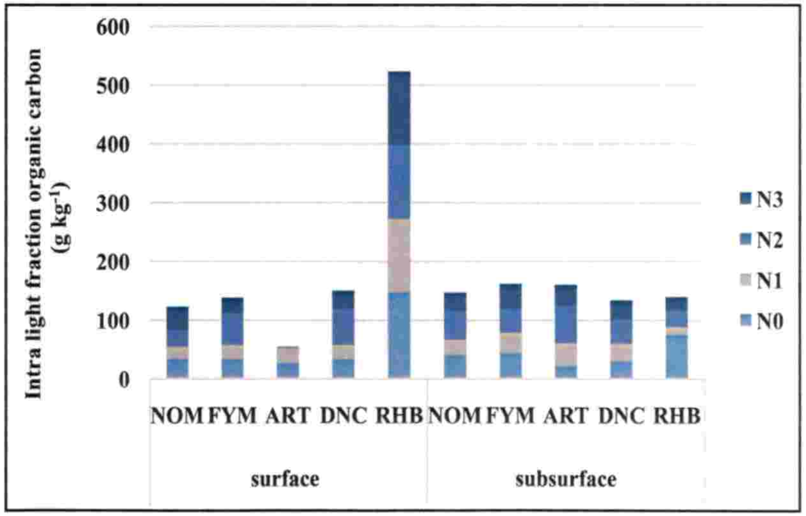

Fig. 28b. Effect of different organic sources on intra light fraction \organic carbon of soil in mundakan season

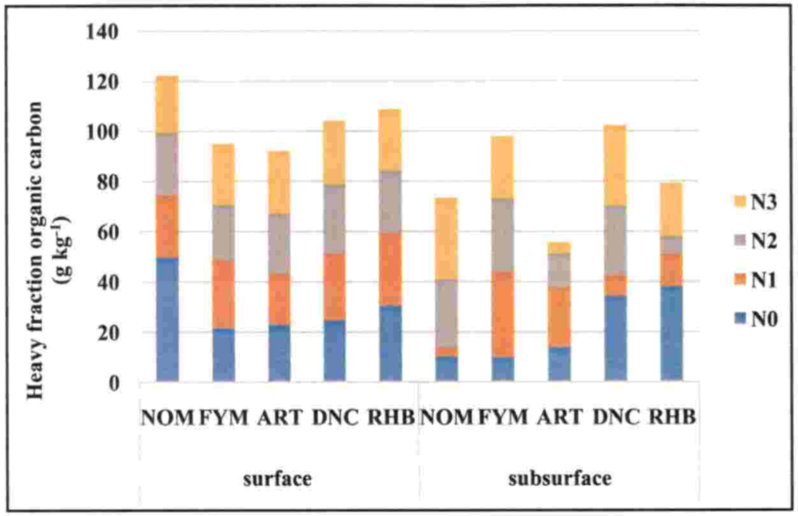

Fig. 29a. Effect of different organic sources on heavy fraction organic carbon of soil in virippu season

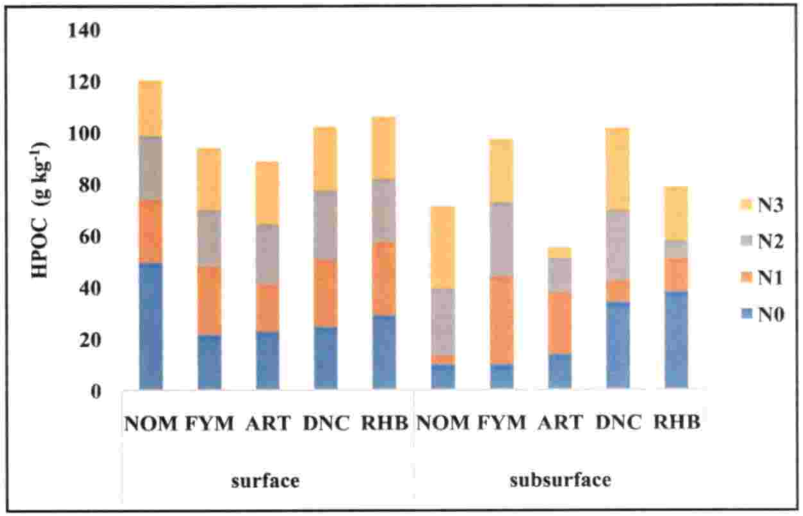

Fig. 29b. Effect of different organic sources on heavy fraction organic carbon of soil in mundakan season

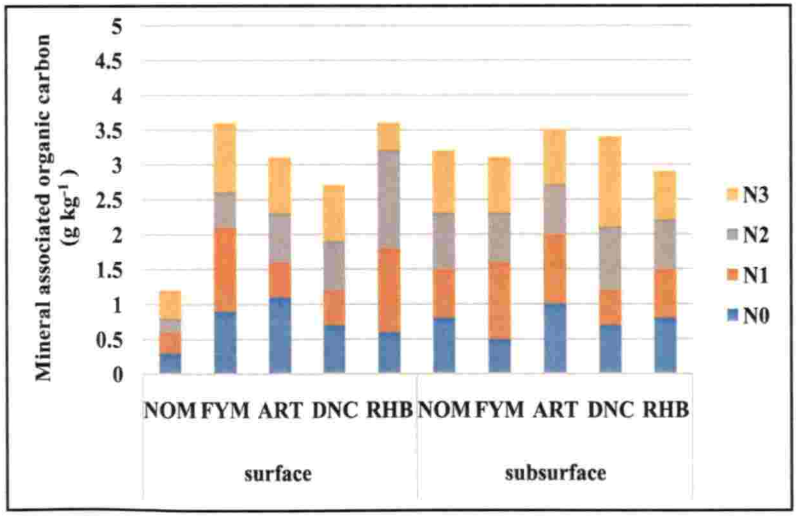

Fig. 30a. Effect of different organic sources on mineral associated organic carbon of soil in virippu season

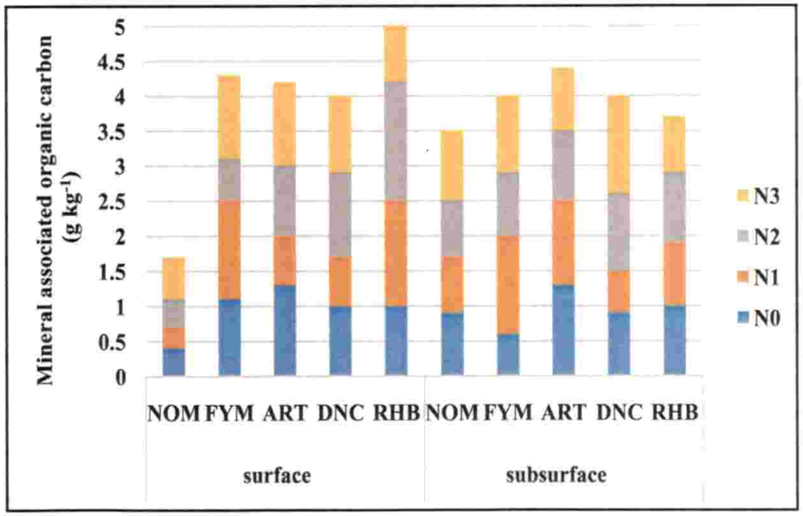

Fig. 30b. Effect of different organic sources on mineral associated organic carbon of soil in mundakan season

organic amendments increased total organic carbon and its associated POM carbon. Organic residues with a low C/N ratio (high nitrogen content) might be decomposed quickly and reduce the accumulation of POM. Soil disturbances such as destruction of aggregates by cultivation and alternating periods of wetting and drying also expose organic matter to microbial decomposition and reduce POM content in soils.

It was seen in this study that the surface soil had highest organic carbon content than the subsurface soil. John *et al.* (2005) pointed out greater concentration of SOC in the A horizon of soil was due to larger amounts of SOC stored in various pools of particulate organic matter.

In cold and/or semiarid region, the carbon stocks in labile particulate SOC fraction constituted approximately 50 per cent of total soil organic carbon and is the most affected by management practices (Chan, 2002). On the other hand, hot and humid environment favored microbial activity that led to intensive decomposition and humification of labile SOC fractions (Bayer and Bertol, 1999). Due to such intensive humification activities in the humid tropics, the labile carbon fractions get aromatised to chemically recalcitrant pools. In the case of rice systems, though microbial activities may be limited, long periods of soil submergencepromoted the formation of passive pools of SOC. The results were in line with the findings of Mandal *et al.,* 2008 who observed that as much as 29 per cent of the organic C applied to the soil was stabilized into recalcitrant C pools in rice systems.

5.1.5.2. *Fractions of organic nitrogen*

The particle size as well as density fractions of organic nitrogen responded well with the addition of organics and inorganics (Fig. 31a and 31b to 36a and 36b). The treatments showed a slight increase in nitrogen content during mundakan season compared to virippu season. Soil organic nitrogen concentrations in the 0– 15 cm and 15–30 cm depths were increased than in the control following NPK addition alone (Fig.31 a and 31b). This might be due to residual nitrogen fertilizer leaching down the soil profile, with a further contribution from the mineralization of

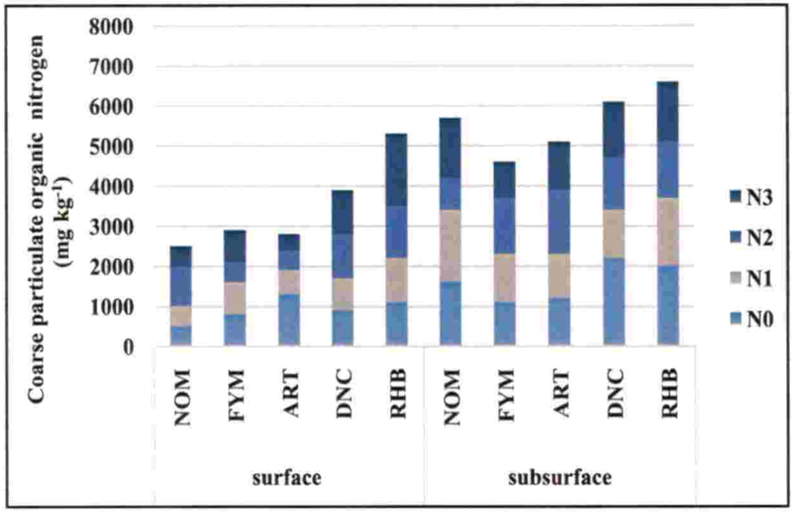

Fig. 31a. Effect of different organic sources on coarse particulate organic nitrogen of soil in virippu season

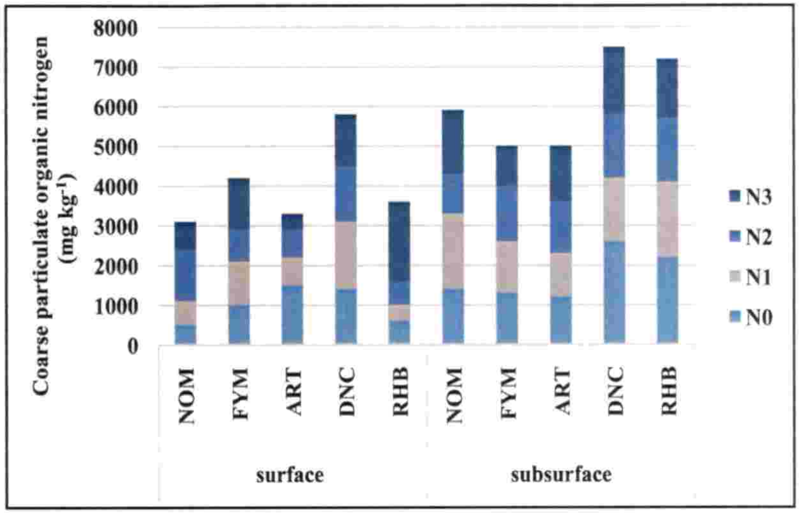

Fig. 31b. Effect of different organic sources on coarse particulate organic nitrogen of soil in mundakan season

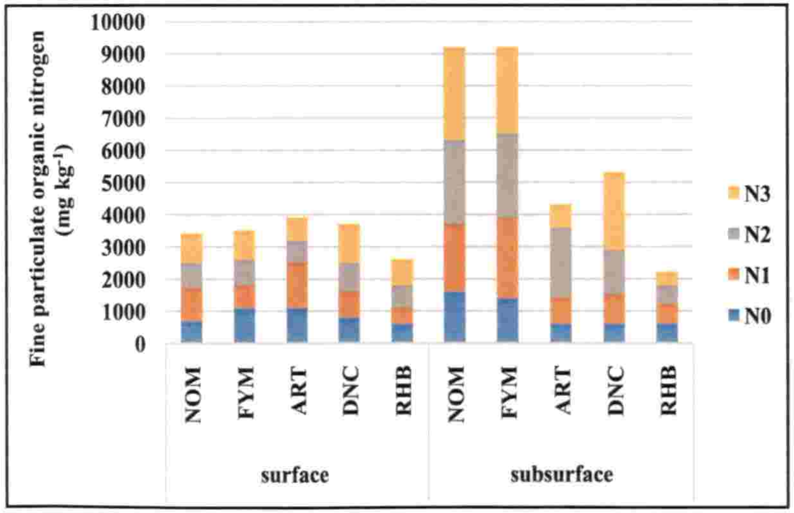

Fig. 32a. Effect of different organic sources on fine particulate organic nitrogen of soil in virippu season

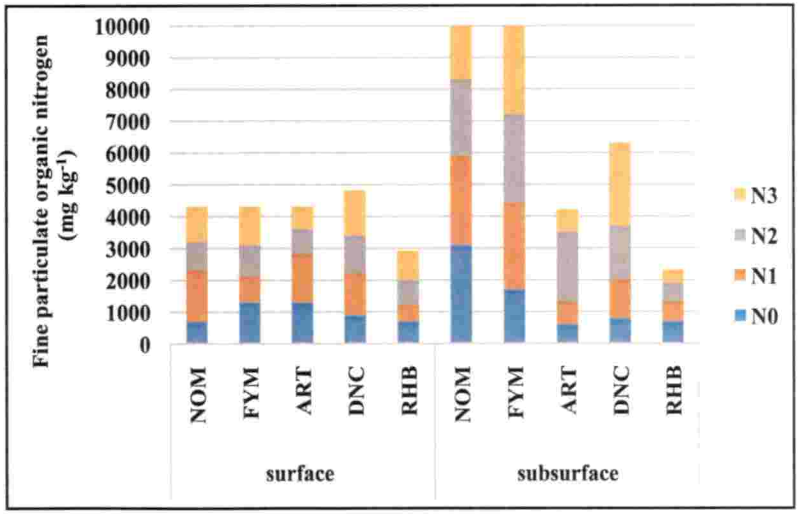

Fig. 32b. Effect of different organic sources on fine particulate organic nitrogen of soil in mundakan season

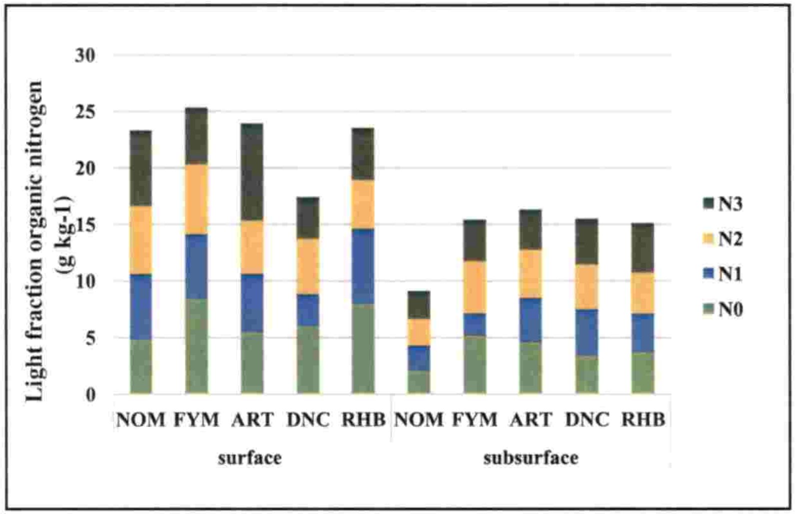

Fig. 33a. Effect of different organic sources on light fraction organic nitrogen of soil in virippu season

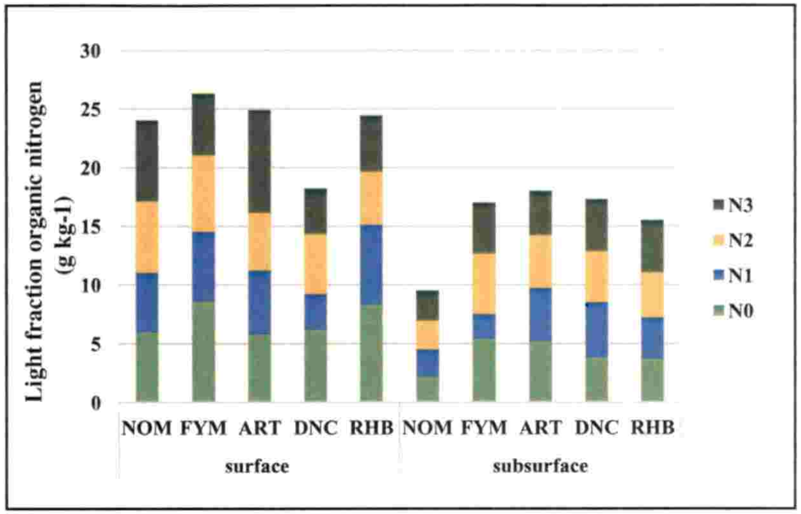

Fig. 33b. Effect of different organic sources on light fraction organic nitrogen of soil in mundakan season

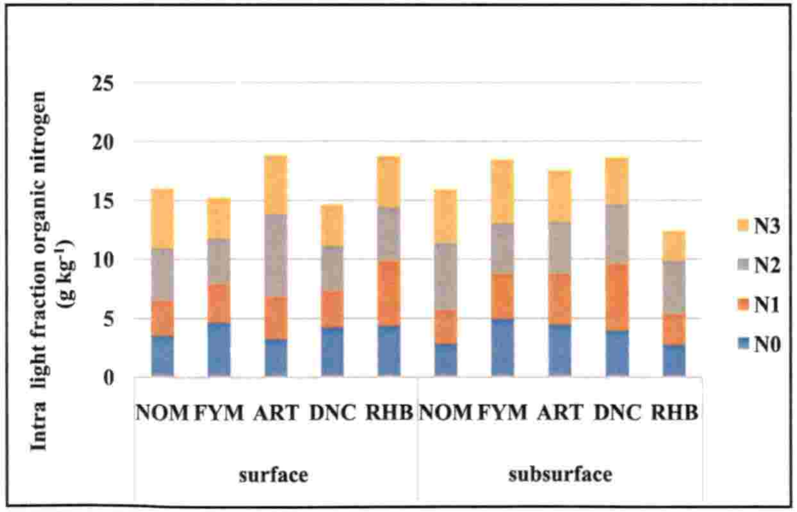

Fig. 34a. Effect of different organic sources on intra light fraction organic nitrogen of soil in virippu season

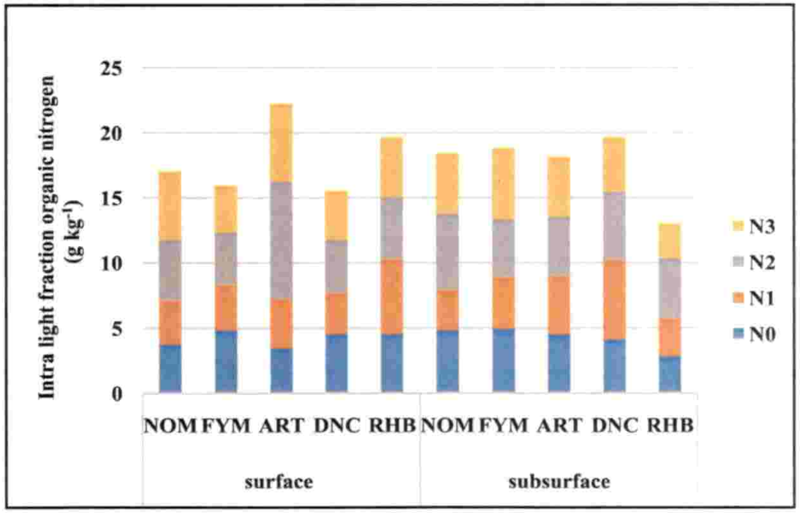

Fig. 34b. Effect of different organic sources on intra light fraction organic nitrogen of soil in mundakan season

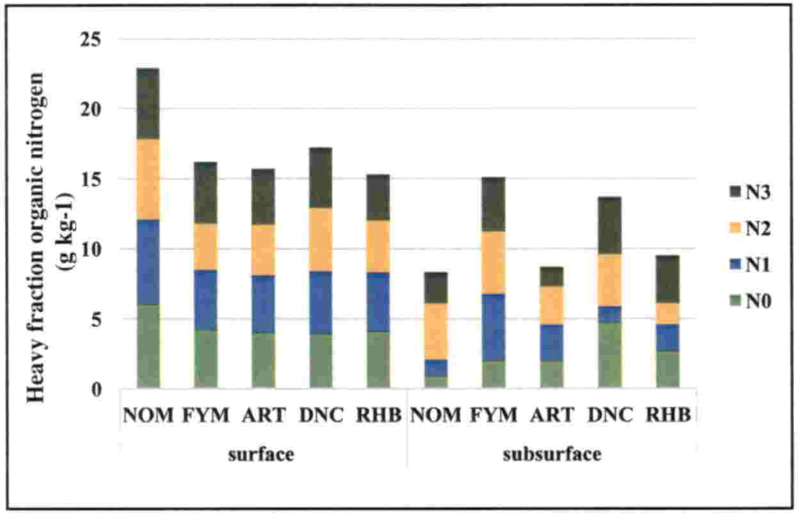

Fig. 35 a. Effect of different organic sources on heavy fraction organic nitrogen of soil in virippu season

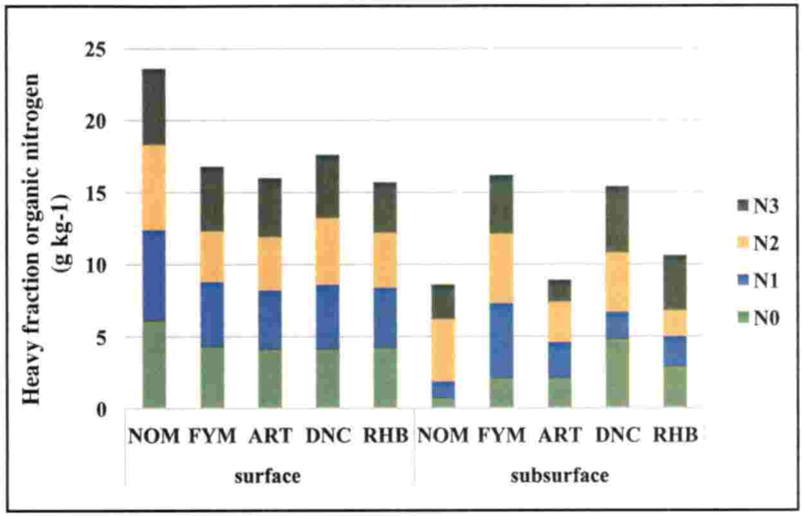

Fig. 35 b. Effect of different organic sources on heavy fraction organic nitrogen of soil in mundakan season

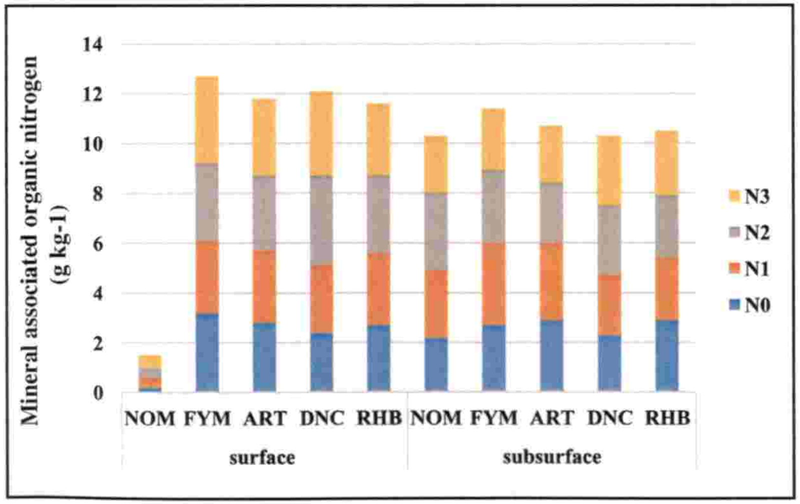

Fig. 36 a. Effect of different organic sources on mineral associated organic nitrogen of soil in virippu season

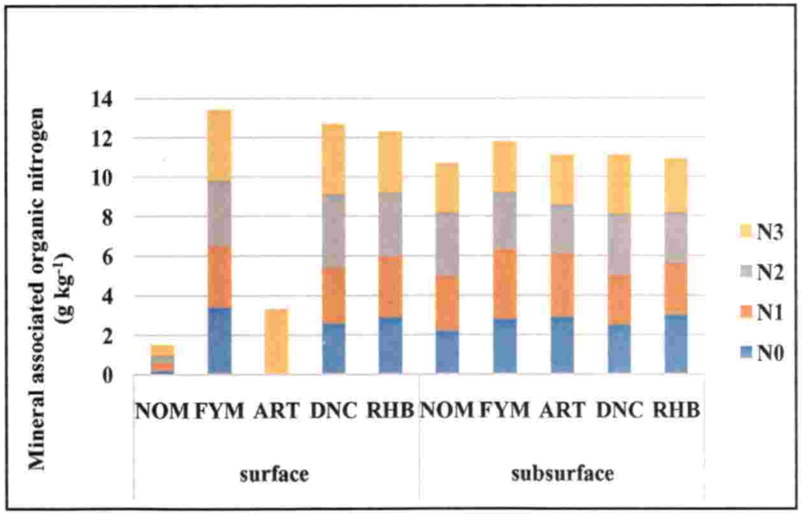

Fig. 36 b. Effect of different organic sources on mineral associated organic nitrogen of soil in mundakan season

