CARBON: NITROGEN DYNAMICS IN ACID SULPHATE AND ACID SALINE RICE SOILS OF KERALA

By

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THESIS

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DECLARATION

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I, hereby declare that this thesis entitled **"Carbon : nitrogen dynamics in acid sulphate and acid saline rice soils of Kerala"** is a bona-fide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other university or society.

Vellanikkara

09/04/2019

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CERTIFICATE

Certified that this thesis, entitled **"Carbon : nitrogen dynamics in acid sulphate and acid saline rice soils of Kerala"** is a record of research work done independently by **Ms. Irene Elizabeth John** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to her.

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We, the undersigned members of the Advisory Committee of **Ms. Irene Elizabeth John (2014-21-126)**, a candidate for the degree of **Doctor of Philosophy in Agriculture** with major in **Soil Science and Agricultural Chemistry,** agree that the thesis entitled **"Carbon:nitrogen dynamics in acid sulphate and acid saline rice soils of Kerala"** may be submitted by Ms. Irene Elizabeth John in partial fulfilment of the requirements for the degree.

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Irene Elizabeth John

Dedicated to whom "farming a divine thing; transcends to divinity; a routine but the very life itself"

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Introduction

1. INTRODUCTION

Rice forms the staple food of Keralites and contributes a major share towards its economy. It is grown in vast array of ecological niches, ranging from regions situated 3 meters below MSL as in Kuttanad to an altitude of 1400 m as in the high ranges. It is cultivated under 3 to 4 meters depth of water as well as in purely rainfed uplands with no standing water. Rice is not cultivated under such a diverse condition in anywhere else in the world.

Kerala is a deficient state in rice production. While the estimated requirement of rice for the state is 35- 40 lakhs t/year, it produces less than one-fifth of its requirement. The deficit in rice production is increasing year after year due to reduction in rice area arising out of the large-scale conversion of paddy lands for raising other crops or for residential purposes. The area and production of paddy is 171398 ha and 436483 MT respectively in 2016-17 (GOK, 2017).

A unique system of rice production is practiced in the rice bowl of the state: the *Kuttanad* in Alappuzha and Kottayam districts and *Kole* land in Thrissur district. Being low-lying estuarine lands, these areas are subjected to floods during the two monsoons and salinity intrusion during post monsoon periods.

In areas that are subjected to tidal action rice is grown during viruppu season, seeking advantage of the heavy southwest monsoon. This system enhances flushing out of the salt from the land and is known as *Pokkali* in central Kerala and *Kaipad* in north Kerala.

Kuttanad, *Kole*, *Pokkali* and *Kaipad* lands of Kerala located 1-2 m below MSL are potentially acid sulphate and acid saline soil with high acidity and high organic matter content with or without sea water inundation.

In soil test based fertilizer recommendation, nitrogen is applied based on the organic carbon status assuming that the C:N ratio stabilizes at 10:1. The organic carbon based nitrogen recommendation is relied on for fertilizer recommendation because more than 95 percentage of nitrogen in soil exists in organic form associated with organic matter. As per recommendations, for such soils with high organic matter under submergence nitrogen rates are to be reduced since the organic carbon content is very high. But if the nitrogen doses are reduced crop is found to be suffering from N deficiency. This is due to the slow decomposition of organic matter under flooded environment resulting in wider C:N ratio at equilibrium (John, 2014). Hence, it becomes necessary to study the chemistry and pattern of decomposition of organic matter as well as the Carbon:Nitrogen relations in these soils under flooded conditions. This in turn will definitely help to have a meaningful organic carbon based nitrogen recommendations exclusively for these acid sulphate/saline soils which ultimately modify the present recommendation.

The above background information necessitated the present study with the following objectives:

- To unravel the chemistry of carbon-nitrogen dynamics in submerged acid sulphate and acid saline soils
- To identify the labile fractions of these elements contributing to soil fertility
- To modify the organic carbon-based fertility ratings for N recommendation in Kole lands.

Review of literature

2. REVIEW OF LITERATURE

Asian lowland rice cultivation contributes significantly to global rice supplies. More than 70% of rice in Asia is produced in lowlands with irrigation. (Bouman and Tuong, 2001). Rice being a sub-aquatic plant could derive benefits from submerged conditions (Kamoshita, 2007). This is due to the presence of aerenchyma conduiting air from leaves to root.

Water logged soils are subjected to flooded or anaerobic condition for a long period of time. These soils have distinctive gley horizons due to redox reactions. This resulted in (a) partially oxidized horizon (b) a mottled horizon and (c) a reduced horizon (Ponnamperuma,1972).

2.1. Chemistry and transformations of nutrient elements in lowland rice ecosystem

2.1.1. Electrochemical changes in flooded soils

Physical, chemical and biological changes occur in flooded rice soils due to absence of oxygen. A variety of electrochemical changes occurs upon submergence (Ponnamperuma,1972).

2.1.1.1. Changes in oxidation- reduction / redox potential

Redox potential is the key factor that distinguish a submerged soil from a well-drained soil. The redox potentials are low in submerged soils (0.20 to -0.40 V) reflecting the reduced state. Represented by pE or Eh and is measured in mV. Upon submergence of an aerobic soil, the redox potential first decreases and reaches a minimum; then it increases to a maximum value, followed by decrease again (Ponnamperuma, 1972).

The sequential reduction in flooded soil systems

Oxygen depletion from submerged soil results in sequential reduction process. Here, nitrate and manganic compounds are reduced first. Later, ferric compounds and lastly sulphate reduction occurs. The various reactions involving in sequential reduction is as follows:

$\rightarrow O_2 + 4H^+ + 4e^- \leftrightarrow 2H_2O$ ……………………………….0.814 V

$\rightarrow 2NO_3^- + 12H^+ + 2e^- \leftrightarrow N_2 + 8H_2O$……………………...0.741 V

$\rightarrow MnO_2 + 4H^+ + 2e^- \leftrightarrow Mn^{2+} + 2H_2O$ …………………….0.401 V

$\rightarrow CH_3COCOOH + 2H^+ + 2e^- \leftrightarrow CH_3CHOHCOOH$ …. -0.158 V

$\rightarrow Fe(OH)_3 + 3H^+ + e^- \leftrightarrow Fe^{2+} + 3H_2O$……………......-0.185 V

$\rightarrow SO_4^{2-} + 10H^+ + 8e^- \leftrightarrow H_2S + 4H_2O$…………………-0.214 V

$\rightarrow CO_2 + 8H^+ + 8e^- \leftrightarrow CH_4 + 2H_2O$……………...……. -0.244 V

$\rightarrow N_2 + 8H^+ + 6e^- \leftrightarrow 2NH_4^+$…………… ……………….-0.278 V

$\rightarrow NADP^+ + 2H^+ + 2e^- \leftrightarrow NADPH$……………………. -0.317 V

$\rightarrow NAD^+ + 2H^+ + 2e^- \leftrightarrow NADH$………………………...-0.329 V

$\rightarrow 2H^+ + 2e^- \leftrightarrow H2$ ……………………………………...-0.413 V

2.1.2. Various elemental transformations in submerged soils

2.1.2.1. Nitrogen dynamics in flooded systems of rice cultivation

In submerged soils, nitrogen mineralization stops at ammonium production due to absence of oxygen. In flooded soils, ammonium is produced by reductive deamination and purine degradation. This causes release of ammonia, carbon dioxide and volatile fatty acids. The ammonium being stable under anaerobic environment readily accumulates (Ponnamperuma1972).

2.1.2.2. Phosphorus availability under flooded rice systems

The phosphorus availability to rice increases upon submergence. Upon submergence there is an increase of pH of acid soils and decrease of pH of alkaline soils. The availability of phosphorus is maximum in neutral range. (Patrick and Mahapatra, 1968). Decrease in redox potential and reduction of iron phosphates resulted in increasing phosphorus availability in acidic soils. Since there is decrease of pH in alkaline soils under submergence, the availability of phosphorus is increased. This is due to solubilization of tri calcium phosphate.

2.1.2.3. Dynamics of potassium, calcium and magnesium under flooded system

The exchangeable K, Ca and Mg in solid phase is released into solution phase under acidic conditions. Thus, the bioavailability of these cations is increased upon flooding. Since Fe and Mn are the dominant cations in the acidic soil environment the competition of K, Ca and Mg with Fe^{2+} and Mn^{2+} results in low plant uptake of K, Ca and Mg (Fagaria *et al.*, 2008).