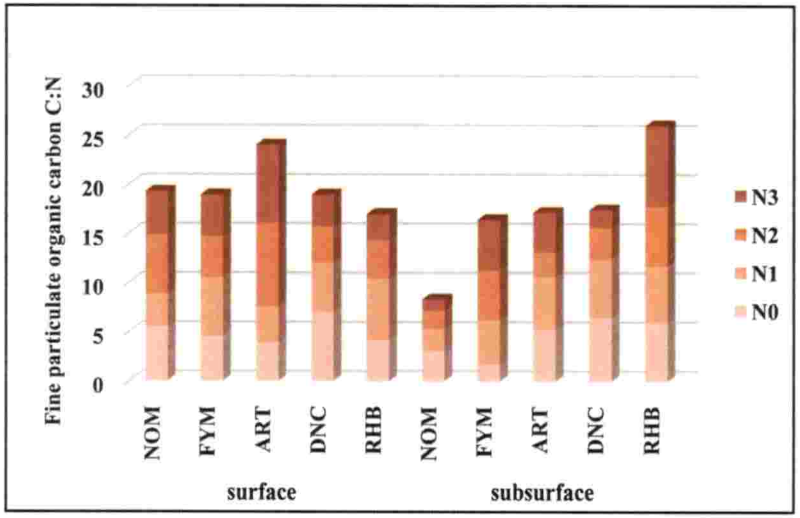

Fig. 37a. Effect of organic sources on coarse particulate C:N ratio of soil in virippu season

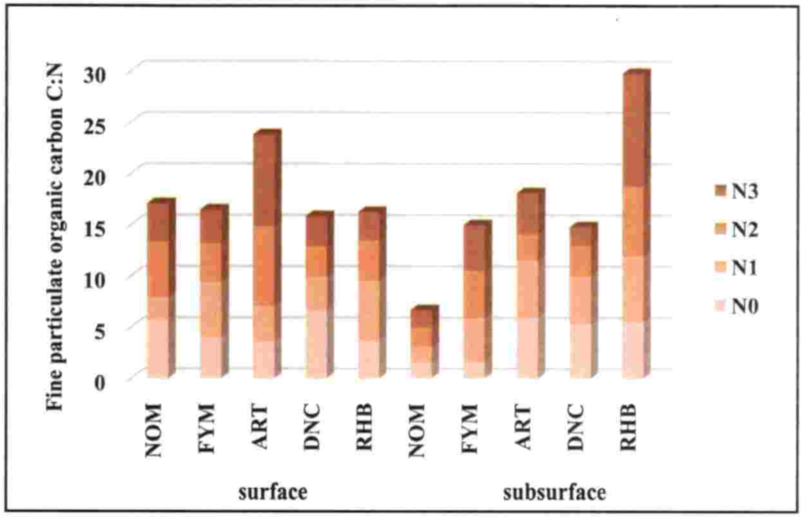

Fig. 37b. Effect of organic sources on coarse particulate C:N ratio of soil in mundakan season

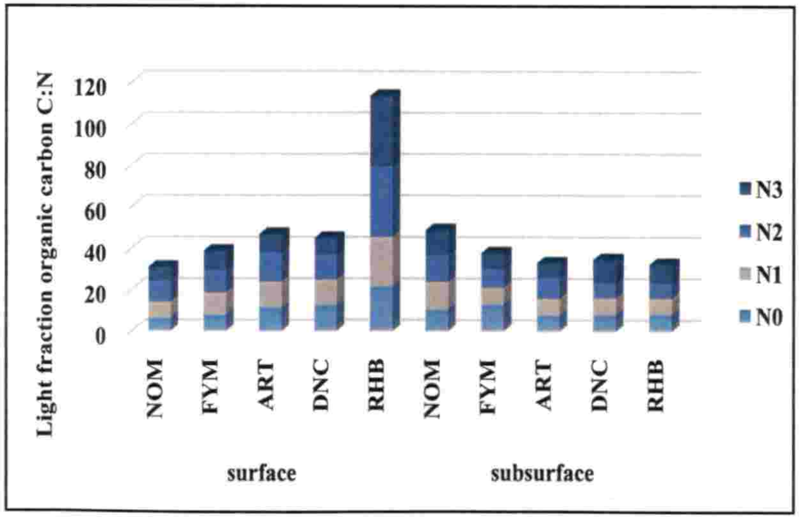

Fig. 38a. Effect of organic sources on fine particulate C:N ratio of soil in virippu season

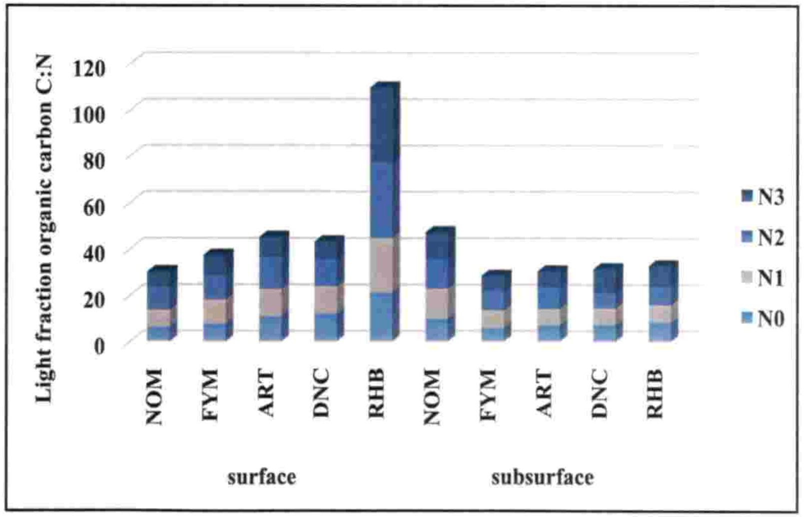

Fig. 38b. Effect of organic sources on fine particulate C:N ratio of soil in mundakan season

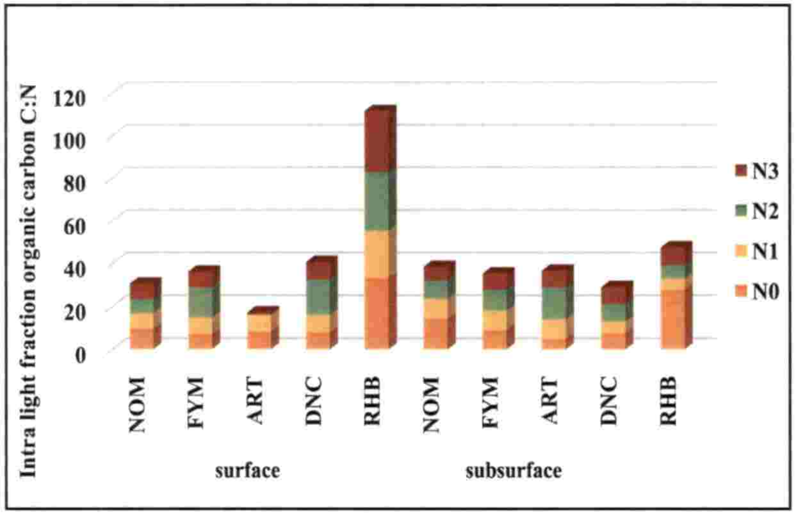

Fig. 39a. Effect of organic sources on light fraction C:N ratio of soil in virippu season

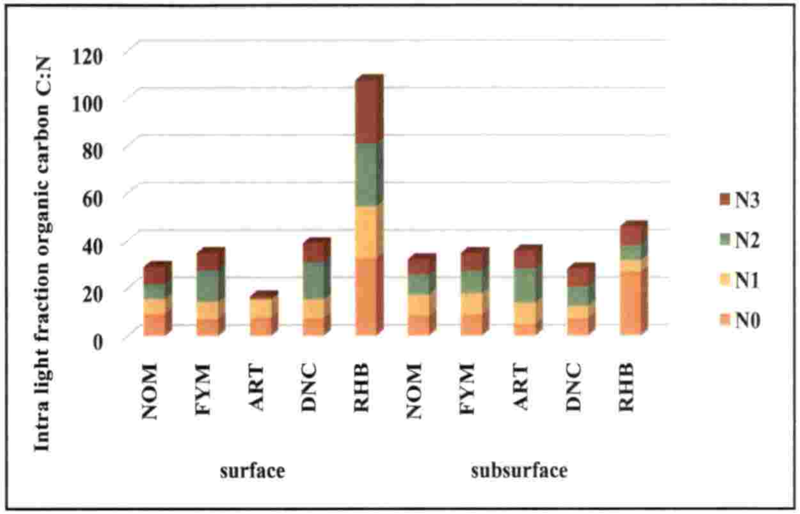

Fig. 39b. Effect of organic sources on light fraction C:N ratio of soil in mundakan season

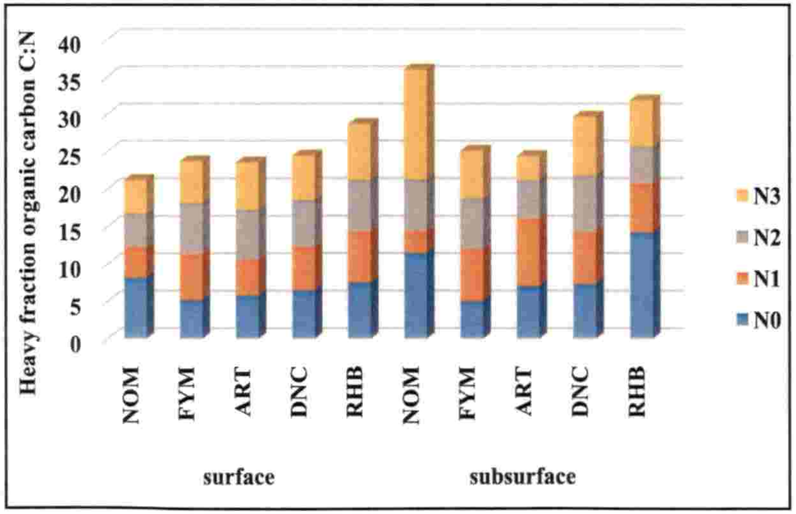

Fig. 40a. Effect of organic sources on intra light fraction C:N ratio of soil in virippu season

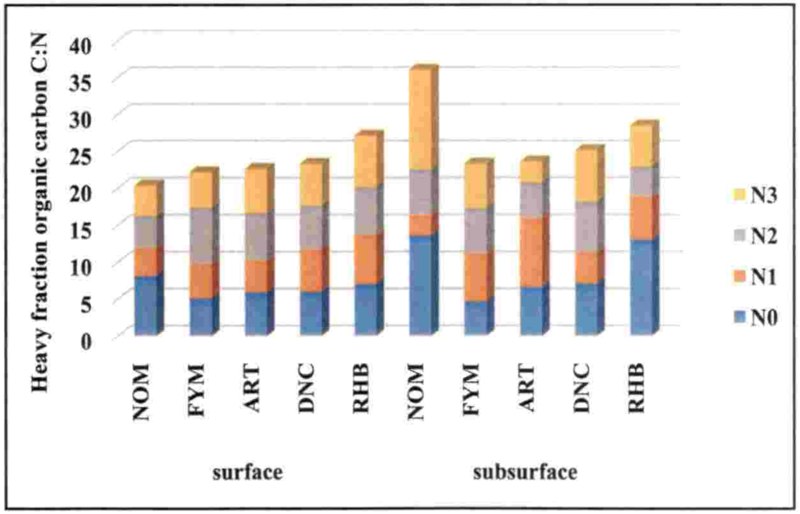

Fig. 40b. Effect of organic sources on intra light fraction C:N ratio of soil in mundakan season

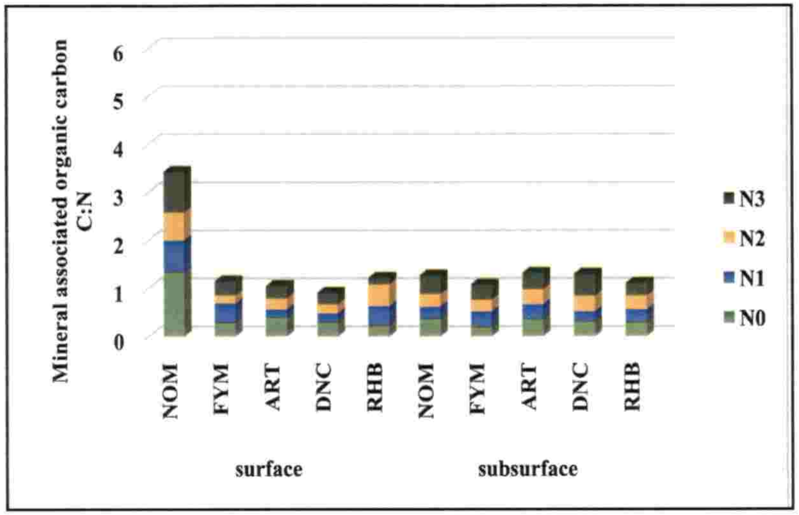

Fig. 41a. Effect of organic sources on heavy fraction C:N ratio of soil in virippu season

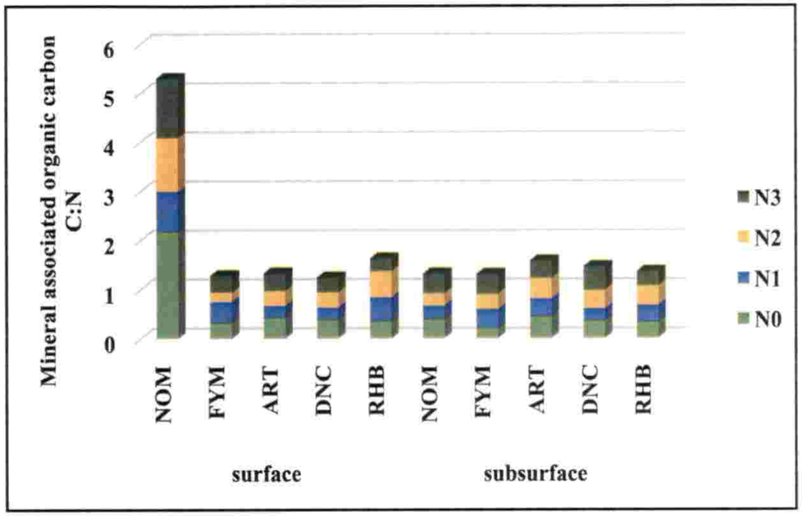

Fig. 41b. Effect of organic sources on heavy fraction C:N ratio of soil in mundakan season

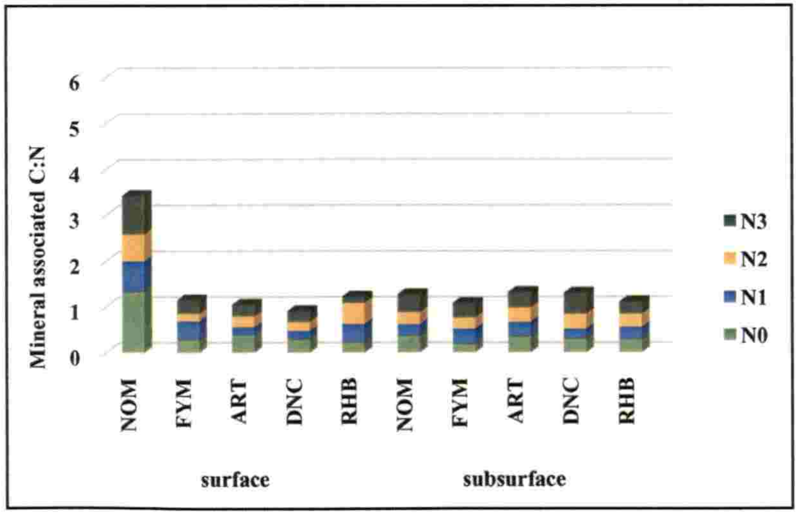

Fig. 42a. Effect of organic sources on mineral associated fraction C:N ratio of soil in virippu season

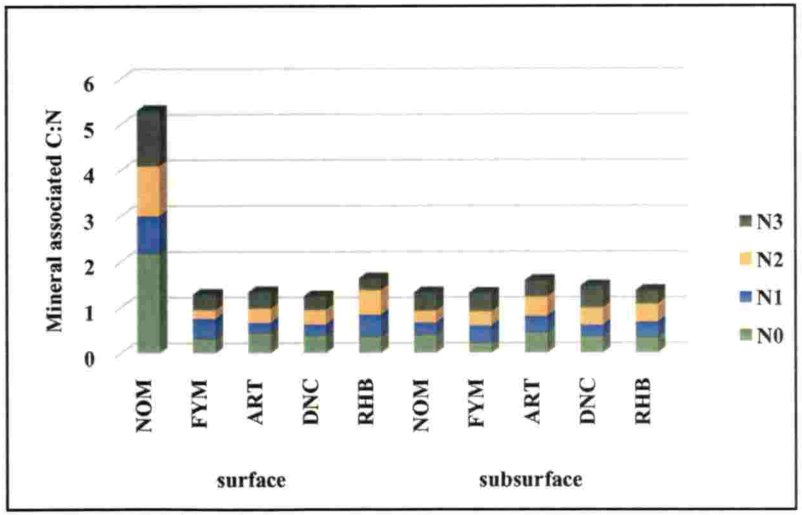

Fig. 42b. Effect of organic sources on mineral associated C:N ratio of soil in mundakan season

crop biomass resulting in more labile N in the soil.Inorganic fertilizer along with daincha resulted in significantly higher N concentrations than other treatments in the surface and subsurface soil depths (Fig.31b). This is attributed to larger extraneous nitrogen input and nitrogen released by rapid decomposition of daincha and mineralization of biomass of crop residues in the soil (Liang *et al.*, 2012). Addition of N through legumes significantly increased CPON content in soil.

5.1.6. Effect of treatments on nutrient content in plant parts

The data (Tables 46a and 46b to 78a and 78b) indicated an increase in nutrient content in various plant parts like grain, shoot and root of rice crop when amended with organics and inorganics. The nutrient content varied significantly and it differed between treatments among the plant parts (Fig. 43 to 60).

A higher value of leaf N content could be attributed to the ability of organic manure to supply nutrients continuously during the growth period of crop as a result of mineralization and improvement of the physical and chemical properties of the soil. Majority of the nutrients were found to be high in the plant parts when the organic sources like FYM and daincha were amended with medium dose of nitrogen (70 kg N ha^{-1}) than at higher levels. This result was in line with the findings of Sharma *et al.*, 2000.This could be ascribed tothe inhibition of SOM decomposition by adding urea which necessitates additional C requirement for microbes.Many scientists have also observed negative or nonsignificant effects of N on the decomposition of organic matter. (Ramirez et al., 2010; Vallack et al. 2012).

Among the organic sources, the nutrient contents in plant parts treated with daincha and FYM werehigher and during mundakan season, the amount increased. This might be due to the low C/N ratio of organic materials which could have provided higher amounts of nutrients slowly during the cropping period. Tejeda *et al.* (2009) foud that the optimum balanced C/ N ratio (10-12) for soils amended with composts originating from leguminous residues, due to organic matter mineralization overcoming immobilization. Eghball *et al.* (2004) observed that from organic sources

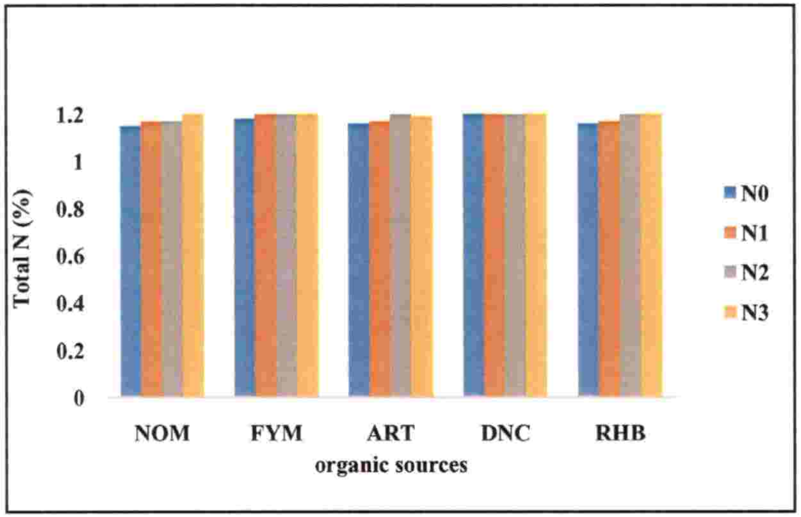

Fig. 43a. Effect of organic sources on nitrogen content in rice grain in virippu season

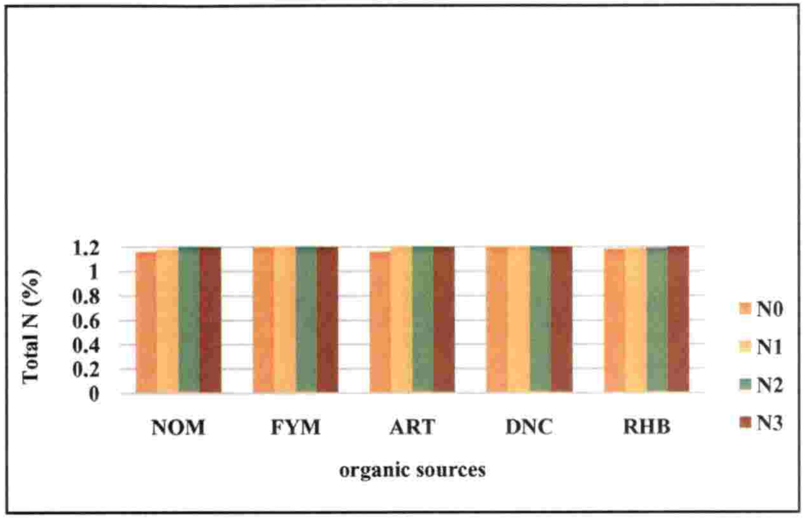

Fig. 43b. Effect of organic sources on nitrogen content in rice grain in mundakan season

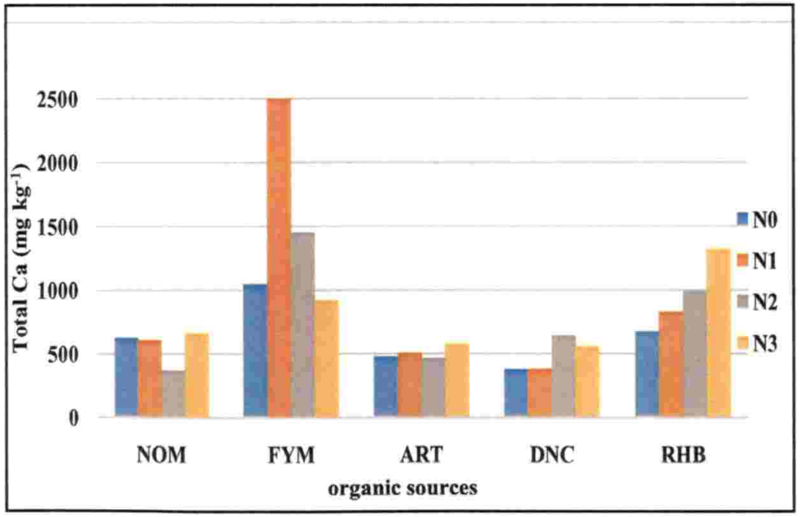

Fig. 44a. Effect of organic sources on calcium content in rice grain in virippu season

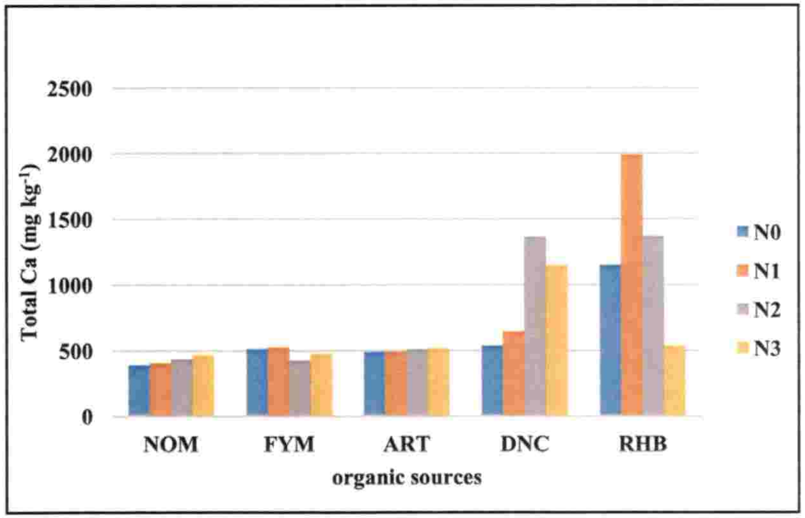

Fig. 44b. Effect of organic sources on calcium content in rice grain in mundakan season

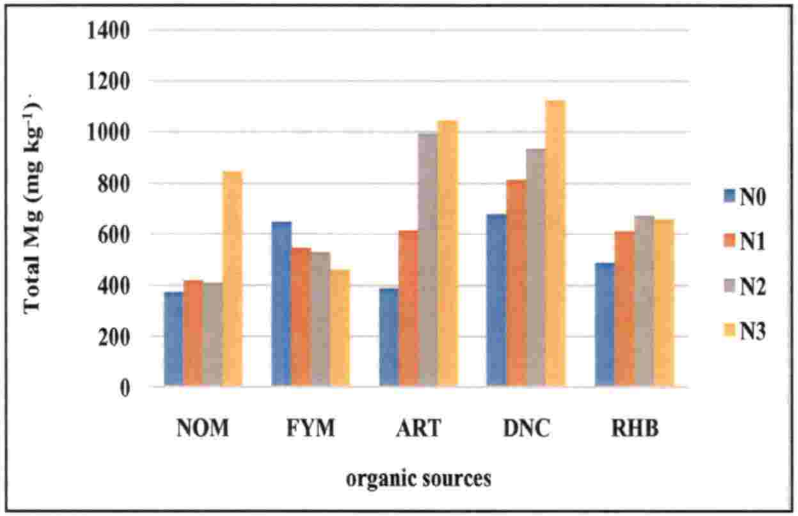

Fig. 45a. Effect of organic sources on magnesium content in rice grain in virippu season

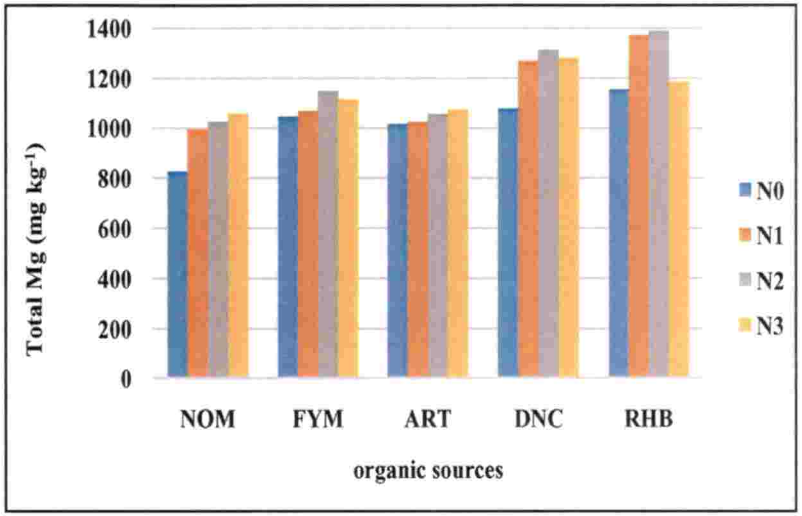

Fig. 45b. Effect of organic sources on magnesium content in rice grain in mundakan season

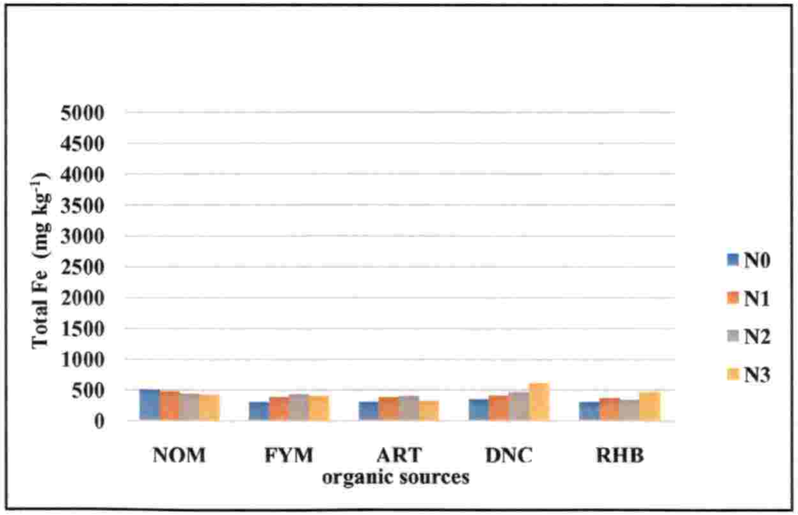

Fig. 46a. Effect of organic sources on iron content in rice grain in virippu season

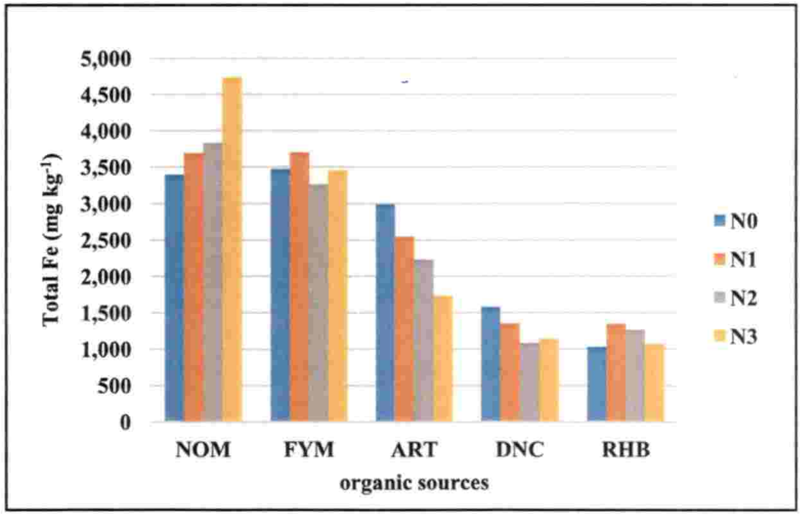

Fig. 46b. Effect of organic sources on iron content in rice grain in mundakan season

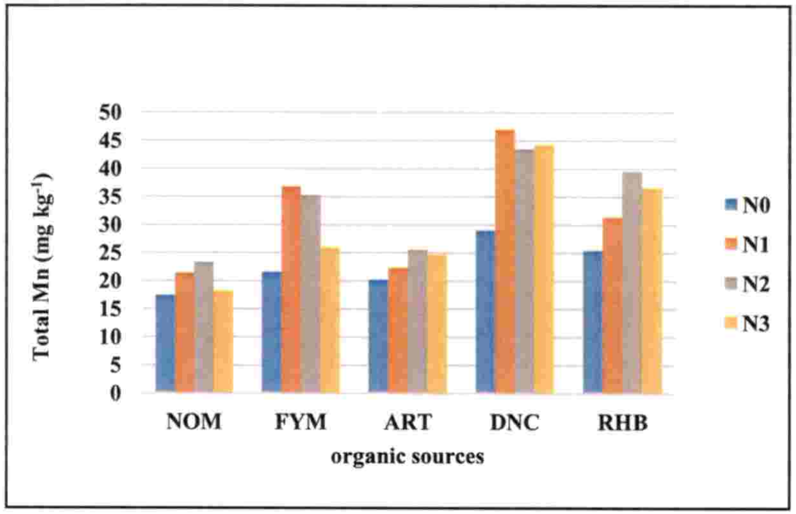

Fig. 47a. Effect of organic sources on manganese content in rice grain in virippu season

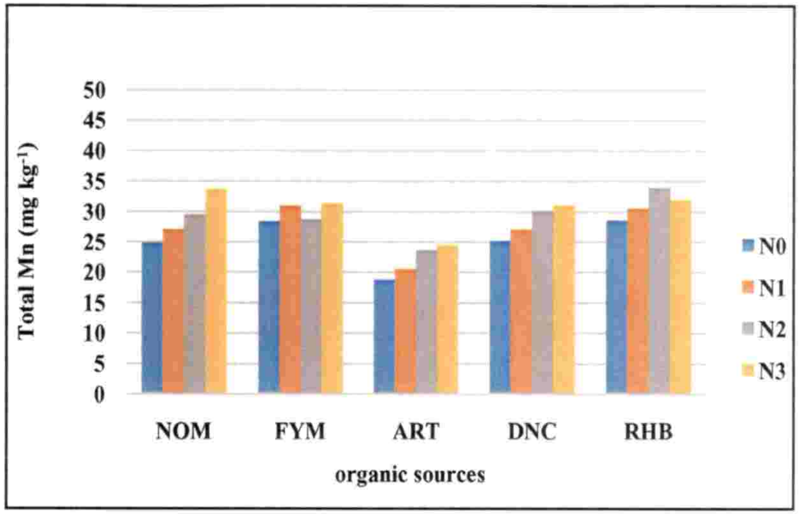

Fig. 47b. Effect of organic sources on manganese content in rice grain in mundakan season

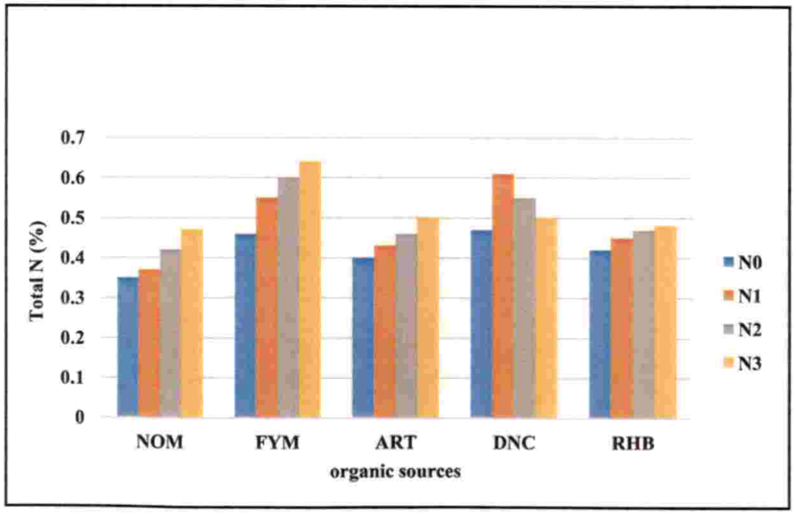

Fig. 48a. Effect of different organic sources on nitrogen content in rice straw in virippu season

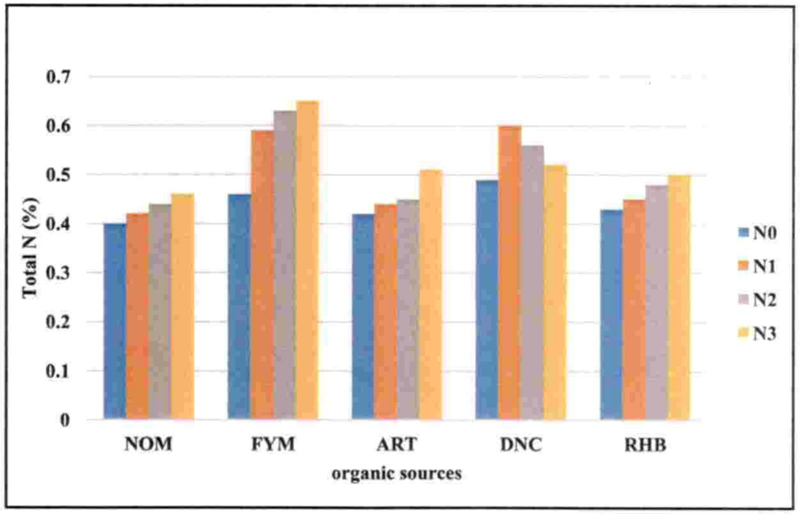

Fig. 48b. Effect of different organic sources on nitrogen content in rice straw in mundakan season

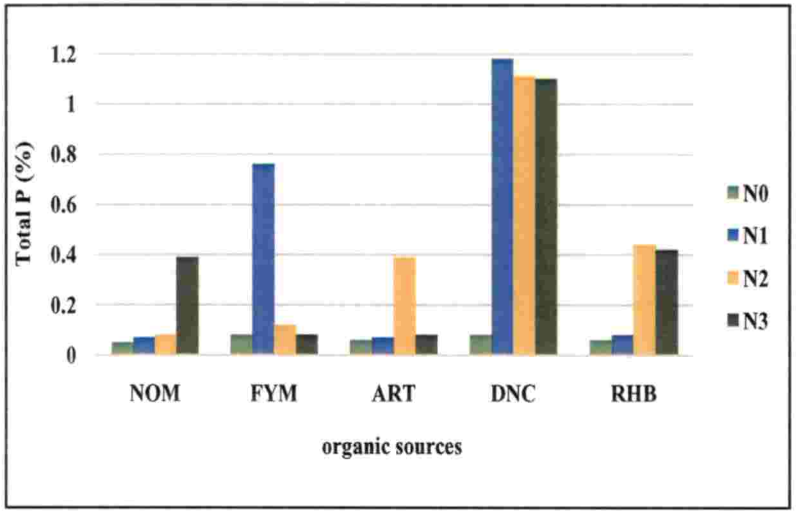

Fig. 49a. Effect of different organic sources on phosphorus content in rice straw in virippu season

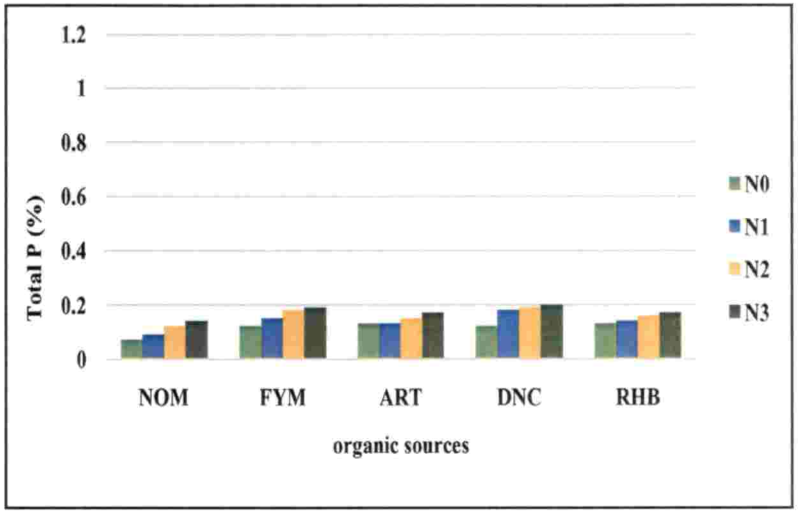

Fig. 49b. Effect of different organic sources on phosphorus content in rice straw in mundakan season

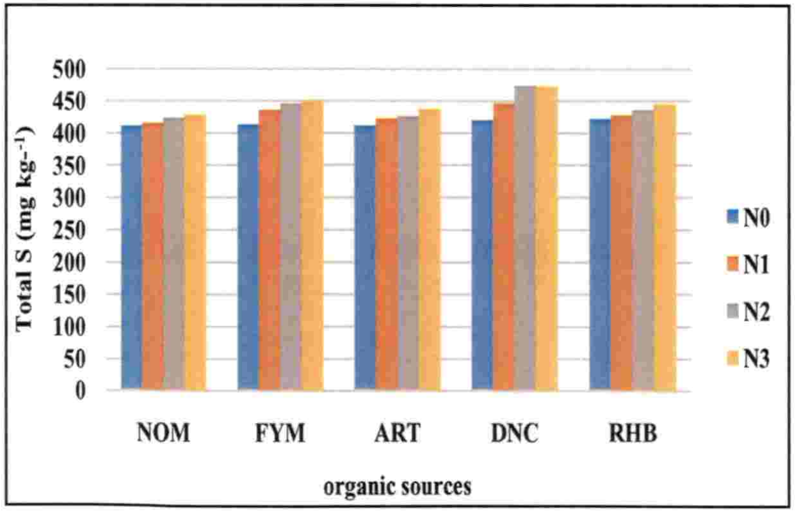

Fig. 50a. Effect of different organic sources on sulphur content in rice straw in virippu season

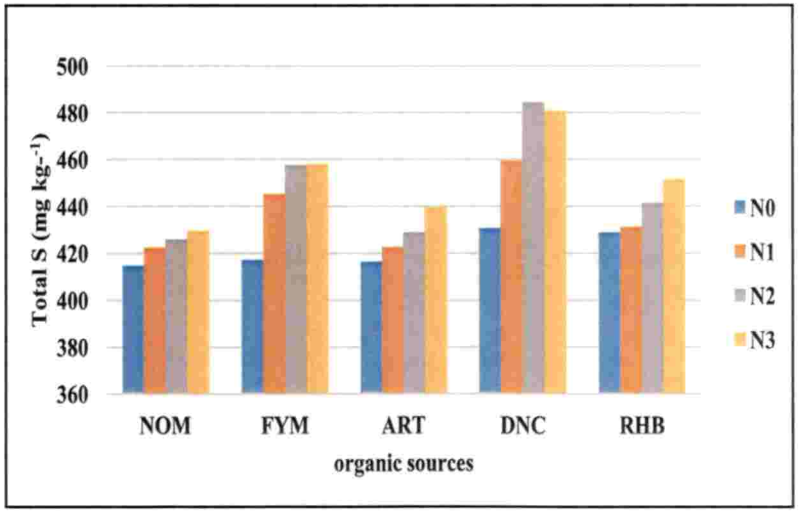

Fig. 50b. Effect of different organic sources on sulphur content in rice straw in mundakan season

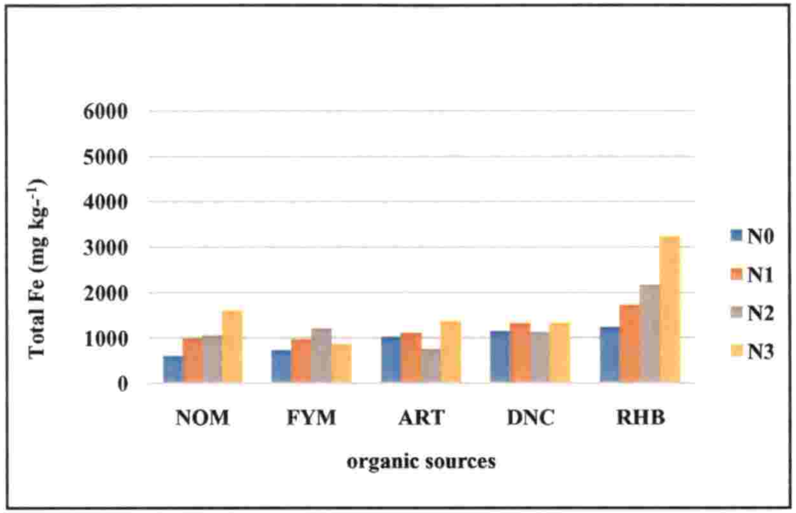

Fig. 51a. Effect of different organic sources on iron content in rice straw in virippu season

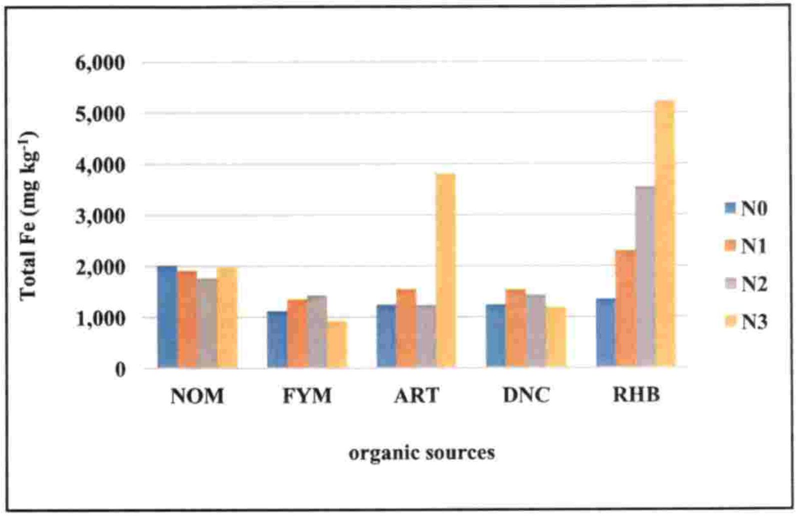

Fig. 51b. Effect of different organic sources on iron content in rice straw in mundakan season

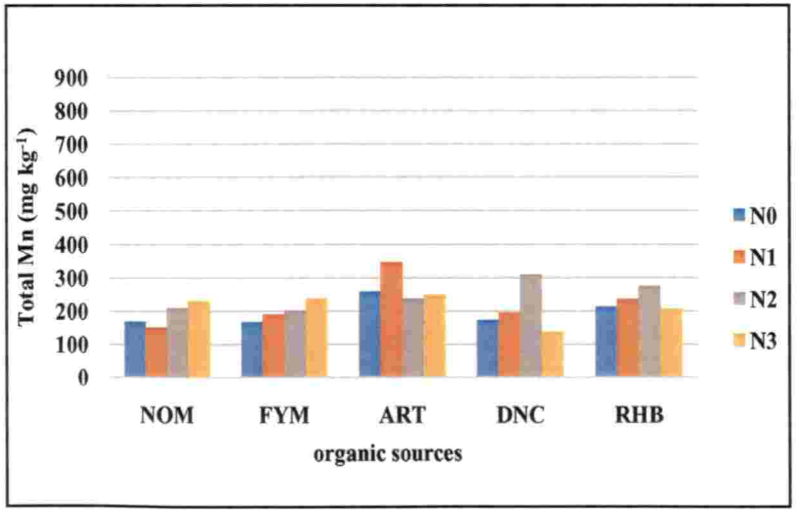

Fig. 52a. Effect of different organic sources on manganese content in rice straw in virippu season

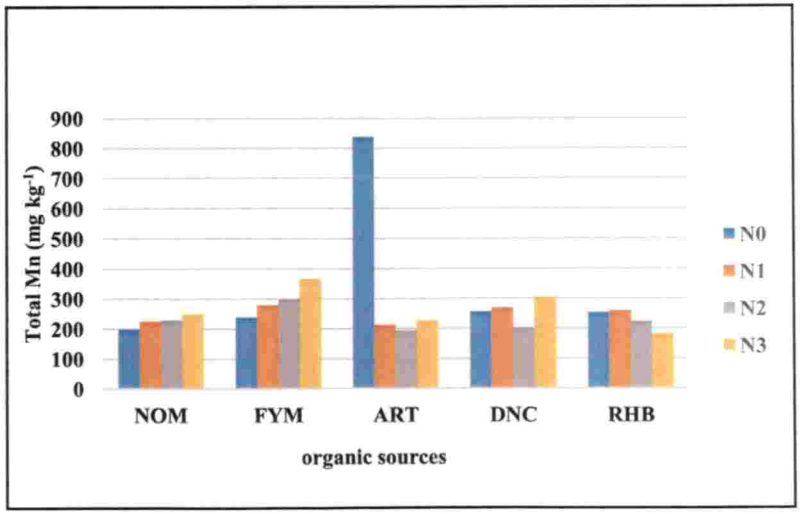

Fig. 52b. Effect of different organic sources on manganese content in rice straw in mundakan season

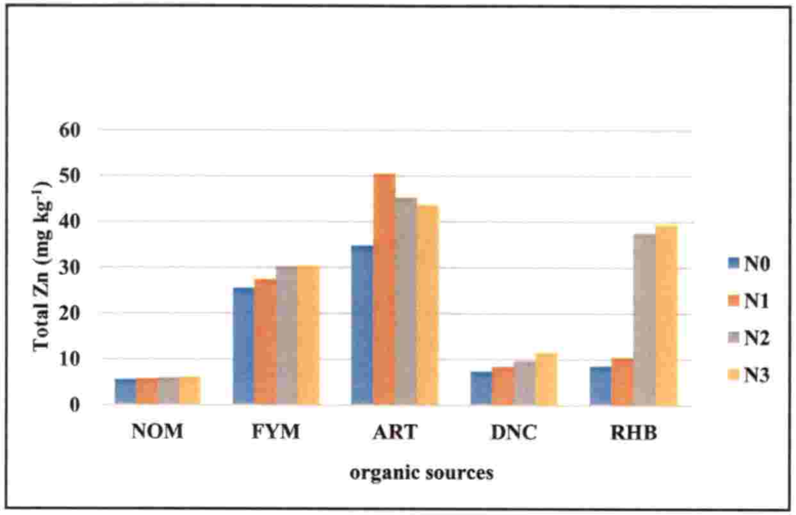

Fig. 53a. Effect of different organic sources on zinc content in rice straw in virippu season

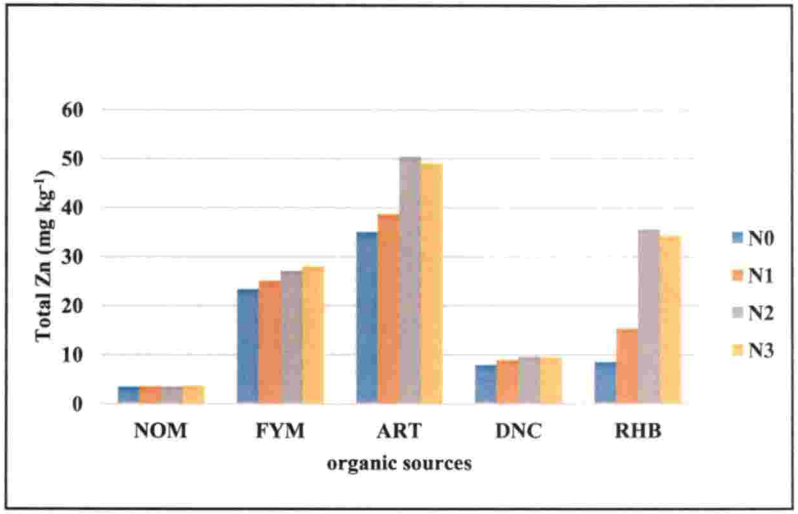

Fig. 53b. Effect of different organic sources on zinc content in rice straw in mundakan season

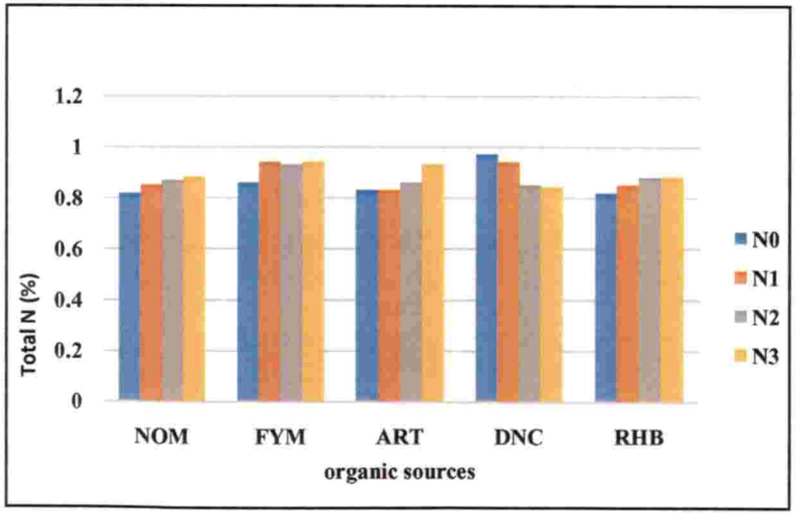

Fig. 54a. Effect of organic sources on nitrogen content in rice root in virippu season

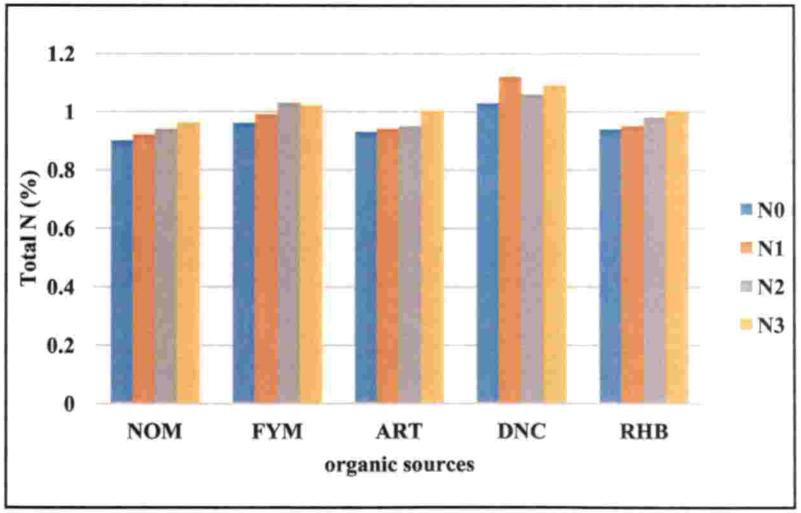

Fig. 54b. Effect of organic sources on nitrogen content in rice root in mundakan season

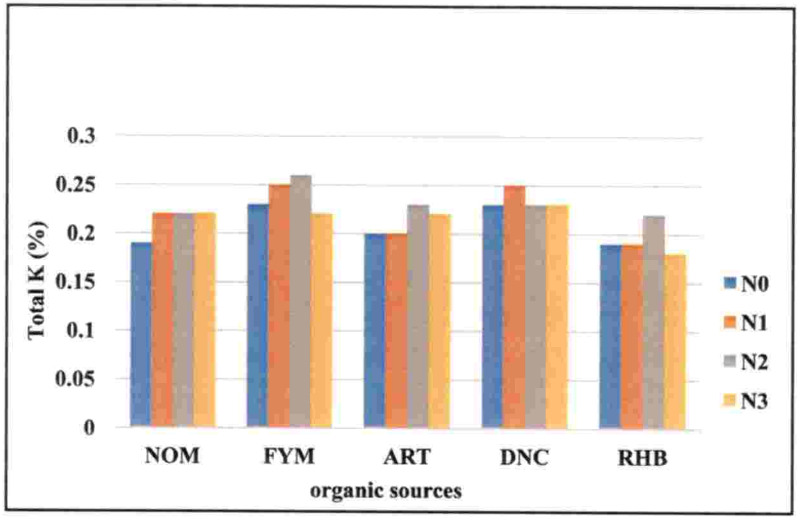

Fig. 55a. Effect of organic sources on potassium content in rice root in virippu season