2.1.2.4. Dynamics of sulphur under flooded system

Upon submergence, reduction of SO_4^{2-} to S^{2-} occurs. Also, there is dissimiation of amino acids to hydrogen sulphide and ammonia (Ponnamperuma, 1972).

2.1.2.5. Dynamics of Fe under flooded systems

Iron is a major constituent of most soils. Iron minerals commonly found in soils include geothite (FeOOH), hematite (Fe_2O_3), pyrite (FeS), siderite ($FeCO_3$) and magnetite (Fe_3O_4). Redox reactions affect the valency of iron and thereby its uptake by plants. The Fe^{3+} ion is reduced to Fe^{2+} due to oxidation-reduction processes which enhances its uptake. The reduction of Fe^{3+} to Fe^{2+} is expressed by following equation:

$$Fe(OH)_3 + 3H^+ + e^- \leftrightarrow Fe^{2+} + 3H_2O$$

2.1.2.6. Dynamics of manganese under flooded system of rice

The manganic Mn^{4+} form of Mn is reduced to manganous Mn^{2+} form upon submergence. This causes an increase in manganese availability.

2.1.2.7. Dynamics of zinc in flooded system

There is an increase in amorphous sesquioxides form and a decrease of water soluble, exchangeable and crystalline sesquioxide bound form of zinc. (Hazra *et al.*,1987). Hence zinc deficiency is widespread under lowland rice systems.

2.1.2.8. Dynamics of Copper under flooded system of rice

Copper availability is decreased due to precipitation of solubilized copper as copper sulphide. The formation of insoluble complexes with organic compounds in organic soils also resulted in copper deficiency.

2.1.3. Carbon:Nitogen dynamics in flooded environment

Most of our understanding of soil carbon and nitrogen dynamics has been gained from research on aerobic soils, predominantly under temperate conditions. Relatively little research has been done on flooded anaerobic soils and tropical conditions. These conditions are essential to rice production systems and are also important in natural wetlands. Recent interest in carbon and nitrogen dynamics in flooded rice soils has been stimulated by trends of declining productivity in intensive rice systems and evidence that this was linked to long-term changes in soil organic matter and the supply of nutrients.

2.1.3.1. Decomposition of organic matter

The organic matter decomposition in a flooded soil is slower and the end products of decomposition are different from that of aerobic soils. The decomposition of organic matter is triggered by the facultative and obligate anaerobes in a submerged soil. The anaerobic bacteria being operating at a lower level of energy than aerobic bacteria, decomposition processes are slower than in flooded system. (Ponnamperuma, 1972). The main end products anaerobic decomposition are: CO_2, H_2, CH_4, NH_3, H_2S etc.

The lack of major electron acceptor: free oxygen enhances or increases organic matter status in submerged soils (Witt *et al.*, 2000). Due to slow, inefficient, and incomplete decomposition, there is net accumulation of organic matter under flooding (Cheng *et al*., 2009).

2.1.4. Soil organic matter-physical fractionation

Physical fractionation separates organic matter based on its origin and degree of transformation. Organic matter of recent plant origin is preferentially recovered in the sand-size fraction (2.00 - 0.053 mm) whereas more microbially processed material in the silt and clay-size (<0.053 mm) fractions (Cheshire and Mundie,1981). The coarser fraction can be further partitioned to macro size (2.00 - 0.250 mm) and micro size (0.250-0.053 mm) fractions. There was a decline in C:N ratio with decrease in particle size and that the organic matter in coarser fractions is composed of comparatively unaltered plant material (Jagadamma and Lal, 2010). Physical fractionation of soil helps in quantifying the functional pools of soil organic matter.

Carbon in the sand size fraction is generally more labile than carbon in clay and silt size fractions (Tiessen and Stewart, 1983). The labile pool is composed of relatively recent plant residues, root exudates and the microbial biomass (Tisdall and Oades, 1982).