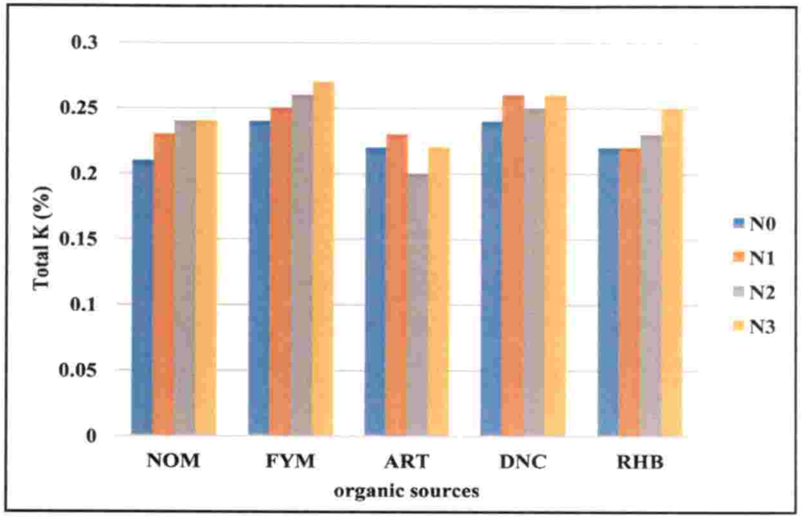

Fig. 55b. Effect of organic sources on potassium content in rice root in mundakan season

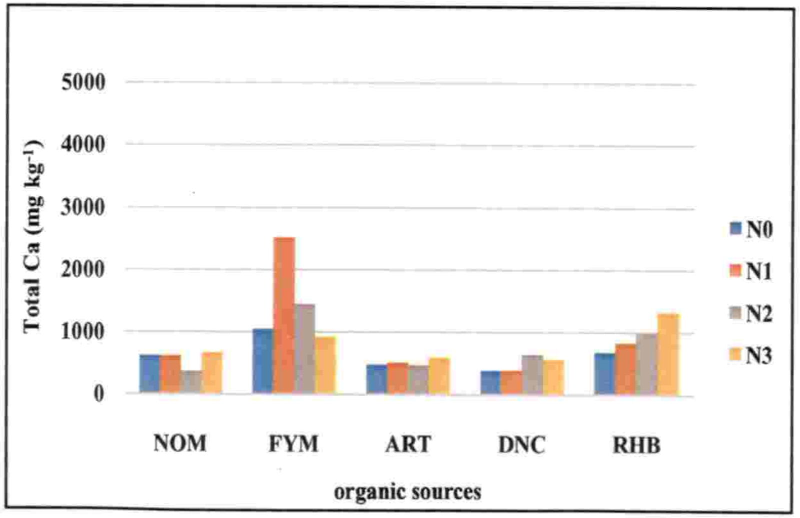

Fig. 56a. Effect of organic sources on calcium content in rice root in virippu season

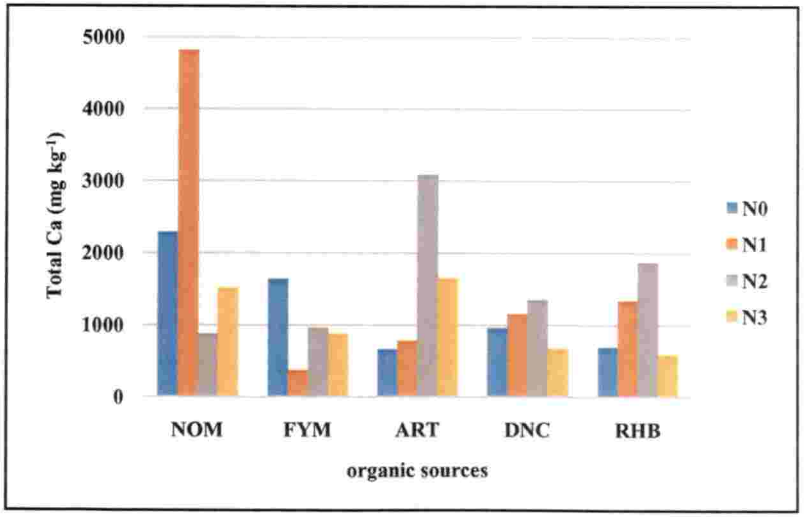

Fig. 56b. Effect of organic sources on calcium content in rice root in mundakan season

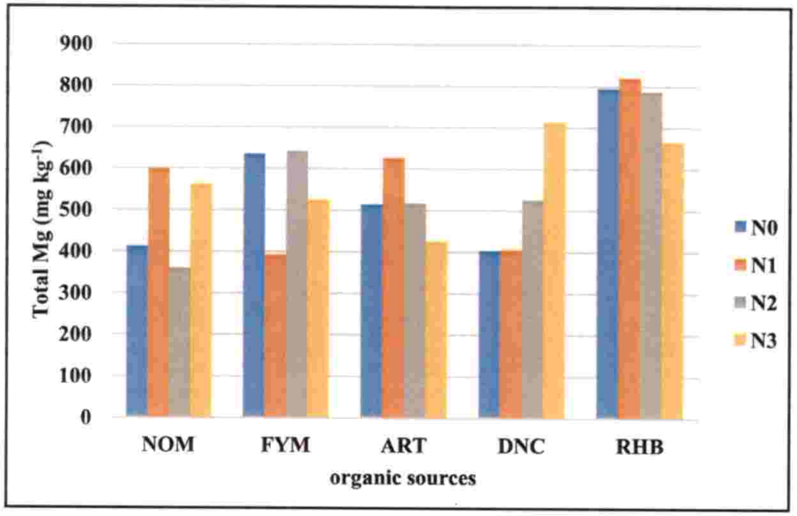

Fig. 57a. Effect of organic sources on magnesium content in rice root in virippu season

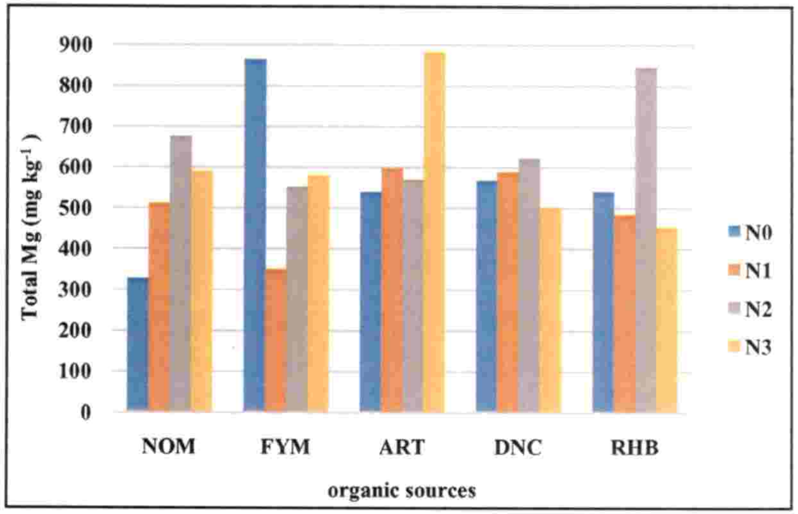

Fig. 57b. Effect of organic sources on magnesium content in rice root in mundakan season

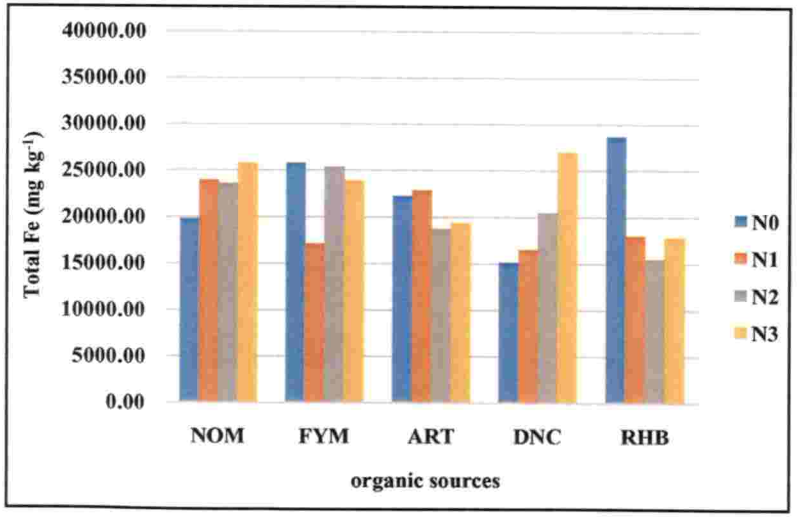

Fig. 58a. Effect of organic sources on iron content in rice root in virippu season

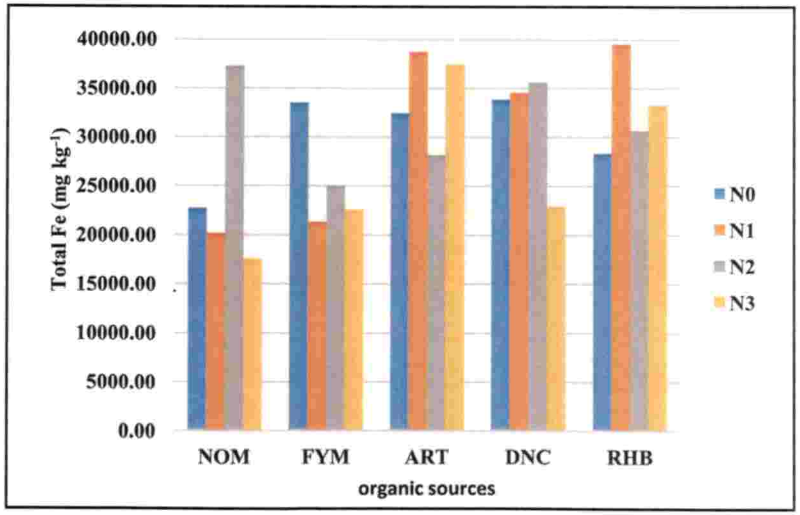

Fig. 58b. Effect of organic sources on iron content in rice root in mundakan season

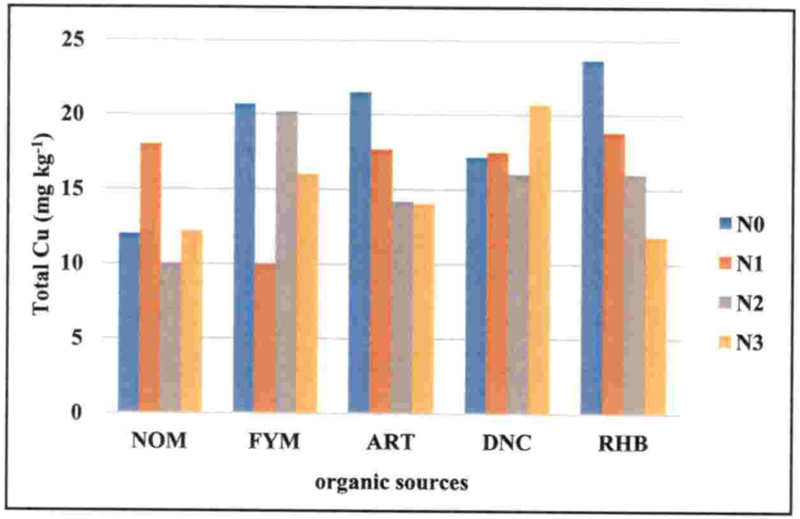

Fig. 59a. Effect of organic sources on copper content in rice root in viippu season

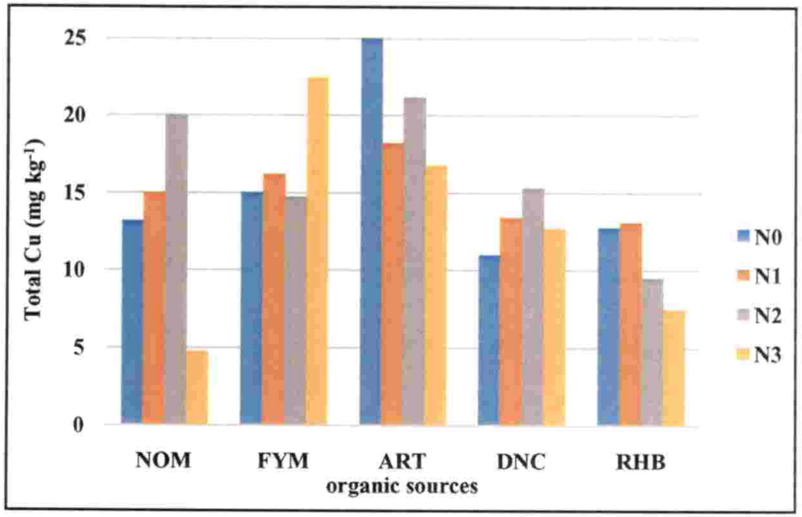

Fig. 59b. Effect of organic sources on copper content in rice root in mundakan season

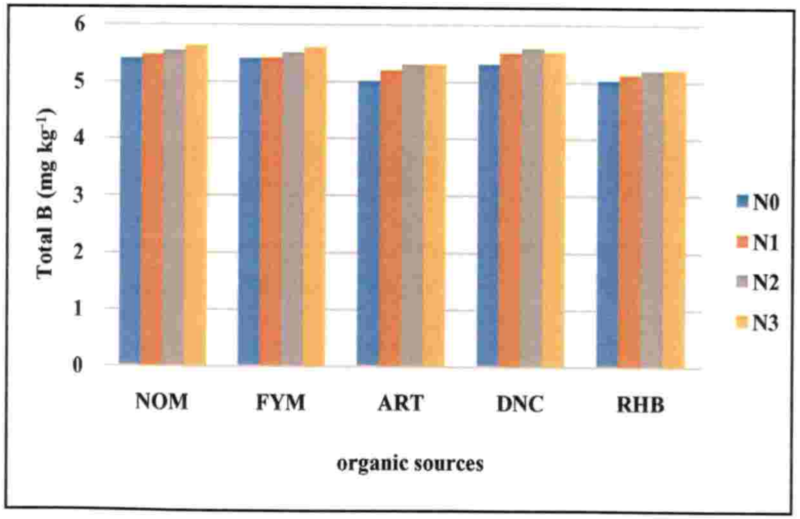

Fig. 60a. Effect of organic sources on boron content in rice root in virippu season

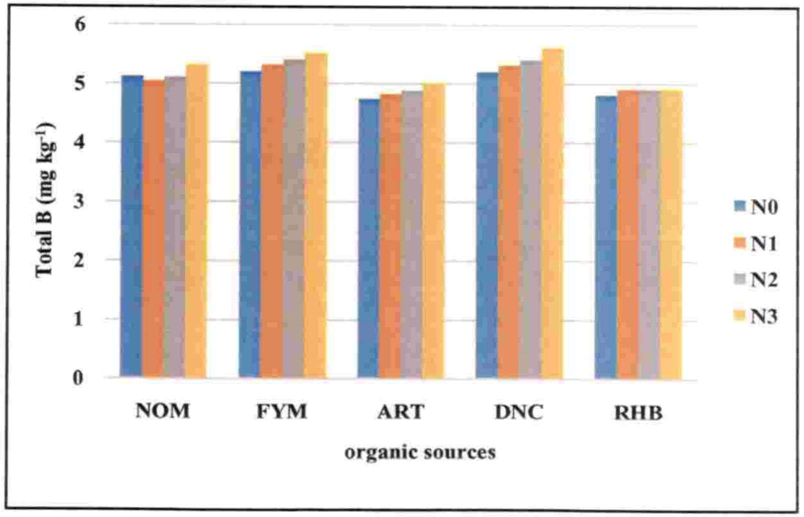

Fig. 60b. Effect of organic sources on boron content in rice root in mundakan season

only a fraction of N and other nutrients are available to plants during the initial period. There was also an increase in nutrient contents in plant parts in the treatments with biochar during mundakan season. Increased microbial activity due to application of biochar could also be another reason for the highest nutrient uptake in biochar treated soils. Biochar acted as a habitat for soil microorganisms involved in N, P or S transformations (Pietikainen *et al.*, 2000). Soil organic matter through chelation process would have strongly held micronutrients like iron, aluminum, zinc, copper and manganese and made them readily available for plant uptake. Improved soil physical properties resulted in greater root distribution and penetration and hence greater nutrient and water uptake (Dexter, 1988).

5.1.7. Yield and yield characteristics

The results under yield and yield attributes of rice clearly showed significant variation among the treatments and an increase in these characteristics. Daincha, a rich organic source is justified by the fact that the supply of daincha with no additional source of nitrogen was effective to the extent of producing an on par plant height of 74.89 cm with the treatments with added nitrogen at the rate of 35 and 70 kg N ha^{-1} which resulted in plant heights of 76.16 and 76.95 cm respectively. But such an observation could not be made when FYM alone was applied.

Plant height, leaf area and dry matter production (Fig. 61 to 64) are the growth attributes which significantly affect the dry weight of leaves and shoots. Higher plant growth as a result of organic amendment application maybe associated with the fact that the organic materials release considerable amount of nutrients especially nitrogen for plant use, which is essential for chlorophyll and protoplasm formation. The cementing action of polysaccharides and other organic compounds released during the decomposition of organic matters, thus leading to taller plants. Babu *et al.* (2001) also reported that plant height was significantly influenced by the application of organic manure and chemical fertilizers. These observations are in line with the findings of Mansour (2002) in Senna; Selvaraj *et al.* (2003) in Rosemary and Thyme.

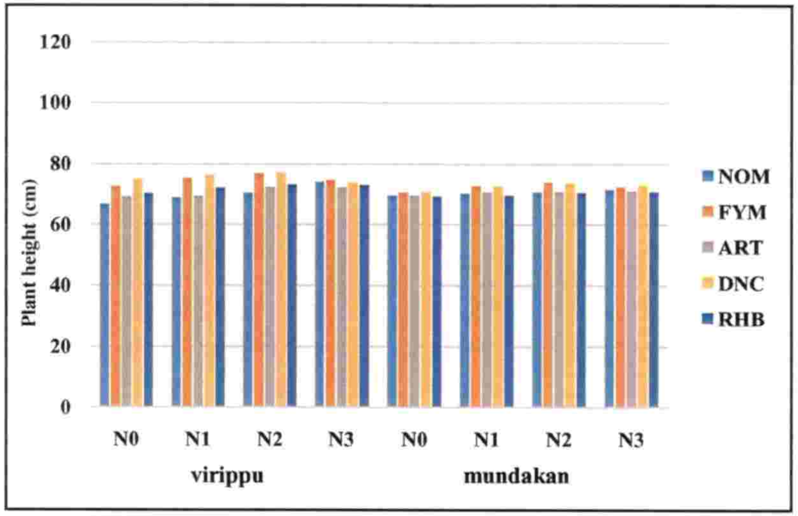

Fig. 61. Effect of different organic sources on plant height at panicle initiation stage of rice crop

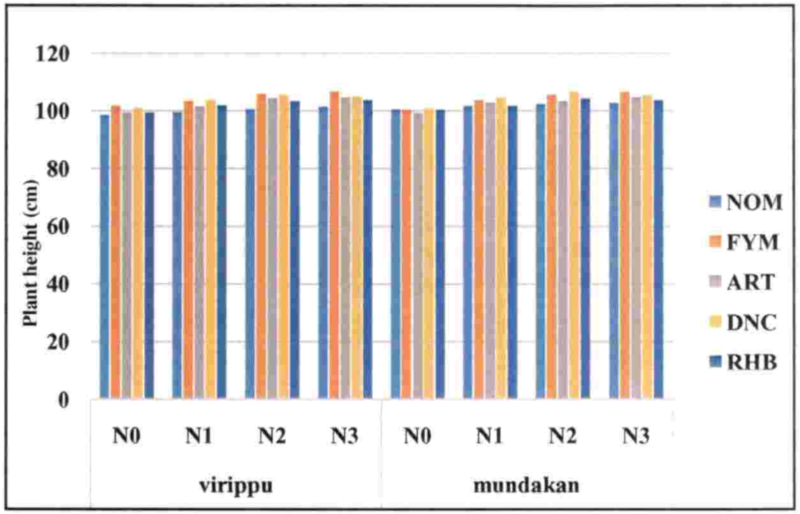

Fig. 62. Effect of different organic on plant height at harvest stage of rice crop

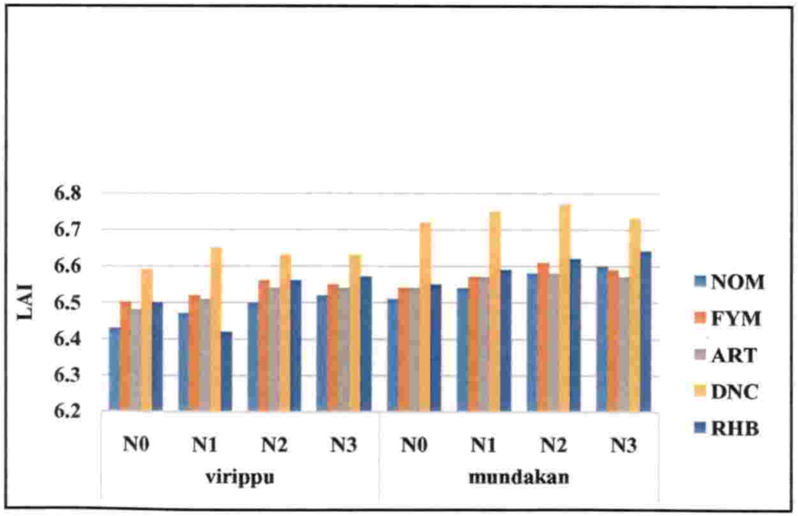

Fig. 63.Effect of different organic sources on leaf area index of rice crop

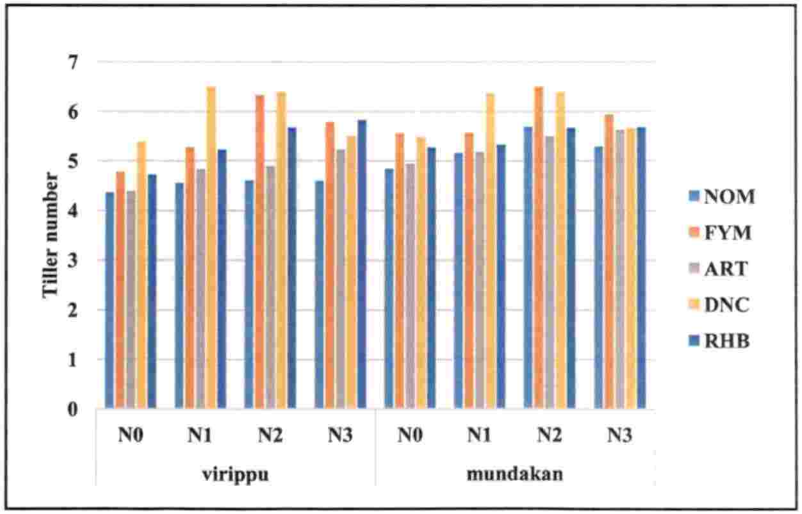

Fig. 64.Effect of different organic sources on number of tillers of rice crop

Agronomic practices such as appropriate nutrient supply can increase the total amount of both root and shoot biomass (Grechi *et al.*, 2007).

Organic amendments and inorganic fertilizers enhancedcrop yield (Fig. 65 to 66) by releasing readily available nutrients to crops. The enhanced soil biological properties provided resiliency and buffering capacity of soil to ameliorate stress (Karlen *et al.* 1992). Application of green manure or other organic fertilizers improved soil physico-chemical and microbiological parameters which could have contributed to sustainable productivity in flooded rice soil.

Liming effect of biochar has been suggested as one of the probable reasons for improved crop yields on acidic soils. Increased nutrient retention by biochar may be the most important factor for increased crop yields (Ding *et al.*, 2010). Improved crop yields may be due to'fertilizer effect'of added biochar, supplying important plant nutrients such as K, N, Ca, and P. The availability of soil nutrients remained higher in the treatments with biochar despite greater nutrient removal due to plant growth and higher grain yields.

5.2. EVALUATION OF GREENHOUSE GAS (GHG) FLUX FROM CULTIVATED ANDFALLOW WETLANDS

The key GHG of concern in paddy cultivation are methane and carbon di oxide respectively. Soil type, temperature and water regimes before and during cultivation period, and organic and inorganic soil amendments all affect GHG emission. The soil in our experimental field was sandy clay loam and clay could lock organic C by adsorption to colloidal surface and aggregate formation (Franzluebbers *et al.*, 1996). Emissions from paddy cultivation and urea fertilization during the experiment were typically small, often negligible for both periods. Tables 91a, b, c and 92a, b, c present emission details.

5.2.1. Measurement of soil CO_2 flux, soil temperature and moisture

During the rice ropping season, the level of CO_2 was high in the initial phase and final phase of crop growth while that of CH_4 was found to be higher in the

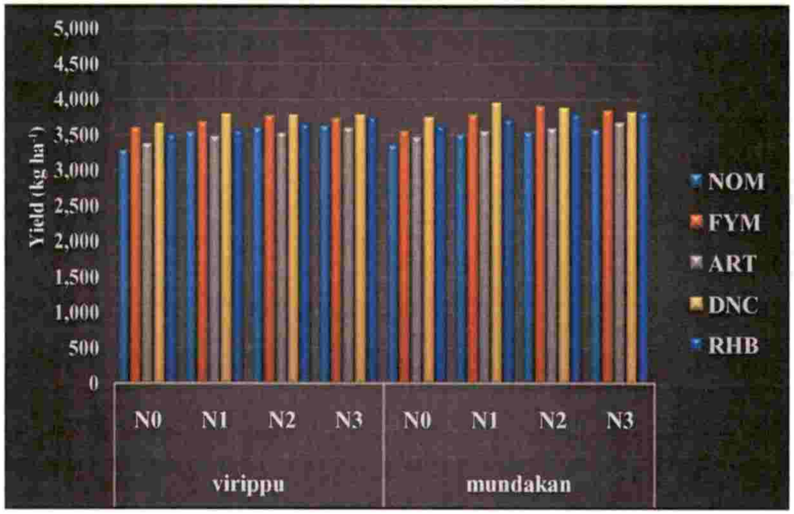

Fig. 65. Effect of different organic sources on grain yield of rice crop

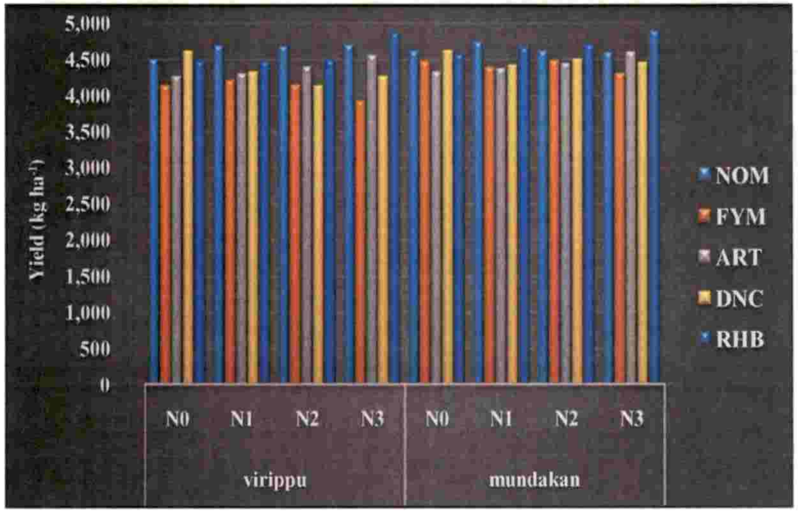

Fig. 66.Effect of different organic sources on straw yield of rice crop

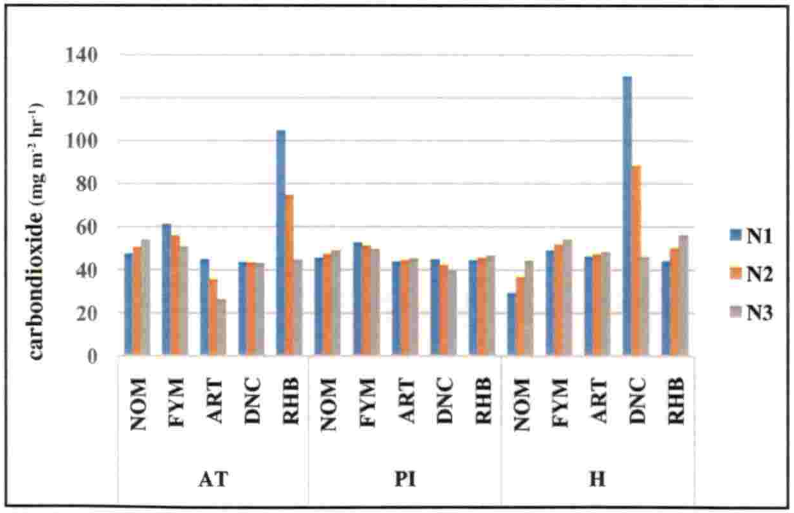

Fig. 67. Emission of carbondioxide at different stages of rice crop

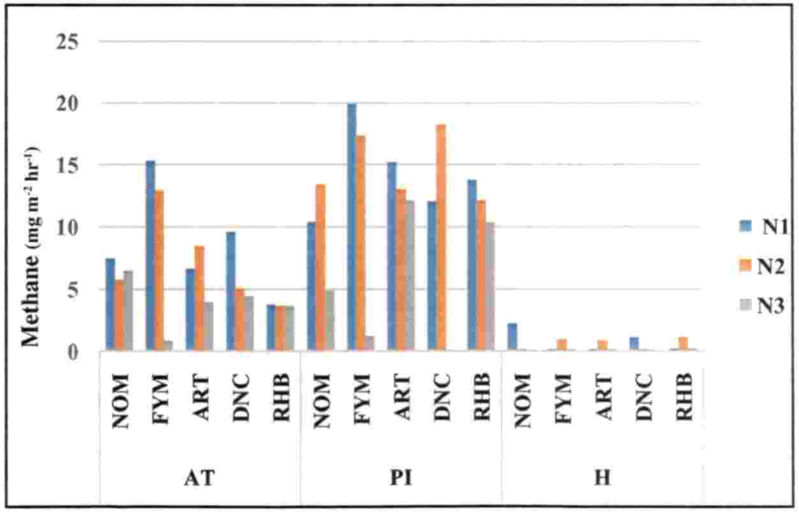

Fig. 68. Emission of methane at different stages of rice crop

panicle initiation phase. The highest emission of carbon di oxide was observed (Fig. 67) in the treatment RHB with 35 kg N $ha^{-1}$with a value 104.52 mg m^{-2} hr^{-1} whereas other treatments of the same organic source and lower nitrogen levels showed very low values (43.54 and 43.11 mg m^{-2} hr^{-1}). Biochar/ daincha amendments produced significantly higher CO_2 but comparatively lower CH_4. The effect of biochar on the GHG emissions obviously depends on the soil environment and the microbial community present, as well as the physicochemical characteristics of the biochar. The increase in CO_2 could be attributed to the wide C:N ratio of the material which could have favoured the escape of C into the atmosphere. But, in the near harvest stage of the crop, it was seen that maximum emission occurred from the treatment with daincha and 105 kg N ha^{-1}. This was due to the rise in carbon level in soil following microbial death from organic source with narrow C:N ratio. Low levels of moisture near the harvest stage of crop also might have favoured an increase in the emission of CO_2. Hanson *et al.* (2000) reported that differences in root respiration and microbial decomposition of soil organic matter reflect in soil CO_2 flux.

Further it could be seen that the methane production was the highest (Fig. 68) in the FYM treated plots in all three phases. Maximum emission was seen at panicle initiation stage when compared to other two stages and this result is in line with the study by Linquist *et al.*, 2012. This may be attributed to the activity of higher microbial populations, especially methanogens in FYM supplied soil. Addition of inorganic fertilizer might have acted as sources of electron donors, thus increasing methanogens in these treatments under flooded rice soil system. Biochar-amended soil showed reduced methane emission and hence low global warming potential (GWP) and this can be attributed to the biological stabilization of carbon and nitrogen in soil. Dubey (2005) pointed out that CH_4 emissions depends on nature, quantity and method of fertilizer application. Urea could enhance CH_4 emissions over the growing seasons which might be due to increase in soil pH following urea hydrolysis and a decrease in redox potential. These two processes enhance methanogenic activities.

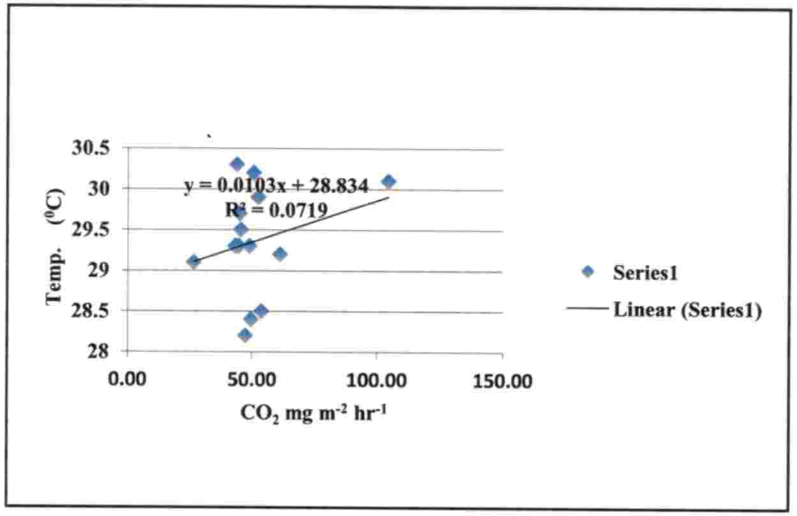

Fig. 69a. Regression between carbondioxide and temperature at active tillering stage

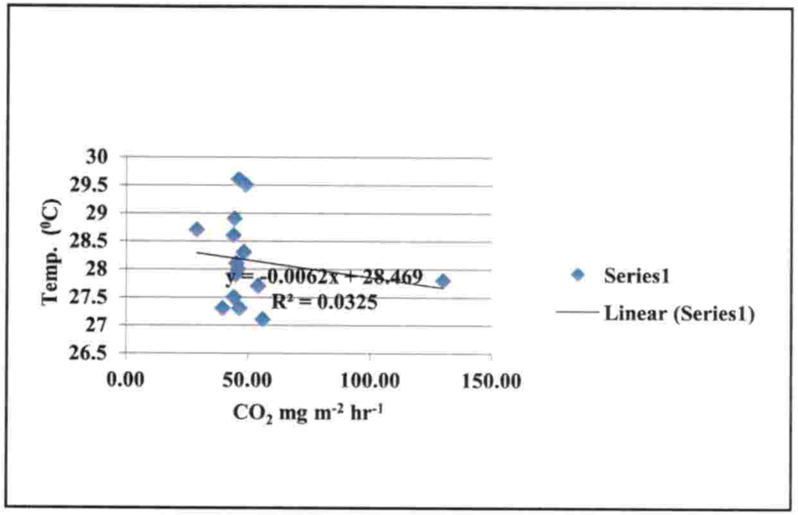

Fig. 69b. Regression between carbondioxide and temperature at panicle initiation stage

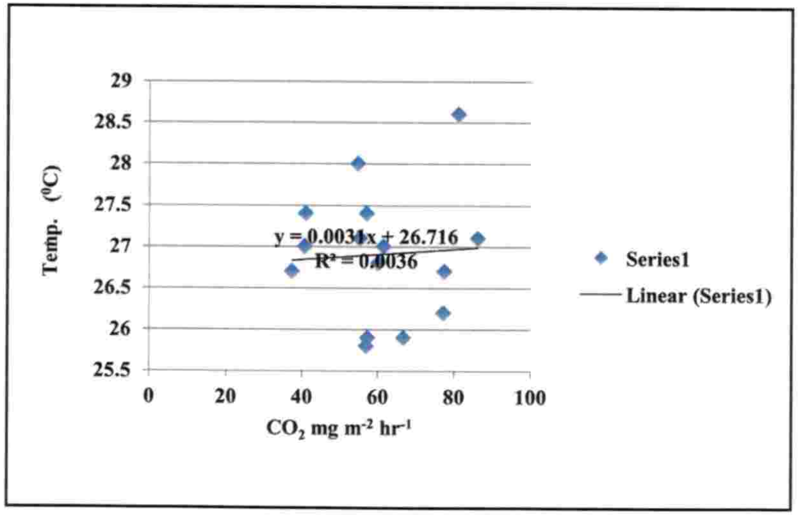

Fig. 69c. Regression between carbondioxide and temperature at harvest stage

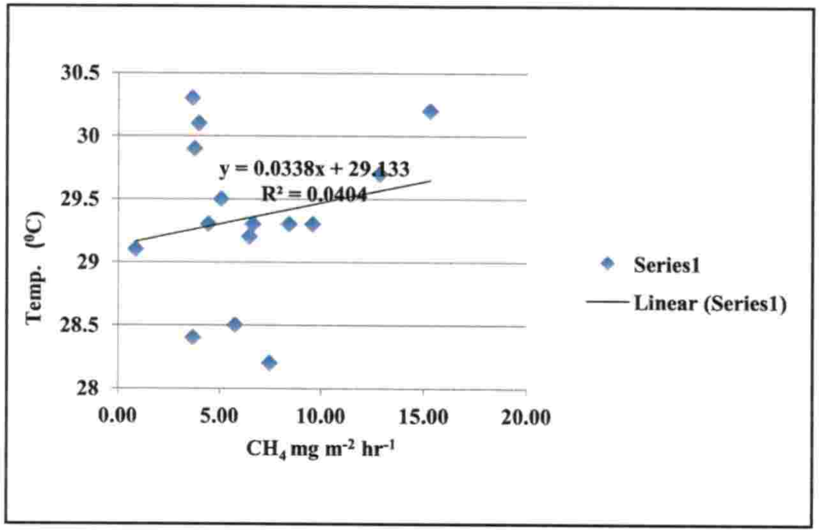

Fig. 70a. Regression between methane and temperature at active tillering stage

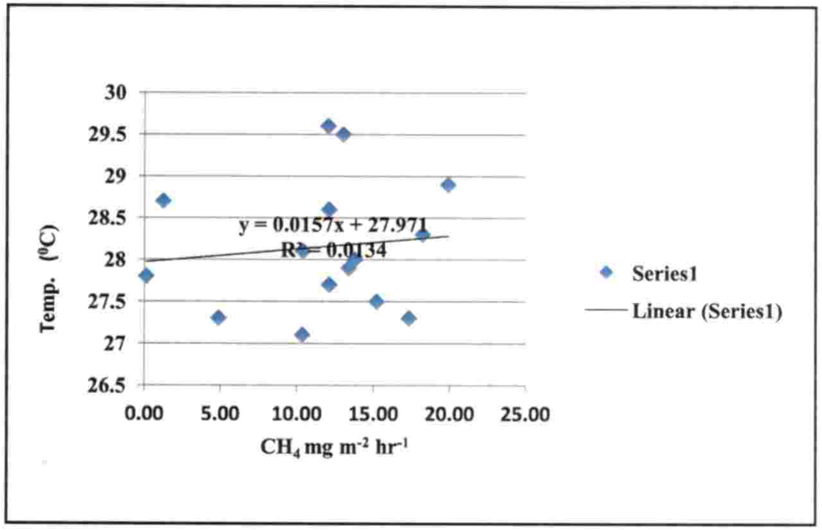

Fig. 70b. Regression between methane and temperature at panicle initiation stage

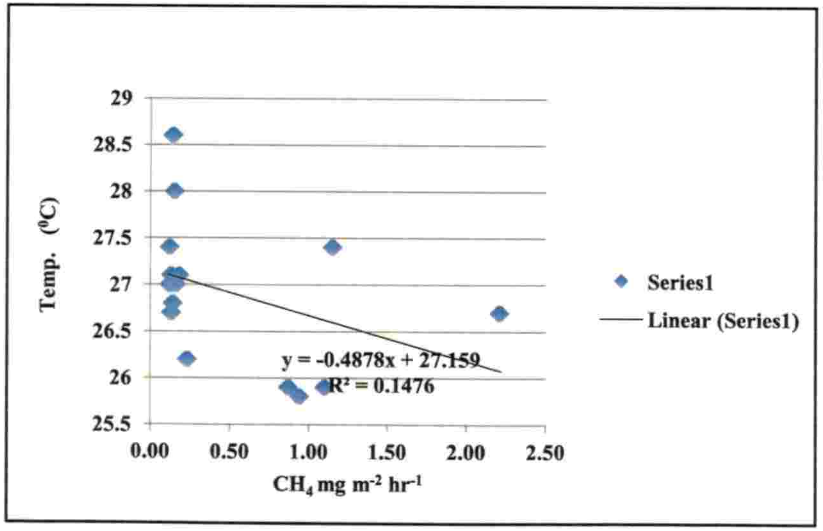

Fig. 70c. Regression between methane and temperature at harvest stage

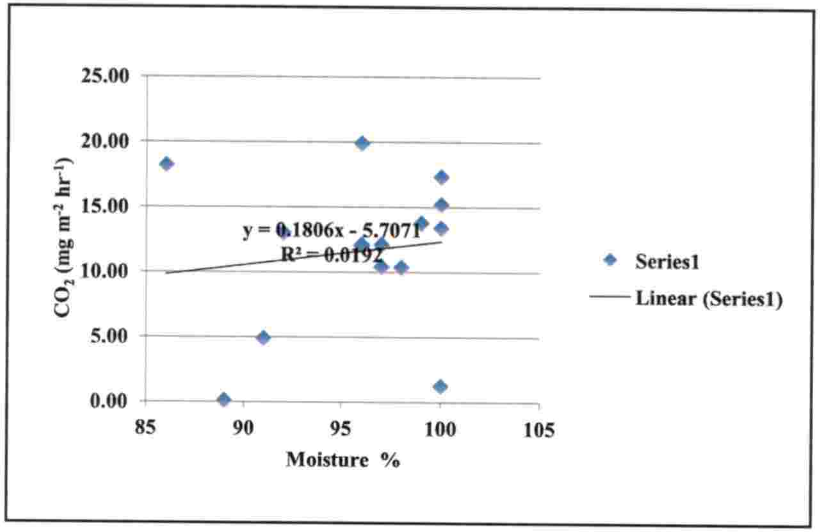

Fig. 71a. Regression between carbondioxide and moisture at active tillering stage

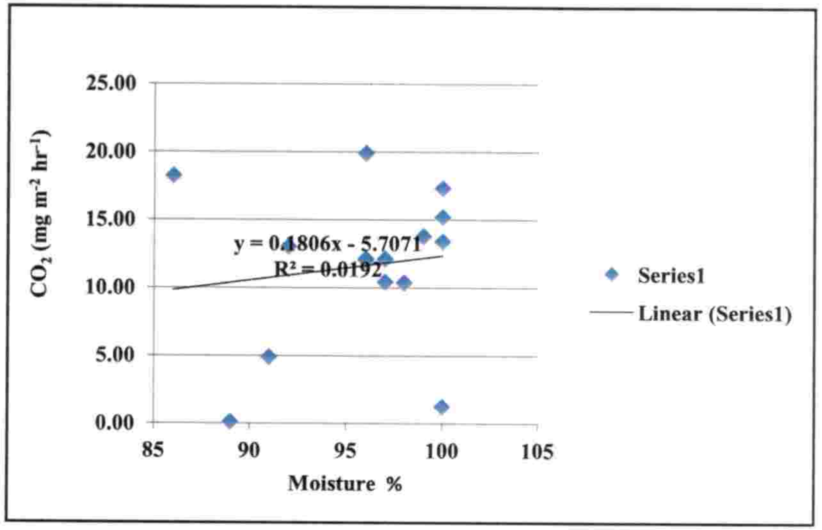

Fig. 71b. Regression between carbondioxide and moisture at panicle initiation stage

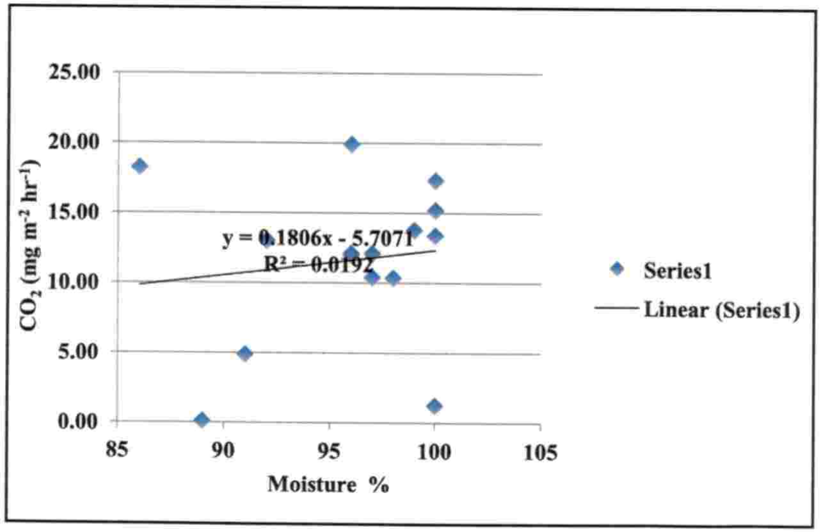

Fig. 71c. Regression between carbondioxide and moisture at harvest stage

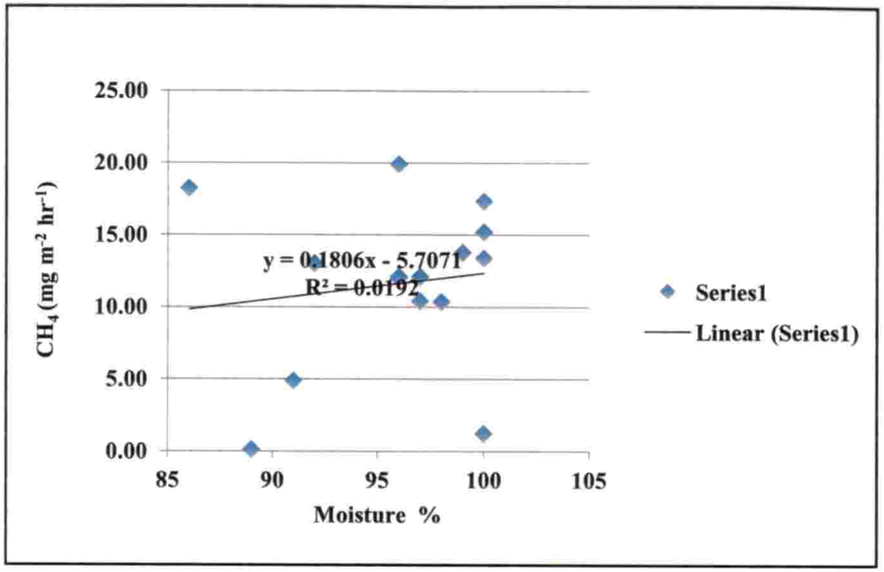

Fig. 72a. Regression between methane and moisture at active tillering stage

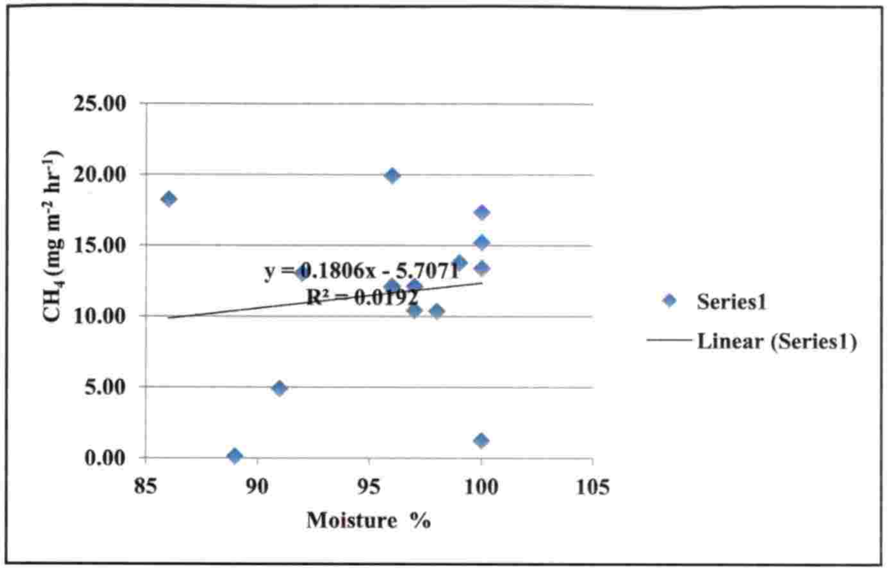

Fig. 72b. Regression between methane and moisture at panicle initiation stage

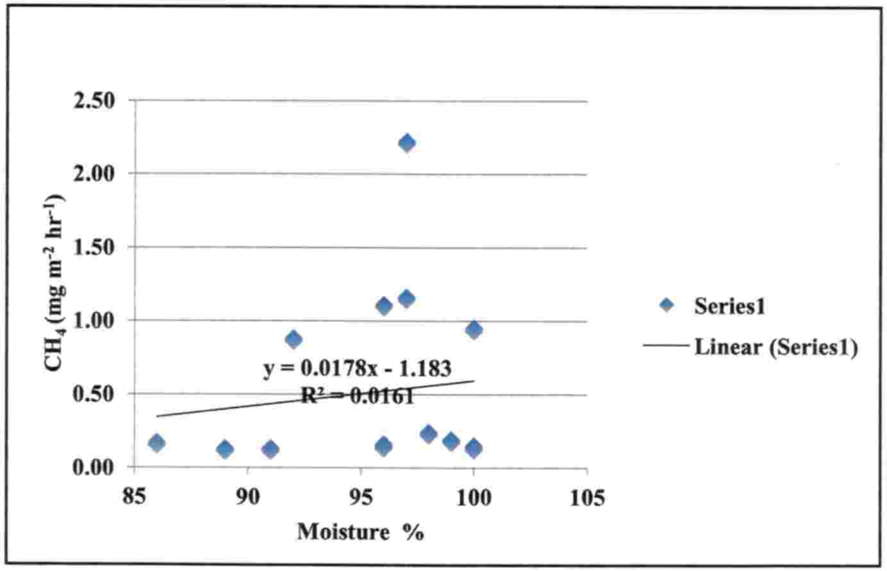

Fig. 72c. Regression between methane and moisture at harvest stage

As products of carbon and nitrogen mineralization, considerable amounts of CO_2 and CH_4 were produced during the cropping period. Total CO_2 production, however, varied in a much wider range from 26.47 mg m^{-2} hr^{-1} to 129.94 mg m^{-2} hr^{-1} in soil as shown in Fig.67. Apparently, CO_2 production predominated over CH_4 in the majority of cases. Fertilization affects CO_2 production differently compared to CH_4, although both were significantly influenced by the different amendments. It has been well addressed that application of different amendments could enhance the bio available pool of organic carbon (Xu *et al.*, 2015).

Soil temperature and soil moisture are important factors (Fig. 69 to 72) controlling CO_2 fluxes by their influence on organic matter decomposition. Rainfall can influence soil CO_2 fluxes through soil moisture fluctuations in surface layers where most of the biological activity occurs. It can also strongly increase soil CO_2 fluxes by a drying and rewetting effect (Lee *et al.*, 2002). Changes in instantaneous soil CO_2 fluxes among treatments could further be explained by the soil C/N ratio and clay content percentage. Both soil C/N ratio and clay content were negatively related to instantaneous soil CO_2 fluxes. In contrast, the highest input of inorganic fertilizer did not result in the highest soil CO_2 flux. So we can conclude the temporal variation in soil CO_2 fluxes was mainly due to soil temperature and moisture.

More rapid rates of C accumulation and loss may occur over shorter time scales as the large component of fast-cycling soil C responds to disturbance such as a change in vegetation. As discussed above, soils may lose a significant portion of their carbon after cultivation; these changes represent a loss of fast-cycling C rather than passive C pools (Ghosh *et al.*, 1995).

The relationship between GHG emission and redox potential was studied. Redox potential, an important soil parameter governing GHG emission, declined rapidly within a few days after submergence and attained steady level.

5.3. PROFILE CHARACTERISATION OF CULTIVATED AND FALLOW WETLANDS

The study showed that the profile from biochar treated plots had higher values for morphological and physico-chemical characteristics than the fallow land.

The profiles from fallow land and cultivated land showed six and seven horizons delineations respectively. The horizons identified common to both profiles were Ap, AC, AC2, AC3, AC4 and C. In addition, the cultivated land had A2 horizon also. The colour of Ap horizon soil in cultivated land was greyish brown (10YR 5/2 M) and was darker than that of fallow land which was dark yellowish brown. This could be due to the addition of organic matter from the organic source. This is in lieu with the findings of Ge *et al.*, 2011. A gradation of soil colour was noticed from top soil to bottom layer of the profile which could be attributed due to the decrease in organic matter content. In case of clay content of soil, an increase was observed with increasing depth. The number of mottlings, its colour and distinctness also increased from top to bottom layer.

The values of pH for both fallow and cultivated lands were found to increase from the surface soil values. The pH values increased upto a certain depth and then got stabilized. Finally the pH values for both cultivated as well as fallow lands bcame equal (5.20). Similar results were also recorded by Haynes and Mokolobate, 2001.