The labile or active fraction of soil organic matter consists of materials with relatively higher C:N ratios (about 15-30) and shorter half-lives. This fraction includes the microbial biomass, some of the fine particulate detritus (coarse and fine particulate organic matter) and most of the polysaccharides. The labile fraction (2.00-0.250 mm) supplies food for the soil microbes. It is responsible for structural stability and better infiltration properties. This fraction accounts for about 10-20% of the organic matter content in soil. The passive fraction (<0.053 mm) of soil organic matter represents the stabilized pool of soil organic matter. This fraction includes the humus that is physically protected in clay-humus complexes, humin, and that of the humic acids. The passive fraction is very much associated with the colloidal properties of soil humus which is responsible for CEC and water holding capacity of soil. The 0.250-0.053 mm size fraction of soil organic matter is intermediate in properties between the active and passive fraction.

Labile soil organic carbon pools includes particulate organic carbon, microbial biomass carbon, dissolved organic carbon, hot water extractable carbon and permanganate oxidisable (Camberdella and Elliot, 1992; Blair *et al.*, 1995; Ghani et al., 2003).

2.1.5. Soil organic matter-chemical fractionation

2.1.5.1. Water soluble carbon (WSC)

Water soluble carbon (WSC) is the most mobile and labile component of soil organic carbon pools. Although it accounts to a smaller part of soil organic matter, it contributes significantly to the nutrient cycle and is the main energy substrate for soil microbes (Qualls *et al.*, 1991). Since the soluble phase tends to be in equilibrium with the solid phase of soil organic matter, WSC generally reflects the composition of total soil organic matter.

2.1.5.2. Hot water extractable carbon (HWEC)

The hot-water extractable pool of carbon tends to relate well with microbial biomass carbon. The hot-water extraction method helps in determining the easily available pool of organic N (Ghani *et al.*, 2003). The HWEC consists of a chemical extraction using hot distilled water to represent 'near to nature' conditions of ongoing mineralization process. The extracted fraction contains soil microbial biomass, simple organic compounds and compounds which are hydrolysable under the given extraction conditions.

HWEC accounts for about 1-5 % of total organic carbon. Ghani *et al.*, (2003) reported that HWEC had significant positive correlation with microbial biomass carbon and nitrogen.

2.1.5.3. Permanganate oxidizable soil carbon (POC)

Permanganate oxidizable carbon (POC) measurement is based on chemical oxidation of organic matter by a weak potassium permanganate solution. It includes the carbon readily degradable by microorganisms and carbon that are bound partially to soil minerals. The turnover time of POC is shorter and is hence more sensitive to management practices (Andrews *et al.*, 2004).

2.1.6. Forms of soil nitrogen

The chemical nature of soil organic nitrogen is not fully under-stood, but the available evidence based on hydrolysis with strong acid and subsequent fractionation of the hydrolyzate indicates the presence of considerable nitrogen in a form that is converted to ammonium during hydrolysis, a variety of amino acids, and a resistant fraction that is not hydrolysed (Stevenson, 1957).

Plants absorb nitrogen in the form of inorganic ionic forms as ammonia and nitrate, also in small quantities as urea. But more than 90 per cent of nitrogen is in the organic form. The inorganic form of nitrogen rarely exceeds 2 per cent in the cultivated soils (Bremner, 1967). Although nitrogen in the soil may come from dissimilar sources - plant residues, microbial cells, or inorganic fertilizers - after the process of humification has taken place, much of the nitrogen is incorporated into complexes of high molecular weight and comparative resistant to microbial degradation (Broadbent, 1968).

2.1.6.1. Inorganic nitrogen

a) Ammonia and Nitrate nitrogen

Generally inorganic forms of nitrogen are comparatively less in the soils compared to organic forms. Cropping systems, cultivation practices and vegetation have their own effect on the inorganic forms of nitrogen. Grassland and forest soils differed much in the exchange-able ammonium nitrogen content (Jorgenson, 1967). Microbiological activity is equally responsible for the amount of ammonia and nitrate content in soils. Chemoautotrophs were responsible for the bulk of nitrification in cultivated soils (Campbell and Lees, 1967). Acidity in soil resulted in low population of nitrifers with more ammonium content in soils (Brar and Giddens, 1968).

The ammoniacal and nitrate forms of nitrogen were found to be increased with increase in altitude and organic carbon (Singh and Datta, 1988).