The biochar treated plot recorded higher organic carbon content (0.95- 2.05%) when compared to the fallow alnd (0.84- 1.05%). Nigusse *et al.*(2012) also obtained the same results and he indicated the presence of recalcitrant carbon in biochar could increase the OC content in soil. Similar trend was observed for the available nutrient content also. This might be due to the combined effect of increased physical, chemical and biological parameters in the cultivated land and were in agreement with the results obtained by Dhull *et al.*, 2010 and Ghosh *et al.*, 2012.

SUMMARY

6. SUMMARY

The present study entitled "Carbon sequestration and soil health under different organic sources in wetland rice" was carried out in a farmer's field (10^{o} 31' 49" N latitude and 76^{o}12' 53"E longitude) cultivating paddy situated on the typical lateritic lowland region in the tropical monsoon land scape zone of Kerala. The experimental field was located in the flat floodplains of village, Varadium in Thrissur district with sandy clay loam soil. The experiment was conducted for two continuous cropping seasons of Virippu and Mundakan in rice crop during 2015-2016. The objectives of the experiment was to assess the effect of different organic sources on carbon sequestration and soil health in wetlands (Ultisol) under rice –rice cropping system and to compare carbon distribution and fluxes with that of adjoining fallow land.

In this study, the treatments included fertilization with four organic sources [no organic manure, farm yard manure (FYM), jack tree (*Artocarpus heterophyllus*) leaves, daincha (*Sesbania aculeata*) and rice husk biochar] in combination with inorganic nitrogen at various levels. The soil and plant samples after the field experiment were collected and analysed for nutrient contents. In the case of soil, analysis of the surface (0-15 cm) and subsurface (15-30 cm) samples were done.

The salient results of the study done in the field and laboratory are summarized below:

Physical properties of surface soil

- The treatment, rice husk biochar (RHB) at N_0 level showed least bulk density and highest WHC of soil compared to other treatments in both seasons. With increasing levels of nitrogen, the BD of soil was found to be increased while the trend was reverse with WHC of soil.

Chemical properties of surface soil

- In both seasons, pH of soil was significantly maximum with the treatment rice husk biochar (RHB) at N_0 level. The pH of the soil increased with increasing levels of nitrogen.
- The significant minimum value for EC was obtained in the treatment RHB without nitrogen in both seasons. The highest significant EC value of 0.164 dS m^{-1} was obtained during virippu season in the treatment daincha with 105 kg N ha^{-1}. In general, there was a decrease in EC values in the second season.
- CEC of soil was the highest with the treatment daincha with 35kg N ha^{-1} which was also significant. In the inorganic nitrogen source, 70 kg N recorded the highest value. Similar results were obtained during mundakan season also.
- The soil organic carbon content was higher in the treatments with organic sources than with inorganic sources. The significantly higher OC content was observed in the treatment with rice husk biochar (RHB) at N_0 level. The same trend was observed in mundakan season also. Total carbon content of the soil showed the same trend as the organic carbon content of soil.

Physical properties of sub-surface soil

- The bulk density of subsurface soil was higher than the surface BD. The treatment *Artocarpus* at N_0 level showed least bulk density. The highest WHC of soil was obtained for the treatment daincha with N_0 level compared to other treatments in both seasons. Here as the depth increased, the WHC of soil decreased. With increasing levels of nitrogen, the BD of soil was found to be increased while the trend was reverse with WHC of soil.

Chemical properties of sub-surface soil

- The treatments with inorganic sources alone showed lesser values of pH. The subsurface pH values were found to be lower than that of surface soil and was significantly maximum with the treatment rice husk biochar (RHB) at N_0 level in both seasons.

- The minimum EC was recorded in the treatment with RHB at N_0 level in virippu season and with *Artocarpus* at N_0 level during mundakan season. CEC of soil was the highest with treatment, daincha with 70 kg. N which was also significant. In the inorganic nitrogen source, 70 kg N recorded the highest values. Similar results were obtained during mundakan season also.
- The highest significant OC content was observed in the treatment with FYM at 35 N. The same trend was observed in mundakan season also. Rice husk biochar with no added N also showed an on par value. The total carbon content of soil was in line with the organic carbon content of the soil.

Nutrient contents of surface soil

- The treatment with daincha and 105 kg N ha^{-1} recorded significant maximum value in both seasons. The nitrogen content in soil increased with the doses of nitrogen levels and the highest nitrogen content was with the greater amount of nitrogen ie. 105 kg N. The treatments with inorganic sources alone showed minimum values.
- The available phosphorus content was maximum with the treatment *Artocarpus* and RHB in virippu and mundakan seasons respectively. Nitrogen level at 35 kg showed maximum phosphorus content.
- The treatment with daincha and 35 kg N ha^{-1} showed a significant maximum value of available potassium content in both seasons.
- Available calcium and magnesium were higher with the organic source daincha. The levels of nitrogen had varied effect in the availability of nutrients. The contents showed a decrease in the mundakan season.

- The highest sulphur content of 8.46 mg kg^{-1} was recorded in the treatment daincha with 70 kg N ha^{-1} and the same trend was observed in mundakan season also.
- The micronutrients like iron and manganese were lower in soil with treatment using RHB as organic source. The nutrient contents were higher with 0 and 35 kg N in case of iron while the contents showed an increasing trend with nitrogen level for magnesium.
- The available zinc content was found to be maximum in the treatment RHB with 105 kg N ha^{-1} (8.01 mg kg^{-1}).
- Available copper content was significantly the highest during virippu season in the treatment *Artocarpus* without any N source.
- Available boron was maximum with the treatment FYM application with 105 kg N ha^{-1} (0.49 mg kg^{-1}).

Nutrient contents of sub-surface soil

- The available nitrogen content did not show variation in the subsurface soil. However, during mundakan season, treatment with daincha and 35 kg N had maximum value. The treatment RHB with or without N recorded lower values in the second season.
- The treatment with daincha and 105 kg N ha^{-1} showed a significant maximum value of available phosphorus content.
- The available potassium content was maximum with the treatment daincha and 105 kg N.
- The treatment, daincha and 105 kg N ha^{-1} showed significant maximum values for available calcium and magnesium contents in virippu season but the contents were significantly higher using RHB with / without N in mundakan season.
- Available S was significantly higher in the treatment daincha with 70 kg N ha^{-1} (5.43 mg kg^{-1}).

- The subsurface soil recorded lower values for iron and manganese contents and they showed a decrease at 105 kg N. Available Mn was the least when inorganics alone were applied.
- The available zinc was the highest in the treatment daincha with 35 kg N ha^{-1} (10.15 mg kg^{-1}).
- The treatment FYM with 70 kg N ha^{-1} showed a significant maximum value of 10.66 mg kg^{-1}.
- The highest value of boron was observed for the treatment FYM with 70 kg N ha^{-1}

Biological characteristics of surface soil

- The microbial biomass carbon and phosphatase activity of soil were significantly higher with the treatment *Artocarpus* at 70 kg N and with RHB at 35/105 kg N in virippu and mundakan seasons respectively. Maximum value of dehydrogenase activity was obtained for the treatment RHB with 105 kg N ha^{-1} in both seasons.

Biological characteristics of sub-surface soil

- The biological characteristics were similar to that of surface soil. The phosphatase activity was significantly higher in the treatment, daincha with 105 kg N ha^{-1} in virippu season and it was maximum in RHB at 105 kg N in mundakan season while the reverse trend was observed for the dehydrogenase activity.

Fractions of soil organicmatter

Fractions of surface soil organiccarbon

- The coarse particulate organic carbon content was significantly the highest in the treatment RHB with 105 kg N ha^{-1}(23.6 g kg^{-1}). All the treatments of the same organic source with/ without inorganic N dose showed values of more than one per cent.

- The fine particulate organic carbon content was the highest in virippu and mundakan seasons in the treatment *Artocarpus* with 105 kg N ha^{-1}.
- The light fraction and intra light fraction organic carbon contents were significantly higher in the treatment with RHB and no added nitrogen. In general, treatments with RHB had higher light and intra light fractions compared to other treatments. During mundakan season also the same trend was observed.
- The heavy fraction organic carbon content was significantly maximum in the control treatment without nitrogen.
- Mineral associated organic carbon was the highest in the treatment RHB with 70 kg N ha^{-1}.

Fractions of sub-surface soil organiccarbon

- The coarseparticulate organic carbon was the highest in the treatment, control in both seasons.
- The fine particulate organic carbon content was significantly maximum in the treatment FYM with 105 kg N ha$^{-1\cdot}$ During mundakan season, the values were found to be lower.
- The significantly higher value of light fraction organic carbon was observed in the treatment FYM without any added nitrogen but intra light fraction organic carbon was maximum in the the treatment, RHB without any nitrogen in both seasons.
- The highest value of heavy fraction organic carbon was observed in the treatment RHB without nitrogen.
- The highest mineral associated organic carbon was observed in the treatment daincha with 105 kg N ha^{-1}.

Fractions of surface soil organicnitrogen

- Significant maximum values of coarse particulate organic nitrogen was observed in the treatment RHB with 105 kg N ha^{-1} in virippu and mundakan seasons respectively.
- The significant and highest value of fine particulate organic nitrogen was seen in the treatment *Artocarpus* with 35 kg N ha^{-1}.
- The significantly higher value of light fraction organic nitrogen was recorded in the treatment *Artocarpus* with 105 kg Nha^{-1}.
- The maximum value of intra light fraction organic nitrogen was in the treatment RHB with 35 kg N ha^{-1}.
- The highest heavy fraction organic nitrogen value was recorded in the treatment with 35 kg N ha^{-1}alone.
- Mineral organic nitrogen was the highest in the treatment daincha with 70 kg N ha^{-1}.

Fractions of sub-surface soil organicnitrogen

- Coarse particulate organic nitrogen was observed significantly higher in the treatment daincha without nitrogen in both seasons.
- The highest value of fine particulate organic nitrogen was observed in the treatment with 105 kg N alone.
- The light fraction organic nitrogenvalue was the highest in the treatment FYM without nitrogen.
- The maximum intra light fraction organic nitrogen was recorded in the treatment, daincha with 35 kg N ha^{-1}.
- The highest heavy fraction organic nitrogen value was observed in the treatment FYM with 35 kg N ha^{-1}.
- Mineral associated organic nitrogen was the highest in the treatment FYM with 35 kg N ha^{-1}.

Fractions of surface soil C:N ratio

- The treatment, *Artocarpus* with 105 kg N ha^{-1} resulted in the highest coarse particulate C:N value of 15.83which was also significant. The treatments, RHB with 35/70 kg N ha^{-1} showed on par values.
- The highest fine particulate C:N value was observed in the treatment *Artocarpus* with 70 kg N ha$^{-1.}$
- The light fraction C:N and intra light fraction C:N ratio were found to be the highest in the treatment, RHB with 105kg N ha^{-1}.
- The highest heavy fraction C:N value was observed in the treatment without any organic or inorganic source.
- Mineral associated C:N value was maximum in the control treatment.

Fractions of sub-surface soilC:N ratio

- The highest and significant coarse particulate C:N value was observed in the treatment without any organic or inorganic source.
- The fine particulate CN ratio was the highest in the treatment RHB with 105 kg N ha^{-1}.
- The light fraction C:N value was significantly higher for the treatment no organic manure with 35 kg N ha^{-1} andintra light fraction C:N ratio was maximum in the treatment RHB without any N dose.
- The highest heavy fraction C:N value was observed for the treatment 105 kg N ha^{-1} alone.
- The highest mineral associated C:N value was observed in the treatment daincha with 105 kg N ha$^{-1.}$

Plant nutrient characteristics

Grain

- The treatment daincha at 35/70 kg N had higher primary nutrient contents.Calcium and magnesium contents were maximum in the treatments with daincha /RHB at 70kg N. Sulphur content was significantly maximum in the treatment FYM with 105 kg N ha^{-1}. Iron content was minimum with *Artocarpus* and RHB at various levels of nitrogen while manganese was found to be the lowest with no organic source and *Artocarpus* in virippu and mundakan seasons respectively.The micronutrients zinc, copper and boron were maximum with FYM as organic source. Zinc and copper were below the detectable level in the treatment with inorganic source alone.

Straw

- The highest significant nitrogen content was observed in the treatment FYM with 105 kg N ha^{-1}. Phosphorus and potassium contents were maximum with daincha at 35/105 kg N. Similarly daincha at 105 kg N showed higher values of calcium magnesium and sulphur while in mundakan RHB with 35 kg N ha^{-1} recorded significant maximum calcium content. Iron content was found to be significantly higher in the treatment RHB with 105 kg N ha^{-1}. The treatment *Artocarpus* with 35 kg N ha^{-1} recorded significant maximum content of zinc.

Root

- Nitrogen, phosphorus and potassium contents were the highest with daincha and FYM as organic source. Calcium and magnesium contents were maximum with FYM and RHB while sulphur was high with daincha. Zn content was significantly the highest in the treatment, RHB with 105 kg N ha$^{-1.}$

Plant biometric characters

- Plant biometric characteristics like plant height at panicle initiation and at harvest, 1000 grain weight and harvest index were maximum with FYM while leaf area index, percentage of filled grains, root biomass and B:C ratio were higher with daincha as organic source. Grain yield was higher with daincha at 35 kg N while straw yield was maximum with RHB at 105 kg N.

Comparison betweenGHG flux from cultivated and fallow land

- The greenhouse gas emission of carbon di oxide and methane from cultivated lands were higher than that of fallow lands. The emission of CO_2 was more prominent in active tillering and harvest stages and the emission was minimum at panicle initiation stage.On the other hand, methane emission was higher at panicle initiation than at active tillering stage. At harvest stage, the emission of methane was nearly nil. The treatment with FYM showed highest emission of methane while the ones with RHB and daincha had highest CO_2 emission.

Soil profile study of cultivated and fallow land

- Soil profiles of cultivated (RHB with 0kg N ha^{-1}) and adjoining fallow lands were taken after harvest of the second crop and their morphological as well as physico-chemical characteristics were studied. Soil profile in the fallow land had a depth of 115 cm and five horizons were delineated while a soil profile depth of more than 70 cm with six horizons was noticed in the cultivated land. Analysis of the available nutrient contents in soil indicated that the nutrient contents in the fallow land was lesser than that of the cultivated land. The values of the parameters were found to be high in the surface and they decreased as we moved down the profile.

Conclusion

The study indicates that organic sources are the best means of incorporating organic matter to the soil and increasing the soil carbon pool. Application of FYM, *Artocarpus*, daincha and biochar stimulated plant growth through out crop period by slowly releasing nutrients which ultimately increased the biomass which in turn promoted the soil fertility. Decomposition and accumulation of organic matter varied with the materials used in the experiment. Biochar increased maximum allocation of carbon both in the soil and biomass, thus portraying its C sink capacity. Moreover, due its alkaline nature, it enhanced the pH of soil. Thus it can be considered to reclaim acidity instead of lime in acid soils of Kerala.However, the organic sources with higher doses of N had enhanced emission of CO_2 and CH_4. Hence a suitable balance between the organic + inorganic N sources is advocated in wetland rice cultivating tracts towards attaining maximum yield without affecting our climate system.

Future line of research

- Liming effect of biochar in acid soils of Kerala may be examined.
- Impact of organic sources and land management practices over a period of 2-3 yearson carbon sequestration and SOC pools shall be studied.
- Assessmentof C stabilizing mechanismsin soils can be deduced.

REFERENCES

REFERENCES

Abbas, T., Rizwan, M., Ali, S., Rehman, M. Z., Qayyum, M. F., Abbas, F. 2017. Effect of biochar on cadmium bioavailability and uptake in wheat (*Triticum aestivum* L.) grown in a soil with aged contamination. *Ecotoxicol. Environ. Saf.* 14: 37-47.

Adebayo, A. G., Akintoye, H. A., Olufolaji, A. O., Aina, O. O., Olatunji, M. T., and Shokalu, A. O. 2011. Assessment of organic amendments on vegetative development and nutrient uptake of *Moringa oleifera* L. in the nursery. *Asian J. Plant Sci.* 10(1): 74-79.

Alamgir, M., McNeill, A., Tang, C., and Marschner, P. 2012. Changes in soil P pools during legume residues decomposition. *Soil Biol. Biochem.* 49: 70-77.

Alvaro- Fuentes, J. and Lopez, M. V. 2008. Tillage effects on soil organic carbon fractions in Mediterranean dry land agro-ecosystems. *Soil Sci. Soc. Am. J.* 72: 541-547.

Aparna, B. 2000. Distribution, characterization and dynamics of soil enzymes in selected soils of Kerala. Ph.D. thesis, Kerala Agricultural University, Thrissur, 346p.

Arocena, J. M. and Opio, C. 2003. Prescribed fire- induced changes in properties of sub-boreal forest soils. *Geoderma* 113: 1-16.

Babu, S., Marimuthu, R., Manivannan, V., and Kumar, R. S. 2010. Effect of organic and inorganic manures on growth and yield of rice. *Agri. Sci. Digest.* 21(4): 232-234.

Basak, B. B., Biswas, D. R., and Rattan, R. K. 2012. Comparative effectiveness of value-added manures on crop productivity, soil mineral nitrogen and soil carbon pools under maize-wheat cropping system in an Inceptisol. *J. Indian Soc. Soil Sci.* 60 (4): 288-298.

29

Batjes, N. H. 1996. Total carbon and nitrogen in the soils of the world. *Eur. J. Soil Sci.* 47: 151-163.

Behera, S. K. and Singh, D. 2009. Effect of 31 years of continuous cropping and fertilizer use on soil properties and uptake of micronutrients by maize (*Zea mays*) – wheat (*Triticum aestivum*) system. *Indian J. Agric. Sci.* 79 (4): 264-267.

Benbi, D. K. 2013. Opportunities for carbon sequestration in soil. *J. Res. PAU.* 49: 186-192.

Benbi, D. K. and Brar, J. S. 2009. A 25 year record of C sequestration and soil properties in intensive agriculture. *Agron. Sustain. Dev.* 29: 257-265.

Benbi, D. K. and Chand, M. 2007. Quantifying the effect of soil organic matter on indigenous soil N supply and wheat productivity in semiarid sub-tropical India. *Nutr. Cycl. Agroecosyst.* 79: 103-112.

Benbi, D. K. and Khosa, M. K. 2014. Effect of temperature, moisture and chemical composition of organic substrates on C mineralization in soils. *Commun. Soil Sci. Plant Anal.* 45: 2734-2753.

Benbi, D. K. and Yadav, S. K. 2015. Decomposition and carbon sequestration potential of different rice residue derived by-products and farmyard manure in a sandy loam soil. *Commun. Soil Sci. Plant Anal.* 46: 2201-2211.

Benbi, D. K., Toor, A. S., and Kumar, S. 2012. Management of organic amendments in rice wheat cropping system determines the pool where carbon is sequestered. *Plant Soil* 360: 145-162.

Bengtsson, J., Janion, C., Chown, S. L., and Leinaas, H. P. 2012. Litter decomposition in fynbos vegetation, South Africa. *Soil Biol. Biochem.* 47: 100-105.

Berg, B. 2000. Litter decomposition and organic matter turnover in northern forest soils. *For. Ecol. Manage.* 133: 13-22.

Berger, K.C. and Troug, E. 1939. Boron determination in soils and plants. *Indian Eng. Chem. Anal. Ed.* 11: 540-542.

Berhe, A. A. and Kleber, M. 2013. Erosion, deposition, and the persistence of soil organic matter: mechanistic considerations and problems with terminology. *Earth Surf. Processes Landforms* 38: 908-912.*

Bhatt, B., Chandra, R., and Ram, S. 2015. Long-term application of fertilizer and manure on rice productivity and soil biological properties. *Int. J. Agric. Environ. Biotech.* 5 (4): 429-433.

Bhattacharyya, K. and Mandal, S. R. 1996. Effect of green manuring on growth parameters and yield of rainfed rice. *Environ. Ecol.* 14: 446-450.

Bingham, F. T. 1982. Boron. In: Page A. L. (ed.), *Methods of Soil Analysis: Part II* (2nd Ed.). Am. Soc. Agron. Madison, WI, USA. pp. 431-447.*

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

Bot, A. and Benites, J. 2005. The importance of soil organic matter: Key to drought-resistant soil and sustained food production. *FAO Soil Bull.* 80p.

Bradley, F., Thelen, K., and Min, D. 2008. Use of manure, compost and cover crops to supplement carbon in corn- stover cropping systems. *J. Agron.* 100(6): 1703-1710.

Bray, R. H. and Kurtz, L.T. 1945. Determining total, organic and available forms of phosphate in soils. *Soil Sci.* 59: 39-45.

Briedis, C., deMoraes, J. C., Caires, E. F., deFátima N. J., Inagaki, T. M., Boer, A., and Santos, J. B. 2012. Soil organic matter pools and carbon-protection mechanisms in aggregate classes influenced by surface liming in a no-till system. *Geoderma* 170: 80-88.

Brown, P. L. and Dickey, D. D. 1970. Losses of wheat straw residue under stimulated field condition. *Soil Sci. Soc. Am. J.* 34(1): 118-121.

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

Campbell, C. A., Bowern, K. E., Schnitzer, M., Zentner, R. P., and Townely-Smith, L. 1991. Effect of crop rotations and fertilization on soil organic matter and some biochemical properties of a thick black Chernozem. *Can. J. Soil Sci.* 71: 377–387.

Carreiro, M. M., Sinsabaugh, R. L., Repert, D. A., and Parkhurst, D. F. 2000. Microbial enzyme shifts explain litter decay responses to simulated nitrogen deposition. *Ecol.* 81: 2359– 2365.

Carrillo, Y., Ball, B. A., Bradford, M. A., Jordan, C. F., and Molina, M. 2011. Soil fauna alter the effects of litter composition on nitrogen cycling in a mineral soil. *Soil Biol. Biochem.* 43: 1440–1449.

Case, S. D. C., Mc Namara, N. P., Reay, D. S., and Whitaker, J. 2012. The effect of biochar addition on N_2O and CO_2 emissions from a sandy loam soil – the role of soil aeration. *Soil Biol. Biochem.* 51: 125-134.

Casida -Jr, L. E., Klein, D. A., and Santoro, T. 1964. Soil dehydrogenase activity. *Soil Sci.* 98(6): 371-376.

Cassman, K. G., De Datta, S. K., Olk, D. C., Alcantara, J. M., Samson, M. I., Descalsota, J. P., and Dixon, M. A. 1995. Yield decline and the nitrogen economy of long term experimentation on continuous irrigated rice systems in the tropics. In: Lal, R. and Stewart, E. (eds), S*oil Management Experimental Basis for Sustainability and Environmental Quality.* Lewis/CRC Press, Boca Raton, pp.181-222.

Chakraborty, D., Garg, R. N.,Tomar, R. K., Singh, R., Sharma, S. K., and Singh, R.K. 2010. Synthetic and organic mulching and nitrogen effect on winter wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agrl. Water Manag*. 97(5): 738-748.

Chan, K. Y. and Xu, Z. 2009. Biochar: Nutrient properties and their enrichment. In: Lehmann, J. and Joseph, S. (eds), *Biochar for Environmental Management, Science and technology.* Earthscan, London, pp. 67-84.

Chang, H. L., Park, C. Y., Park, K. D., Jeon, W. T., and Kim, P. J. 2004. Long-term effect of fertilization on the forms and availability of soil phosphorus in rice paddy. *Chemosphere.* 56: 299-304.

Chaphale, S. D., Chaphale, B. S., Yeerne, A. Z., and Laniewar, A. D. 2000. Effect of green manuring on soil properties and yield performance of rice. *J. Soil Crops* 10 (1): 136-140.

Chapin, F. S., Matson, P. A., and Mooney, H. A. 2002. Principles of Terrestrial Ecosystem Ecology. *Springer-Vorlag*, New York, USA. 245p.*

Chesnin, L. and Yien, C. H. 1951. Turbidimetric determination of available sulfates. *Soil Sci. Soc. Am. J.* 15: 149-151.

Choudhary, H. R., Sharma, O. P., Singh, R. K., Singh, K., Kumar, R., and Yadav, L. 2013. Influence of organic manures and chemical fertilizer on nutrient uptake, yield and profitability of mungbean [*Vigna radiata* (L.) Wilczek]. *Madras Agric. J.* 100 (1-3): 747-750.

Christensen, B. T. 1992. Physical fractionation of soil and organic matter in primary particle size and density separates, *Adv. Soil Sci.*5: 90-94.

Cornwell, W. K., Cornelissen, J. H. C., Amatangelo, K., Dorrepaal, E., Eviner, V. T., Godoy, O., Hobbie, S. H., Hoorens, B., Kurokawa, H., Perez-Harguindeguy, N., Quested, H. M., Klein, J. A., Read, J., Reich, P. B., Soudzilovskaia, N. A., Vaieretti, M. N., and Westoby, M. 2008. Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecol.* 11: 1065–1071.

Curtin, D. and Wen, G. 1999. Organic matter fractions contributing to soil nitrogen mineralization potential. *Soil Sci. Soc. Am. J.* 63(2): 410-415.

Curtin, D., Campbell, C. A., and Jalil, A. 1998. Effects of acidity on mineralization: pH dependence of organic matter mineralization in weakly acidic soils. *Soil Biol. Biochem.* 30: 57-64.

Datta, A. and Devi, L. S. 2001. Effect of organic and inorganic amendments on CO_2 evolution and rate of decomposition of coir dust. *J. Trop. Agric.* 39: 184-185.

Datta, A., Basak, N., Chaudhari, S. K., and Sharma, D. K. 2015. Soil properties and organic carbon distribution under different land uses in reclaimed sodic soils of North-West India. *Geoderma* 4:134-146.

Deshpande, H. and Devasenapathy, P. 2010. Influence of green manure and different organic sources of nutrients on yield and soil chemical properties of rice (*Oryza sativa* L.) grown under lowland condition. *Int. J. Agric. Sci.* 6(2): 433-438.

Dhull, S., Kapoor, K., and Mundra, M. 2010. Microbial biomass carbon and microbial activities of soils receiving chemical fertilizers and organic amendments. *Arch. Agron. Soil Sci.* 50 (6): 641-647.

Dinesh, R., Srinivasan, V., Hamza, S., and Manjusha, A. 2008. Influence of short term incorporation of organic manures and biofertilizers on biochemical and microbial characteristics of soils under an annual crop [Turmeric (*Curcuma longa* L.). *Biores. Tech.* 101(12): 4697-4702.

Ding, Y., Liu, Y., Wu, W., Shi, D., Yang, M., and Zhong, Z. 2010. Evaluation of biochar effects on nitrogen retention and leaching in multi-layered soil columns. *Water Air Soil Pollut.* 213: 47-55.

Dodds, W.K. and Martin, E. 2004. Carbon and nitrogen stoichiometry and nitrogen cycling rates in streams. *Oecologia* 140:458-467.

DOE [Department of Energy] 2008. Carbon cycling and biosequestration. In: *Biological and Environmental Research Workshop;* March 4-6 and 17-18, U.S. p.34.

Dong, D., Yang, M., Wang, C., Wang, H., Li, Y., Luo, J., and Wu, W. 2013. Responses of methane emissions and rice yield to applications of biochar and straw in a paddy field. *J. Soils Sediments* 13(8): 1450-1460.

Dong, W., Zhang, X., Wang, H., Dai, X., Sun, X., Qiu, W., and Yang, F. 2012. Effect of different fertilizer application on the soil fertility of paddy soils in red soil region of southern China. *Plos One* 10: 13-17.

Doran, J. W., Sarrantonio, M., and Liebig, M. 1996. Soil health and sustainability. In: Sparks, D. L. (ed.) *Adv. Agron*. San Diego, 56, pp.1-54.

Dubey, S. K. 2005. Microbial ecology of methane emission in rice agroecosystem: a review. *Appl. Ecol. Environ. Res.* 3:1–27.

Duraisami, V. P., Perumal, R., and Mani, A. K. 2001. Changes in organic carbon available nitrogen and inorganic N fractions under integrated nitrogen management of sorghum in a mixed black soil. *J. Indian Soc. Soil Sci.* 49(3): 435 - 439.

Durenkamp, M., Luo, Y., and Brookes, P. C. 2010. Impact of black carbon addition to soil on the determination of soil microbial biomass by fumigation extraction. *Soil Biol. Biochem.* 42**:** 2026-2029.

Eghball, B., Ginting, D., and Gilley, J. E. 2004. Residual effects of manure and compost applications on corn production and soil properties. *Agron. J.* 96: 442-447.

Elangovan, K. 1984. Potassium transformation under continuous cropping and fertilization. M.Sc. (Ag.) thesis, Tamil Nadu Agricultural University, Coimbatore, India.

Elliott, E. T., Paustian, K., and Frey, S. D. 1996. Modelling the measurable or measuring the modelable: A hierarchial approach to isolating meaningful soil organic matter fractions. In: D.S. Powlson (ed.) *Evaluation of Soil Organic Matter Models*, NATO ASI Series. Vol. 1-38. Springer-Verlag. Berlin Heildelberg, pp. 161-179.*

Fang, C. and Moncreiff, 2001. The dependence of soil CO_2 efflux on temperature. *Soil Biol. Biochem*. 33: 155-165.

Feller, C. and Beare, M. H. 1997. Physical control of soil organic matter dynamics in the tropics. *Geoderma* 79: 69–116.

Fontaine, S., Barot, S., Barre, P., Bdioui, N., Mary, B., and Rumpel, C. 2007. Stability of organic carbon in deep soil layers controlled by fresh carbon supply. *Nature* 450: 277–281. Available:http://dx.doi.org/10.1038/nature06275.

Franzluebbers, A. and Arshad, M. 1996. Water-stable aggregation and organic matter in four soils under conventional and zero tillage. *Can. J. Soil Sci.* 76: 387-393.

Freixo, A. A., Machado, P. L., and Santos, H. P. 2002. Soil organic carbon and fractions of a rhodic ferralsol under the influence of tillage and crop rotation systems in southern Brazil. *Soil Tillage Res.* 64: 221-230.

Fuentes, J. P., Bezdicek, D. F., Flury, M., Albrecht, S., and Smith, J. L. 2006. Microbial activity affected by lime in a long-term no-till soil. *Soil Tillage Res.* 88: 123–131.

Gaines, T. P. and Mitchell, G. A. 1979. Boron determination in plant tissue by the azomethine-H method. *Commn. Soil Sci. Plant Anal.* 10: 99-108.

Galdo, I. D., Six, J., Peressotti, A., and Cotrufo, M. F. 2003. Assessing the impact of land use change on soil C sequestration in agricultural soils by means of organic matter fractionation and stable C isotopes. *Glob. Change Biol.* 9: 1204-1213.

Ganeshamurthy, A. N. 2011. Soil carbon sequestration strategies through horticultural crops. In: Sreenivasarao, B., Venkateshwarlu, K. S., Kundu, S., and Singh, A. K. (eds), *Soil Carbon Sequestration for Climate Change Mitigation and Food Security*, CRIDA, Hyderabad, pp. 102-117.

Ge, T., Nie, S., Wu, J. and Hong, Y. 2011. Chemical properties, microbial biomass and activity differ between soils of organic and conventional horticultural systems under greenhouse and open field management: a case study. *J. Soils Sediments* 11(1): 25-36.

Ghosh, S., Jain, M. C., and Sinha, S. 1995. Estimates of global methane production from rice paddies based on substrate requirement. *Curr. Sci.* 69: 937–939.

Ghosh, S., Wilson, B., Ghoshal, S., Senapati, N., and Mandal, B. 2012. Organic amendments influence soil quality and carbon sequestration in the Indo-Gangetic plains of India. *Agric. Ecosyst. Environ.* 15:134-141.

Glaser, B., and Amelung, W. 2009. Pyrogenic carbon in native grassland soils along a climosequence in North America. *Glob. Biogeochem. Cycles* 17: 33-41.

Glaser, B., Balashov, E., Haumaier, L., Guggenberger, G., and Zech, W. 2000. Black carbon in density fractions of anthropogenic soils of the Brazilian Amazon region. *Org. Geochem.* 31(7-8): 669-678.

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

Govarts, B., Sayre, K. D. and Deckers, J. 2006. A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. *Soil Till. Res.* 87(2): 163-174.

Goyal, S., Mishra, M. M., Hooda, I. S., and Singh, R. 1992. Organic matter-microbial biomass relationships in field experiments under tropical conditions: effects of inorganic fertilization and organic amendments. *Soil Biol. Biochem.* 24(11): 1081–1084.

Goyal, S., Mishra, M. M., Shanker, S. S. and Chander, K. 1994. Relationship of soil microbial biomass and mineralisation of nitrogen following incorporation of organic materials to soil. *J. Indian Soc. Soil Sci.* 42: 474-476.

Goyal, S., Mundra, M. C., Chander, K., and Kapoor, K. K. 1999. Influence of inorganic fertilizers and organic amendments on soil organic matter and soil microbial properties under tropical conditions. *Biol. Fert. Soils* 29(2): 196-200.

Goyal, S., Sakamoto, K., and Inubushi, K. 2006. Long term effects of inorganic fertilization and organic amendments on soil organic matter and soil microbial properties in Andisols. *Arch. Agron. Soil Sci.* 52(6): 617-625.

Grechi, I., Vivin, P., Hilbert, G., Milin, S., Robert, T., and Gaudille, J. P. 2007. Effect of light and nitrogen supply on internal C:N balance and control of root to-shoot biomass allocation in grapevine. *Env. Exp. Bot.* 59: 139–149.

Gregorich, E. G., Drury, C. F., and Baldock, J. A. 2001. Changes in soil carbon under long-term maize in monoculture and legume-based rotation. *Can. J. Soil. Sci.* 81: 21–31.

Guo, J. and Chen, B. 2014. Insights on the molecular mechanism for the recalcitrance of biochars: interactive effects of carbon and silicon components. *Environ. Sci. Technol.* 48: 91039-91142.

Gupta, R. K. and Rao, D. L. 1994. Potential of waste lands for sequestering carbon by reforestation. *Curr. Sci.* 66: 370- 378.

Gupta, U.C. 1979. Boron nutrition of crops. *Adv. Agron.* 31: 273-307.

Gusewell, S. and Gessner, M. O. 2009. N:P ratios influence litter decomposition and colonization by fungi and bacteria in microcosms. *Funct. Ecol.* 23: 211-219.

Haefele, S. M. 2007. Black soil green rice. *Rice Today* 5: 26-27.

Hamilton, S. K., Kurzman, A. L., Arango, C., Jin, L., and Robertson, G. P. 2007. Evidence for carbon sequestration by agricultural liming. *Glob. Biogeochem. Cyc.* 2: 2121-2028.

Hanson, P. J., Edwards, N. T., Garten, C. T., and Andrews, J. A. 2000. Separating root and soil microbial contributions to soil respiration: a review of methods and observations. *Biogiochem.* 48: 115-146.

Hassink, J. 1995. Density fractions of soil macroorganic matter and microbial biomass as predictors of C and N mineralization. *Soil Biol. Biochem.* 27: 1099-1108.

300

Hassink, J. 1997. The capacity of soils to preserve organic C and N by their association with clay and silt particles. *Plant Soil* 191: 77-87.

Hattenschwiler, S. and Jorgensen, H. B. 2010. Carbon quality rather than stoichiometry controls litter decomposition in a tropical rain forest. *J. Ecol.* 98: 754-763.

Haynes, R. J. 2005. Labile organic matter fractions as central components of the quality of agricultural soils: an overview. *Adv. Agron.* 85: 221–268.

Haynes, R. J. and Mokolobate, M. S. 2001. Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues: a critical review of the phenomenon and the mechanisms involved. *Nutr. Cycl. Agroecosyst.* 59: 47-63.

Hayness, R. J. 1990. Active ion uptake and maintenance of cation–anion balance: a critical examination of their role in regulating rhizosphere pH. *Plant Soil* 126: 247–264.

Hemalatha, M., Thirumugan, V., and Balasubramanian, R. 2000. Effect of organic sources of nitrogen on productivity and quality of rice (*Oryza sativa*) and soil fertility. *Indian J. Agron.* 45 (3): 564-567.

Hutchinson, G. L. and Mosier, A. R. 1981. Improved soil cover method for field measurement of nitrous oxide fluxes. *Soil Sci. Soc. Am. J.* 45(2): 311- 316.

IPCC [Intergovernmental Panel on Climate Change] 2000. In: Watson, R. T., Noble, I. R., Bolin, Ravindranath, N. H., Verardo, D. J., and Dokken, D. J. (eds), *IPCC Special Report on Land Use, Land Use Change, and Forestry.* Cambridge, UK and New York, pp. 200-235.

IPCC WGI 2001. Climate change: the scientific basis. Cambridge university press, Cambridge, UK, 1032p.*

301

Jackson, M. L. 1958. *Soil Chemical Analysis* (Indian Reprint, 1967). Prentice-Hall, Englewood Cliffs, 498p.

Jama, B.A. and Nair, P.K.R. 1996. Decomposition and nitrogen mineralization patterns of *Leucaena leucocephala* and *Cassia siamea* mulch under tropical semiarid conditions in Kenya. *Plant Soil*. 179: 275-285.

Janzen, H. H., Campbell, C. A., Brandt, S. A., Lafond, G. P., and Townley-Smith, L.1992. Light-fraction organic matter in soils from long-term crop rotations. *Soil Sci. Soc. Am. J.* 56: 1799-1806.

Jarecki, M. K. and Lal, R. 2003. Crop management for Soil Carbon Sequestration. *Critical Rev. Plant Sci*. 22: 471-502.

Jeffrey, M. N., Busscher, W. J., Laird, D. L., Ahmedna, M., Watts, D. W., and Niandou, M. A. S. 2009. Impact of biochar amendment on fertility of a south eastern coastal plain soil. *Soil Sci.* 174: 105-112.

Jenkinson, D. S. 1988. Microbial biomass in soil-measurement and turnover. *Soil Biochem.* 6: 415-471.

Jenkinson, D. S. 1990. The turnover of organic carbon and nitrogen in soil. *Phil. Trans. R. Soc. Series B.* 329: 361–368.*

Jenkinson, D. S. and Ayanaba, A. 1977. Decomposition of plant material in soil-IV: the effect of rate and addition. *J. Soil Sci.* 28: 417-423.

Jenkinson, D. S. and Powlson, D. S. 1976. The effects of biocidal treatments on metabolism in soil—V: a method for measuring soil biomass. *Soil Boil. Biochem.* 8(3): 209-213.

Jien, S. H. and Wang, C. S. 2013. Effect of biochar on soil properties and erosion potential in a highly weathered soil. *Catena* 110: 225-233.

Jobbagy, E. G. and Jackson, R.B. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecol. Appl.* 10: 423–436.

John, B., Yamashita, T., Ludwig, B., and Flessa, H. 2005. Storage of organic carbon in aggregate and density fractions of silty soils under different types of land use. *Geoderma* 128: 63- 79.

Joseph, S. 2010. Studies on water management of aerobic rice cultivation under different irrigation methods. Ph. D thesis, Tamil Nadu Agricultural University, Coimbatore, pp. 168-172.

Kaiyong, W., Hua, F., Ranab, T., Hanjrac, M. A., Bo. D., Huan, L., and Fenghua, Z. 2011. Changes in soil carbon and nitrogen under long-term cotton plantations in China. *J. Agric. Sci.* 149-505.

Kaleemulla, S. 1984. Effect of long term application of manures and fertilizers on soil fertility and yield of finger millet in Alfisols of Bangalore. M.Sc. (Ag.) Thesis, University of Agricultural Sciences, Bangalore, 65p.

Karlen, D. L., Eash, N. S., and Unger, P. W. 1992. Soil and crop management effects on soil quality indicators. *Am. J. Altern. Agr.* 7(1–2): 48–55.

Karlen, D. L., Mausbach, M. J., Doran, J. W., and Cline, R. G. 1997. Soil quality: a concept, definition, and framework for evaluation. *Soil Sci. Soc. Am. J.* 61: 4-10.

Katkar, R. N., Sonune, B. A., and Kadu, P. R., 2011. Long-term effect of fertilization on soil chemical and biological characteristics and productivity under sorghum (*Sorghum bicolor*)-wheat (*Triticum aestivum*) system in Vertisol. *Indian J. Agric. Sci.* 81(8): 734.

KAU, 2011. *Package of Practices Recommendations*. Directorate of Extension, Kerala Agricultural University, Thrissur, 140p.

Kaur, T., Brar, B. S., and Dhillon, N. S. 2008. Soil organic matter dynamics as affected by long-term use of organic and inorganic fertilizers under maize–wheat cropping system. *Nutr. Cycl. Agroecosyst.* 23: 234-240.

Keiluweit, M. and Kleber, M. 2009. Molecular-level interactions in soils and sediments: the role of aromatic p-systems. *Environ. Sci. Tech.* 43: 3421-3429.

Kell, D. B. 2012. Large scale sequestration of atmospheric carbon via plant roots in natural and agricultural ecosystems: why and how. *Phil. Trans. R. Soc. B.* 367: 1589-1597. doi:10.1098/rstb.2011.0244.

Keogel-Knabner, I., Guggenberger, G., Kleber, M., Kandeler, E., Kalbitz, K., Scheu, S., Eusterhues, K., and Leinweber, P. 2008. Organo-mineral associations in temperate soils: integrating biology, mineralogy, and organic matter chemistry. *J. Plant Nutr. Soil Sci.* 171: 61-82.

Khosa, M. K., Sidhu, B. S., and Benbi, D. K. 2012. Effect of organic materials and rice cultivars on methane emission from rice field. *J. Environ. Biol.* 31: 281–285.

Khursheed, S., Arora, S., and Ali, T. 2013. Effect of organic sources of nitrogen on rice (*Oryza sativa*) and soil carbon pools in Inceptisols of Jammu. *Int. J. Environ. Pollut. Solut.* 1: 17-21.

Kobak, K. I., Kondrasheva, N. Y., and Turchinovich, E. 1998. Changes in carbon pools of peatland and forests in northwestern Russia during the Holocene. *Global Planetary Change.* 16: 75-84.*

Kuhlbusch, T. A. J. 1998. Black carbon in soils, sediments, and ice cores. In: Meyers, R. A. (ed.) *Encyclopedia of Environmental Analysis and Remediation.* New York, Wiley, pp.3424-3456.

Kuhlbusch, T., Andreae, M., Cachier, H., Goldammer, J., Lacaux, J. P., Shea, R., and Crutzen, R. 1996. Black carbon formation by savanna fires: measurements and implications for the global carbon cycle, *J. Geophy. Res.* 101: 23651-23665.

Kukal, S. S., Rasool, R., and Benbi, D. K. 2009. Soil organic carbon sequestration in relation to organic and inorganic fertilization in rice-wheat and maize-wheat systems. *Soil. Tillage Res.* 102: 87-92.

Kumar, M., Baishaya, L. K., Ghosh, D. C., and Gupta, V. K. 2012. Productivity and soil health of potato (*Solanum tuberosum* L.) field as influenced by organic manures, inorganic fertilizers and biofertilizers under high altitudes of eastern Himalayas. *J. Agric. Sci.* 4(5): 223-224.

Kumar, S. D. and Singh, H. J. 1997. Comparative studies on organic fertilizers and chemical fertilizers with tall scented rice in rice-wheat sequence. *Haryana Agric. Univ. J. Res.* 29 (1-2): 7-10.

Kumar, V. and Prasad, R. K. 2008. Integrated effect of mineral fertilizer and green manure on crop yield and nutrient availability under rice-wheat cropping system in calciotthents. *J. Indian Soc. Soil Sci.* 56: 209-214.

Kurumthottical, S. T. 1982. Dynamics and residual effects of permanent manorial experiment on rice. M.Sc. (Ag.) thesis. KAU, Vellanikkara, Trichur.

Ladha, J. K., Reddy, C. K., Padre, A. T., and Kessel, C. 2011. Role of nitrogen fertilization in sustaining organic matter in cultivated soils. *J. Environ. Qual.* 40(6): 1756–1766.

Lal, R. 1977. Soil management systems and erosion controls. In: Greenland, D. J. and Lal, R. (eds), *Soil Conservation and Management in the Humid Tropics*, John Wiley and sons publishers, U. K. pp. 93-98.

Lal, R. 2000. World crop land soils as a source or sink of atmospheric carbon. *Adv. Agron.* 71: 145- 191.

Lal, R. 2003. Global potential of soil carbon sequestration to mitigate the greenhouse effect. *Crit. Rev. Plant Sci.* 22: 151-184.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. *Geoderma* 123(1): 1-22.

Lal, R., Follett, R. F., and Kimble, J. M. 2003. Achieving soil carbon sequestration in the United States: a challenge to the policy makers. *Soil Sci.* 168: 827-845.

Lal, R., Hassan, H. M., and Dumanski, J. 1999. Desertification control to sequester C and mitigate the greenhouse effect. In: Rosenberg, N., Izaurrald, R. C., and Malone, E. L. (eds), *Carbon Sequestration in Soils: Science, Monitoring and Beyond*. Battelle Press, Columbus, USA, pp. 83 – 149.

Lal, R., Kimble, J. M., Follett, R. E., and Cole, C. V. 1998. The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Sleeping Bear Press, Chelsea, MI, 128p.

Lee, M., Nakane, K., Nakatsubo, T., Mo, W., and Koisumi, H. 2002. Effects of rainfall events on soil CO_2 flux in a cool temperate deciduous broad leaved forest. *Ecol. Res.* 17(3): 401-409.

Lehmann, J. and Rondon, M. 2005. Bio-char soil management on highly-weathered soils in the humid tropics: Biological approaches to sustainable soil systems. Boca Raton, CRC Press, 789p.

Lehmann, J., Cheng, C. H., Nguyen, B., Liang, B., Major, J., and Smernik, R. 2007. Permanency and long term changes of bio-char in soil.In: *International Agriculture Initiative (IAI) Conference*, Terrigal Aus. pp. 23.

Lehmann, J., Da Silva, J., Steiner, C., Nehls, T., Zech, W., and Glaser, B. 2003. Nutrient availability and leaching in an archaeological anthrosol and a ferralsol of the central Amazon basin: Fertilizer, manure and charcoal amendments. *Plant Soil* 249: 343- 357.

306

Lehmann, J., Gaunt, J., and Rondon, M. 2006. Bio-char sequestration in terrestrial ecosystems - A review. *Mitig. Adapt. Strat. Glob. Change* 11: 403–427.

Lehmann, J., Liang, B., and Solomon, D. 2005. Near-edge X-ray absorption fine structure (NEXAFS) spectroscopy for mapping nano-scale distribution of organic carbon forms in soil: Application to black carbon particles. *Glob. Biogeo. Cyc.* 19:1013.

Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., and Crowley, D. 2011. Biochar effects on soil biota–a review. *Soil Biol. Biochem.* 43(9): 1812-1836.

Leitner, S., Wanek, W., Wild, B., Haemmerle, I., Kohl, L., Keiblinger, K. M., Zechmeister-Boltenstern, S., and Richter, A. 2012. Influence of litter chemistry and stoichiometry on glucan depolymerisation during decomposition of beech (*Fagus sylvatica* L.) litter. *Soil Biol. Biochem.* 50: 174-187.

Lin, J., Yu, L., Zhu, G. Q., and Tong, L.Y. 2008. Estimate of carbon sequestration under cropland management in China- The key laboratory for agro environment and sustainable development. *Chin. Acad. Agric. Sci.* 34:134-140.

Linquist, B. A., Borbe, M. A., Pittelkow, C. M., Kessel, C. V., Groenigen, K. J. V. 2012. Fertilizermanagement practices and greenhouse gas emissions from rice systems: A quantitative review and analysis. *Field Crops Res.* 135: 10-21.

Liu, X. B., Han, X. Z., Herbert, S. J., and Xing, B. 2003. Soil organic matter and water-stable aggregates under different tillage and residue conditions in a tropical dry land agro – ecosystem. *Appl. Soil Ecol.* 16: 229-241.

Logah, V., Ewusi-Mensah, N., and Tetteh, F. K. M. 2011. Soil organic carbon and crop yield under different soil amendments and cropping systems in the semi-deciduous forest zone of Ghana. *J. Plant Sci.* 6(4): 165-173.

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Lu, F., Wang, X. K., Han, B., Ouyang, Z. Y., and Zhen, H. 2009. Soil carbon sequestrations by nitrogen fertilizer application, straw return and no-tillage in China's cropland. *Glob. Change Biol.* 15: 281-305. Available:http://dx.doi.org/10.1111/j.1365-486.2008.01743.

Lu, F., Wang, X., Han, B., and Duan, X. 2008. Assessment on the availability of nitrogen fertilization in improving carbon sequestration potential of China's cropland soil. *J. Appl. Ecol.* 19(10): 2239- 2250.

Luo, Y., Durenkamp, M., De Nobili, M., Lin, Q., and Brookes, P. C. 2011. Short term soil priming effects and mineralization of biochar following its incorporation to soils of different pH. *Soil Biol. Biochem*. 43: 2304-2314.

Luo, Z., Wang, E., and Sun, O. J. 2010. Can no-tillage stimulate carbon sequestration in agricultural soils: a meta-analysis of paired experiments. *Agric. Ecosyst. Environ.* 139 (1-2): 224–231

Lupwayi, N. Z., Lea, T., and Beaudoin, J. L. 2005. Soil microbial biomass, functional diversity and crop yields following application of cattle manure, hog manure and inorganic fertilizers. *Can. J. Soil Sci.* 85(2): 193-201.

Mairan, N. R., Patil, S. G., and Kachhave, K. G. 2005. Physico-chemical properties under sorghum-sunflower cropping sequence in Vertisols. *J. Soils Crops* 15(2): 352-355.

Majumder, B., Mandal, B., Bandyopadhyay, P. K., Gangopadhyay[a], A., Mani, P. K., Kundu, A. L. and Mazumdar, D. 2008. Organic amendments influence soil organic carbon pools and rice–wheat productivity. *Soil Sci. Soc. Am. J.* 72(3): 775-785.

Malhi, S. S., Moulin, A. P., Johnston, A. M., and Kutcher, H. R. 2008. Short-term and long-term effects of tillage and crop rotation on soil physical properties,

308

organic C and N in a black Chernozem in northeastern Saskatchewan. *Can. J. Soil Sci.* 88: 273- 282.

Mandal, B., Majumder, B., Adhya, T. K., Bandyopadhyay, P. K., Gangopadhyay, A., Sarkar, D., Kundu, M. C., Choudhury, S. G., Hazra, G. C., Kundu, S., and Samantaray, R. N. 2008a. Potential of double-cropped rice ecology to conserve organic carbon under subtropical climate. *Glob. Change Biol.* 14(9): 2139-2151.

Mandal, B., Majumder, B., Bandyopadhyay, P. K., Hazra, G. C., Gangopadhyaya, A., Samantaray, R. N., Misra, A. K., Chaudhury, J., Saha, M. N., and Kundu, S. 2008b. Potential of cropping systems and soil amendments for carbon sequestration in soils under long –term experiments in subtropical India. *Glob. Change Biol.* 3: 357-369.

Manickam, T. S. and Venkitaramanan, C. R. 1972. Effect of continuous application of manures and fertilizers on some of the physical properties of soil under irrigated conditions. *Madras Agric. J.* 59: 508- 512.

Manna, M. C., Swarup, A., Wanjari, R. H., Ravankar, H. N., Mishra, B., Saha, M. N., Singh, Y. V., Sahi, D. K., and Sarap, P. A. 2005. Long-term effect of fertilizer and manure application on soil organic carbon storage, soil quality and yield sustainability under sub-humid and semi-arid tropical India. *Field Crops Res.* 93(2): 264-280.

Mansour, H. A. 2002. Influence of soil amendments and NPK fertilization on the growth and chemical composition of *Senna sulfurea* plants grown in a sandy soil. *Ann. Agric. Sci.* 40(3): 1779-1796.

Manzoni, S., Trofymow, J. A., Jackson, R. B., and Porporato, A. 2010. Stoichiometric controls on carbon, nitrogen and phosphorus dynamics in decomposing litter. *Ecol. Monographs* 80(1): 89-106.

Marek, K. J. and Lal, R. 2003. Crop management for soil carbon sequestration: critical reviews. *Plant Sci.* 22:471–502.

Marumoto, T. 1984. Mineralization of C and N from microbial biomass in paddy soil. *Plant Soil* 76: 165-173.

Mathew, R. 2003. Methane emission from wetland rice fields of Kerala. Ph. D thesis, Kerala Agricultural University, Thrissur, 132p.

Mayer, L. M. and Xing, B. 2001. Organic matter-surface area relationships in acid soils. *Soil Sci. Soc. Am. J.* 65: 250-258.

Mazumder, B. and Kuzyakov, Y. 2010. Effect of fertilization on decomposition of ^{14}C labelled plant residues and their incorporation into aggregates. *Soil Tillage Res.* 109: 94-102.

Mendhe, S. N., Chaudhari, C. S., Sawaji, B. V., Farkade, B. K., and Khadse, V. A. 2002. Nitrogen requirement and yield performance of promising cultures of transplanted paddy. *J. Crop Soils* 22 (2): 284-288.

Moore, J. D., Quimet, R., and Duchesne, L. 2012. Soil and sugar maple response 15 years after dolomitic lime application. *For. Ecol. Manag.* 281: 130-139.

Nakhro, N. and Dkhar, M. S. 2010. Impact of organic and inorganic fertilizers on microbial populations and biomass carbon in paddy field soil. *J. Agron.* 9 (3): 102-110.

Nannipieri, P., Grego, S., and Ceccanti, B. 1990. Ecological significance of the biological activity in soil. In: Bollag, J. M. and Stotzky, G. (eds), *Soil Biochemistry.* Marcel Dekker, New York. pp. 293-355.

Needelman, B. A., Wander, M. M., Bollero, G. A., Boast, C. W., Sims, G. K., and Bullock, D. G. 1999. Interaction of tillage and soil texture: biologically active soil organic matter in Illinois. *Soil Sci. Soc. Am. J.* 63: 1326–1334.

Neff, J. C., Townsend, A. R., Gleixner, G., and Lehman, S. J. 2002. Variable effects of nitrogen additions on the stability and turnover of soil carbon. *Nature* 41(6): 910-915.

Nguyen, B., Lehmann, J., Kinyangi, J., Smernik, R., Riha, S. J., and Engelhard, M. H. 2008. Long-term black carbon dynamics in cultivated soil. *Biogeochem.* 89: 295-308.

Nigussie, A., Kissi, E., Misganaw, M., and Ambaw, G. 2012. Effect of biochar application on soil properties and nutrient uptake of lettuces *(Lactuca sativa)* grown in chromium polluted soils. *Am. Eur. J. Agric. Environ. Sci.* 3: 369-376.

Novak, J. M., Busscher, W. J., Watts, D. W., Laird, D. A., Ahmedna, M. A., and Niandou, M. A. 2010. Short-term CO_2 mineralization after additions of biochar and switchgrass to a Typic Kandiudult. *Geoderma* 154(3-4): 281-288.

Nungkat, P., Kusuma, Z., and Handayanto, E. 2015. Effects of organic matter application on methane emission from paddy fields adopting organic farming system. *J. Degraded Mining Lands Manage.* 2(2): 303-312.

Nye, P. H. 1981. Changes in pH across the rhizosphere induced by roots. *Plant Soil* 61: 7–26.

OECD [Organization for Economic Co-operation and Development] Executive Summary. 2000. Environmental indicators for agriculture methods and results, Paris, 57p.

Pampolino, M. F., Laureles, E. V., Gines, H. C., and Buresh, R. J. 2008. Soil carbon and nitrogen changes in long-term continuous lowland rice cropping. *Soil Sci. Soc. Am. J.* 72: 798–807.

Paneerselvam, A., Lourduraj, A. C., and Balasubramanian, N. 2000. Soil available phosphorus and its uptake by soybean (*Glycine max* L.) as influenced by organic manures, inorganic fertilizers and weed management practices. *Indian J. Agric. Res.* 34(1): 9-16.

Parfitt, P. R., Theng, B. K. G., Whitton, J. S., and Shepherd, T. G. 1997. Effects of clay minerals and land use on organic matter pools. *Geoderma* 75: 1–12.

Parton, W. J., Schimel, D. S., Cole, C. V., and Ojima, D. S. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grassland. *Soil Sci. Soc. Am. J.* 51: 1173-1179.

Pascual, J. A., Garcí, A. C., and Hernández, T. 2002. Comparison of fresh and composted organic waste in their efficacy for the improvement of arid soil quality. *Biores. Technol.* 68(3): 255–265.

Pascual, J. A., Moreno, J. L., Hernandez, T., and Garcia, C. 2002. Persistence of immobilised and total urease and phosphatase activities in a soil amended with organic wastes. *Biores. Technol.* 82(1): 73-78.

Pathak, H., Byjesh, K., Chakrabarti, B., and Aggarwal, P. K. 2011. Potential and cost of carbon sequestration in Indian agriculture: Estimates from long-term field experiments. *Field Crops Res.* 120(1): 102-111.

Paustian, K., Collins, H. P., and Paul, E. A. 1997. Management controls on soil carbon. In: Paul, E. A., Paustian, K. A., Elliott, E. T., Cole, C. V. (eds), *Soil Organic Matter in Temperate Agroecosystems: Long-term Experiments in North America*. CRC Press, New York, pp. 15-49.

Pietikäinen, J., Kiikkilä, O., and Fritze, H. 2000. Charcoal as a habitat for microbes and its effects on the microbial community of the underlying humus. *Oikos.* 89: 231-242.

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

Post, W. M. and Kwon, K. C. 2000. Soil carbon sequestration and land-use change: processes and potential. *Glob. Change Biol.* 6: 317–327.

Prabha, S. V., Renuka, R., Sreekanth, N. P., Padmakumar, B., Thomas, A. P. 2013. A study of the fertility and carbon sequestration potential of rice soil with respect to the application of biochar and selected amendments. *Annals Environ. Sci.* 7: 17-30.

Pramanik, M., Das, A. K., Jana, P. K., and Dwary, A. 2004. Vermicompost- a potential source of organic plant nutrients for production sustainability in rice-rapeseed-green gram cropping sequence in lower Gangetic plains of eastern India. In: Proceedings of *"3rd RDA/ARNOA International Conference on Development of Basic Standard for Organic Rice Cultivation"*. 8-10 September, Yangpyung, Korea. pp 24-26.

Qian, L. and Chen, B. 2014. Interactions of aluminum with biochars and oxidized biochars: implications for the biochar aging process. *J. Agric. Food Chem.* 62: 373-380.

Raison, R. J. 1979. Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformation: A review. *Plant Soil* 51: 73-108.

Ram, S. and Saha, S. 1999. Economics of conjunctive use of organics and chemical fertilizer in rice crop grown under shallow lowland situation. *Oryza* 36(3): 286-287.

Rawls, W. J., Pachepsky, Y. A., Ritchie, J. C., Sobecki, T. M., and Bloodworth, H. 2003. Effect of soil organic carbon on soil water retention. *Geoderma* 116(1–2): 61–76.

Reeves, D.W. 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil Tillage Res.* 43: 131-167.

Reichardt, W., Mascarina, G., Padre, B., and Doll, J. 1997. Microbial communities of continuously cropped irrigated rice fields. *Appl. Environ. Microbiol.* 63: 233-238.

Rodríguez, L., Salazar, P., and Preston, T. R. 2009. Effect of biochar and biodigester effluent on growth of maize in acid soils. *Livest. Res. Rural Dev.* 21: 102-110.

Rudrappa, L., Purakayastha, T. J., Singh, D., and Bhadraray, S. 2006. Long-term manuring and fertilization effects on soil organic carbon pools in a typic Haplustept of semi-arid sub-tropical India. *Soil Tillage Res*. 88:180–192.

Saha, S., Prakash, V., Kundu, S., Kumar, N., and Mina, B. L. 2008. Soil enzymatic activity as affected by long term application of farm yard manure and mineral fertilizer under a rainfed soybean-wheat system in N-W Himalaya. *Eur. J. Soil Biol*. 44: 309-315.

Salazar, S., Sánchez, L. E., Alvarez, J., Valverde, A., Galindo, P., Igual, J. M., Peix, A., and Regina, I. 2011. Correlation among soil enzyme activities under different forest system management practices. *Ecol. Eng.* 37(8): 1123-1131.

Sampanpanish, P. 2012. Effect of organic fertilizer use in rice to reduce greenhouse gases. *Int. Conf. Environ. Agric. Eng*. 37: 79–85.

Sanderman, J., Farquharson, R., and Baldock, J. 2010. Soil carbon sequestration potential: A review for Australian agriculture. Department of climate change and energy efficiency. *CSIRO Natl. Res. Flagships* 51(8): 771-780.

Sardans, J., Rivas-Ubach, A., and Penuelas, J. 2012. The elemental stoichiometry of aquatic and terrestrial ecosystems and its relationships with organismic lifestyle and ecosystem structure and function: a review and perspectives. *Biogeochem.* 111: 1–39.

Sarma, B., Borkotoki, B., Gogoi, N., and Kataki, R. 2017. Responses of soil enzymes and carbon mineralization to applied organic amendments: a short-term study in acidic sandy loam soil. *J. Indian Soc. Soil Sci.* 65(3): 283-289.

Schimel, J.P. and Weintraub, M.N. 2003. The implications of exoenzyme activity on microbial carbon and nitrogen limitation in soil: a theoretical model. *Soil Biol. Biochem.* 35: 549-563.

Schipper, L. A., Baisden, W. T., Parfitt, R. L., Ross, C., Claydon, J. J., and Arnold, G. 2007. Large losses of soil C and N from soil profiles under pasture in New Zealand during the past 20 years. *Glob. Change Biol.* 13: 1138–1144.

Schulze, D. G., Nagel, J. L., Van Scoyoc, G. E., Henderson, T. L., Baumgardner, M. F., and Stott, D. E., 1993. Significance of organic matter in determining soil colors. In: *Soil Color.* SSSA, pp. 71-90.

Selvaraj, N., Ramaraj, B., Devrajan, K., Sreenivasan, N., Senthil Kumar, S., and Sakthi, E. 2003. Effect of organic farming on growth and yield of thyme. In: *National Seminar on Production and Utilisation of Medicinal Plants.* Annamalai University, Tamilnadu. pp 13-14.

Selvi, D. and Selvaseelan, D. A. 2003. Effect of mushroom spent rice straw compost on nutrient availability in laterite soil of Nilgiris during potato crop growth. *Int. J. Trop. Agric.* 21(1-4): 99-107.

Shalini, S., Kumar, S., and Jain, M. C. 1997. Methane emission from two Indian soils planted with different rice cultivars. *Biol. Fert. Soils* 25(3): 285-289.

Sharma, M. L. and Uehara, G. 1986. Influence of soil structure in soil water relations in low humic latosols. *Soil Sci. Soc. Am. Proc.* 32: 765-768.

Sharma, M. P. Bali, S. V., and Gupta, D. K. 2000. Crop yield and properties of inceptisol as influenced by residue management under rice - wheat cropping sequence. *J. Indian Soc. Soil Sci.* 48: 506 -509.

Shenbagavalli, S. and Mahimairaja, S. 2012. Characterization and effect of biochar on nitrogen and carbon dynamics in soil. *Int. J. Adv. Res.* 2: 249-255.

Sheoran, O. P., Tonk, D. S., Kaushik, L. S. Hasija, R. C., and Pannu, R. S. 1998. *Statistical Software Package for Agricultural Research Workers.* Recent advances in information theory, statistics and computer applications, Department of Mathematics Statistics, CCS HAU, Hisar, 139-143.

Shibahara, F. and Inubushi, K. 1997. Effect of organic matter application on microbial biomass and available nutrients in various types of paddy soils. *Soil Sci. Plant Nutr.* 43: 681-689.

Shield, J. A. and Paul, E. A. 1973. Decomposition of ^{14}C labelled plant material under field conditions. *Can. J. Soil Sci.* 53: 297-306.

Shirani, H., Hajabbasi, M. A., Afuni, M., and Hemmat, A. 2002. Effects of farmyard manure and tillage systems on soil physical properties and corn yield in central Iran. *Soil Tillage Res.* 68: 101-08.

Sims, J. R. and Johnson, G.V. 1991. Micronutrient soil tests. In: Mortvedt, J. J., Cox, F.R., Shuman, L. M., and Welch, R. M. *Micronutrient in Agriculture* (2nd Ed.), SSSA, Madison, USA, pp.427-476.

Singh, B. and Sharma, K. N. 2012. Depth wise distribution of soil organic carbon and nutrients under some tree species after seventeen years of plantation. *J. Indian. Soc. Soil Sci.* 60(3): 198-203.

Singh, N. P., Sachan, R. S., Pandey, P. C., and Bisht, P. S. 1999. Effect of a decade long fertilizer and manure application on soil fertility and productivity of rice-wheat system in a Mollisol. *J. Indian Soc. Soil Sci.* 47(1): 72-80.

Singh, P. B., Hatton, J. B., Singh, B., Cowie, L. A., and Kathuria, A. 2010. Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils. *J. Environ. Qual.* 39: 1224-1235.

Singh, R., Singh, S., and Prasad, K. 2001. Effect of fertilizer, FYM and row spacing on transplanted rice. *Crop Res.* 22 (2): 296-299.

Smolander, A., Kurka, A., Kitunen, V., and Malkonen, E. 1994. Microbial biomass C and N, and respiratory activity in soil of repeatedly limed and N- and P-fertilized Norway spruce stands. *Soil Biol. Biochem.* 26:957–962.

Sophi, J. A., Rattan, R. K., and Datta, S. P. 2012. Soil organic carbon pools in the apple orchards of Shopian district of Jammu and Kashmir. *J. Indian Soc. Soil Sci.* 60(3): 187-197.

Sridevi, S., Katyal, J. C., Srinivas, K., and Sharma, K. L. 2003. Carbon mineralisation and microbial biomass dynamics in soil amended with plant residues and residue fractions. *J. Indian Soc. Soil Sci.* 51 (2): 133-139.

Srinivasarao, C., Deshpande, A. N., Venkateswarlu, B., Lal, R., Singh, A. K., Kundu, S., Vittal K. P. R., Mishra, P. K., Prasad, J. V. N. S., Mandal, U. K., and Sharma, K. L. 2012. Grain yield and carbon sequestration potential of post monsoon sorghum cultivation in Vertisols in the semi arid tropics of central India. *Geoderma* 175-176: 90–97.

Srinivasarao, C., Lal, R., Kundu, S., Babu, M. P., Venkateswarlu, B., and Singh, A. K. 2014. Soil carbon sequestration in rainfed production systems in the semiarid tropics of India. *Sci. Total Environ.* 487: 587-603.

Srinivasarao, C., Venkateswarlu, B., Sreenathdixit, S., Kundu, S., and Gayatridevi, K. 2011. Livelihood impacts of soil health improvement in backward and tribal districts of Andhra Pradesh. Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh, India, 192p.

Stark, C., Condron, L. M., Stewart, A., Di, H. J., and O'Callaghan, M. 2007. Influence of organic and mineral amendments on microbial soil properties and processes. *Appl. Soil Ecol.* 35(1): 79–93.

Steenwerth, K. and Belina, K. M. 2008. Cover crops enhance soil organic matter, Carbon dynamics and microboligical function in a vineyard agrosystem. *Appl. Soil Ecol.* 40: 359-369.

Stevenson, F. J. 1986. *Carbon balance of the soil and role of organic matter in soil fertility.* Wiley, New York, pp. 45-77.

Stevenson, F. J. and Cole, M. A. 1999. Cycles of soil carbon, nitrogen, phosphorus, sulphur, micronutrients. USA, John Wiley and Sons, 68p.

Stewart, C. E., Paustian, K., Conant, R. T., Plante, A. F., and Six, J. 2008. Soil carbon saturation, evaluation and corroboration by long-term incubations. *Soil Biol. Biochem.* 40: 1741- 1750.

Subbiah, B. and Asija, G. 1956. A rapid procedure for the determination of available nitrogen in soils. *Curr. Sci.* 25: 259-260.

Sudha, B. and George, A. 2011. Tillage and residue management for organic carbon sequestration in coconut (*Cococs nucifera*) based cropping systems. *Indian J. Agron.* 56(3): 223-227.

Sulaiman, S. 2017. Sequestration of carbon as influenced by nutrient management practices under long term fertilizer experiments. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 148p.

Sundermeier, A., Reeder, R., and Lal, R. 2005. Soil carbon sequestration fundamentals. Ohio State University Extension Fact Sheet, CDFS. pp. 186-96.

Swarup, A. 1998. Emerging soil fertility management issues for sustainable crop productivity in irrigated systems. In: Swarup, A., Reddy, D.D., and Prakash, R.N. (eds), *Long Term Soil Fertility Management through Integrated Plan Nutrient Supply.* Proceedings of workshop, Indian Institute of Soil Science, Bhopal, India, pp.54-68.

Tabatabai, M. A. and Bremner, J. M. 1989. Use of *p*- nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biol. Biochem.* 1 (4): 301-307.

Tadesse, T., Dechassa, N., Bayu, W., and Gebeyehu, S. 2013. Effects of farmyard manure and inorganic fertilizer application on soil physico-chemical properties and nutrient balance in rain-fed lowland rice ecosystem. *Am. J. Plant Sci.* 4:309-316.

Tejada, M., Hernandez, M. T., and Garcia, C. 2009. Soil restoration using composted plant residues: Effects on soil properties. *Soil Tillage Res.*102: 109–117.

Theng, B. K. G., Tate, K. R., Sollins, P., Moris, N., Nadkarni, N., and Tate, R. L. 1989. Constituents of organic matter in temperate and tropical soils. In: Coleman, D. C., Oades, J. M., and Uehara, G. (eds), *Dynamics of Soil Organic Matter in Tropical Ecosystems.* NitTAL project, University of Hawai Press, Honolulu, HI, pp. 5-32.

Tian, G., Granato, T. C., Cox, A. E., Pietz, R. I., Carlson, C. R., and Abedin, Z. 2009. Soil carbon sequestration resulting from long-term application of biosolids for land reclamation. *J. Environ. Qual.* 38 (1): 61-74.

Trettin, C. C. and Jurgensen, M. F. 2003. Carbon cycling in wetland forest soils. In: Kimble, J. M., Lal, R., Birdsey, R., and Heath, L. S. (eds), *The potential of U.S. forest soils to sequester carbon and mitigate the greenhouse effect*, Lewis publishers, New York, pp. 311-332.

Trevors, J. T. 1984. Dehydrogenase activity in soil: A comparison between the INT and TTC assay. *Soil Biol. Biochem*. 16(6): 673-674.

Trumbore, S. E. 1997. Potential responses of soil organic carbon to global environmental change. *Phoc. Natl. Acad. Sci.* 94: 8284-8291.*

Tweeten, L., Sohngen, B., and Hopkins, J. 2009. Assessing the economics of carbon sequestration in Agriculture. In: *Conference on Assessment of Method for Soil Carbon Pools.* Columbus, Ohio, pp. 1-22.

UN REDD 2009. Reducing emissions from deforestation and forest degradation (REDD):an options assessment report. Available online at http://www.reddoar.org/links/REDD-OAR-en.pdf,acessed16/11/2009.

Verma, B. C., Datta, S. P., Rattan, R. K., and Singh, A. K. 2010. Monitoring changes in soil organic carbon pools, nitrogen, phosphorus, and sulfur under different agricultural management practices in the tropics. *Environ. Monit. Assess.* 171(1): 579-593.

Walkley, A. E. and Black, C. A. 1934. Estimation of soil organic carbon by chromic acid titration method. *Soil Sci.* 37: 29–38.

Wang, M., Wang, J. J., Wang, X. 2018. Effect of KOH-enhanced biochar on increasing soil plant-available silicon. *Geoderma* 32: 22-31.

Whalen, J. K. and Chang, C. 2002. Macroaggregate characteristics in cultivated soils after 25 annual manure applications. *Soil Sci. Soc. Am. J.* 66: 1637 - 1647.

Woolf, D., Amonette, J. E., Street-Pererott, F. A., Lehmann, J., and Joseph, S. 2010. Sustainable biochar to mitigate global climate change. *Nature Commun*. 1: 1-9.

Xie, W., Zhou, J., Wang, H., Chen, X., Lu, Z., Yu, J., and Chen, X. 2009. Short-term effects of copper, cadmium and cypermethrin on dehydrogenase activity and microbial functional diversity in soils after long-term mineral or organic fertilization. *Agric. Ecosyst. Environ.* 129 (4): 450-456.

Xinjian, L., Fei, W., Haisong, C., and Rongbin, L. 2009. Effects of different organic fertilizers on soil microbial biomass and yield of peanut. *Chin. J. Eco-Agric.* 17(2): 235-238.

Xu, Z., Zhou, Z., Liu, Y., Xu, X., Wang, J., Zhang, H., and Xiong, Z. 2015. Effects of water-saving irrigation practices and drought resistant rice variety on greenhouse gas emissions from a no-till paddy in the central lowlands of China. *Sci. Total Environ*. 505: 1043–1052.

Yaduvanshi, N. P. S. 2001. Effect of five years of rice-wheat cropping and NPK fertilizer use with and without organic and green manures on soil properties and crop yields in a reclaimed sodic soil. *J. Indian Soc. Soil Sci.* 49(4): 714-719.

Yan, X., Cai, Z., Wang, S., and Smith, P. 2011. Direct measurement of soil organic carbon content change in the croplands of China. *Glob. Change Biol*. 17: 1487–1496.

Zech, W., Senesi, N., Guggenberger, G., Kaiser, K., Lehmann, J., Miano, T. M., Miltner, A., and Schroth, G. 1997. Factors controlling humification and mineralization of soil organic matter in the tropics. *Geoderma* 79: 117-161.

Zhang, N., Xing-Dong, H. E., Yu-Bao, G. A. O., Yong-Hong, L. I., Hai-Tao, Wangdi, M.A., Zhang, R., and Yang, S. 2010. Pedogenic carbonate and soil dehydrogenase activity in response to soil organic matter in Artemisia ordosica community. *Pedosphere* 20(2): 229-235.

Zhang, P., Wei, T., Jia, Z., Han, Q., Ren, X., and Li, Y. 2014. Effects of straw incorporation on soil organic matter and soil water-stable aggregates content in semiarid regions of northwest China. *PLos One* 9: 928-939.Available:doi:10.1371/journel.pone.0092839.*

Zhang, W., Xu, M., Wang, B., and Wang, X. J. 2009. Soil organic carbon, total nitrogen and grain yields under long-term fertilizations in the upland red soil of southern China. *Nutr. Cycl. Agroecosys.* 84: 59–69.

Zhao, Y., Wang, P., Li, J., Chen, Y., Ying, X., and Liu, S. 2014. The effects of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat-maize cropping system. *Eur. J. Agron*. 31: 36-42.

Zhou, P., Song, G. H., Pan, G., Li, L., Zhang, X., and Wu, L. S. 2008. SOC accumulation in three major types of paddy soils under long-term agro-ecosystem experiments from south China. *Acta Pedologica Sinica.* 45(6): 1063-1071.

* Originals not seen

APPENDIX

Appendix

Important cultural operation dates

virippu

- Incorporation of daincha - 5-6-15
- Date of transplanting - 17-6-15
- First fertiliser application - 24-6-15
- Second fertiliser application - 4-8-15
- Harvest - 17-9-15

mundakan

- Incorporation of daincha - 12-10-15
- Date of transplanting - 16-10-15
- First fertiliser application - 24-10-15
- Second fertiliser application - 5-12-15
- Harvest - 4-2-16

CARBON SEQUESTRATION AND SOIL HEALTH UNDER DIFFERENT ORGANIC SOURCES IN WETLAND RICE

By

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ABSTRACT OF THE THESIS

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Abstract

In the current scenario of global climate change, wetland paddy fields are considered as major sources of greenhouse gases (GHG), especially methane (CH_4) and carbon dioxide (CO_2) as they experience both dry and wet situations depending on water availability. On the other hand, wetland characteristics promote the accumulation of organic matter in the soil and sediment, serving as carbon (C) sinks and making them one of the most effective ecosystems for storing soil carbon. In this context, the present study was undertaken with the objective to assess the combined effect of organic and inorganic sources on carbon sequestration and soil health under rice –rice cropping system and to compare the carbon distribution and fluxes with that of adjoining fallow land.

The experiment was conducted in the farmer's field at Varadium, Thrissur with rice as test crop in sandy clay loam soil for two continuous cropping seasons *viz.*, Virippu and Mundakan during April 2015 - January 2016. The treatments consisted of different organic sources like farm yard manure (FYM), jack tree (*Artocarpus heterophyllus*) leaves, daincha (*Sesbania aculeata*), rice husk biochar and no organic manure. These were applied in combination with four levels of nitrogen (N) *viz.*, 0, 35, 70 and 105 kg ha^{-1} represented respectively as N_0, N_{35}, N_{70} and N_{105}. The soil samples from surface (0-15 cm) and subsurface (15-30 cm) and plant samples were analysed at harvest stage in both seasons to assess the impact of treatments.

Gas samples were collected during the second cropping season at three stages *viz.*, active tillering, panicle initiation and near harvest of the crop from fifteen treatments (except N_0 level) so as to evaluate the GHG flux (CO_2 and CH_4) from the cultivated land and it was compared with that of adjoining wetland.

Soil characterization of cultivated land (biochar treatment with N_0 level) and fallow wetland (1 m depth) was also carried out after the field experiment.

Combined use of both organic and inorganic sources improved the physico-chemical properties of soil over inorganics alone. The impact was more pronounced with biochar + N_0 treatment and its effect on increasing soil pH was also note-worthy. The build- up of soil organic carbon (SOC) as well as total carbon (TC) contents were more in the surface layer compared to the subsurface. Irrespective of treatments, the carbon content decreased after Virippu season as a result of high temperature. The high carbon content noted in the biochar with all levels of N had positive effect even in the second season. The soil carbon storage was also high with this organic source.

The distribution of organic C among physical pools of soil organic matter viz., coarse particulate organic carbon (cPOC), fine particulate organic carbon (fPOC), light fraction organic carbon (LFOC), intra light fraction organic carbon (iLFOC), heavy fraction organic carbon (HFOC) and mineral associated organic carbon (MinOC) separated on size and density basis using standard procedures were also studied. Though the organic sources had positive effect on various pools, biochar with all levels of N had a strong impact in the carbon content of cPOC, LFOC and iLFOC. The cPOC concentration decreased over time while the reverse happened with fPOC. However, in the density fractions with biochar treated soils, the LFOC had the highest C concentration followed by iLFOC and the effect was more prominent in the surface layer.

Combined application of organic sources and inorganic fertilizers significantly increased the cation exchange capacity and nutrient availability in soil than that of inorganic fertilizers alone. The amount of nutrients decreased with increasing soil depth. Levels of N also had varied effect on these contents. The nutrient content in plant parts like grain, shoot and root of rice crop varied among treatments. Adequate improvement in soil physical, chemical and microbiological parameters on application of green manure contributed to increased grain yield at 35 kg N ha^{-1} in flooded rice soil while the straw yield was maximum in the treatment with biochar at N_{105}.

Measurement of GHG emission during the rice growth stages showed that the level of CO_2 was high in the active tillering phase and near harvest phase of crop growth, while that of CH_4 was found to be higher in the panicle initiation phase. Application of biochar as well as green manure with 105 kg N ha^{-1} resulted in greatest emission of CO_2, whereas the FYM + N_{105} showed highest emission of CH_4.

Soil profile study carried out after the field experiment indicated that the soil profile in the fallow land had a depth of 115 cm and five horizons while a soil profile depth of more than 70 cm with six horizons in the cultivated land. The effect of biochar on distribution of carbon and available nutrients within 30 cm depth was maximum in cultivated land in comparison with fallow wetland.

The study revealed that the application of biochar without N had great impact on soil pH and various pools of carbon but its effect at this level on soil available nutrients was reverse. The soil available nutrients were higher with FYM and daincha and their effects increased with higher levels of N which subsequently improved the plant nutrient contents and rice yield. However, the organic sources with higher doses of N had enhanced emission of CO_2 and CH_4. Hence a suitable balance between the organic + inorganic N sources is advocated.