Many of the soils of Kerala have pH values lower than the reported optimum for nitrification and often lower than the critical limit. There was significant negative correlation between pH and NH_4-N and positive correlation with NO_3 -N (Zacharias, 1989).

b) Fixed ammonia nitrogen

Soil properties, especially clay and organic matter are responsible for ammonium fixation. Fixed ammonium was very much resistant and high molecular weight fractions fixed more ammonium (Broadbent, 1968).

2.1.6.2. Organic nitrogen

More than 95% of the total N in most of the surface soil is organically combined. Hydrolysis studies with hot acid have shown that 20-40% of the total N in most of the surface soils is in the form of bound amino acid and that of 4-10% in the form of combined hexosamine (Stevenson, 1996).

a) Total hydrolysable nitrogen

Hydrolysable nitrogen contains different forms like ammoniacal, amino acid, hexosamine and other forms. Hydrolysable nitrogen decreased gradually with the progress of humification. Under the conditions of intensive farming the hydrolysable nitrogen may increase, with 50 to 60 per cent of nitrogen in the hydrolysable nitrogen as amino acid (Russell, 1966).

(i) Amino acid nitrogen

Considerable amount of nitrogen from hydrolysable nitrogen is in amino acid form. Gupta (1962) has indicated that the amino acid estimated by hydrolysis procedure was minimal as it was destroyed during hydrolysis. However, Singh and Bhandarl, 1963 obtained a higher value as the duration of hydrolysis was increased to 72 hours.

Soil characters and conditions were found to influence amino acid fraction of the hydrolysable nitrogen. Haider *et al.*, (1965) confirmed the fixation of amino acids in the lattices of clay minerals. Alpha-amino nitrogen was 21 per cent of hydrolysable nitrogen as per Quinn and Solomon (1966).

Organic matter content and its nature are the other factors which affect the amino acid distribution in soils. Maximum number of amino acids was noted in the soils which are high in organic matter and nitrogen (Malival and Khangarot, 1966 and Krishnamoorthy and Durairaj, 1968).

Broadbent (1968) has shown that recently immobilised nitrogen would have more of amino acid than ammoniacal nitrogen. Isirimah and Keeney (1973) concluded that most of the mineralised nitrogen came from amino acid nitrogen.

Ramamoorthy and Velayutham (1976) found that about 18 to 30 per cent of the total nitrogen in most surface soils occurred as bound amino acids. Soils from warmer climates yielded relatively more amino acids than those from colder regions (Sowden *et al.*, 1977). But they found that climate doesn't influence the amino acid composition of soils.

2.1.7. Carbon:nitrogen (C:N) ratio

There is a decrease in organic matter content with depth in *Kari* soils of *Kuttanad.* Due to slow decomposition of organic matter, the C: N ratios of these soils are wider. This is due to the presence of lignin in undecomposed planting material. The C: N ratio of upper *Kuttanad* soil is above 10:1 indicating slow and incomplete decomposition. Lower C:N ratio was recorded in *Kayal* lands (Manorama, 1997).

During the active tillering stage of rice, the C:N ratio on wet basis was not found to stabilize at 10:1. It was 18:1 in *Kuttanad*, 15:1 in *Kole* lands and 17: in

Pokkali lands (John, 2014).The response to nitrogen fertilizers were higher in soils with higher C:N ratio (13-17:1). The soils having high C:N ratio showed higher response to nitrogen fertilizer application (Usha and Jose, 1983).

Materials and methods

3. MATERIALS AND METHODS

The present investigation entitled "Carbon: Nitrogen dynamics in acid sulphate and acid saline rice soils of Kerala" was carried out at the Radiotracer laboratory, College of Horticulture, Kerala Agricultural University during 2014-2017. This project included both laboratory research and field experiments. The laboratory studies were conducted to assess the Carbon: Nitrogen relations in submerged acid sulphate and acid saline rice soils of Kerala. A field experiment was conducted in farmer's field at Puzhakkal in Adattu panchayat in *Kole* lands of Thrissur district to investigate the response of rice to different levels nitrogen. The materials used and the methods adopted to achieve the objectives mentioned in chapter 1, the introduction are summarized here under.

The initial soil samples from the experiment site was collected and characterized with respect to pH, EC, total N, available nutrient status (organic carbon, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn and boron. The soil samples were analysed as such after sampling on wet basis.

Experiment 1. Collection and characterization of soil samples

3.1. Procedure for sampling of soil from lowlands

Soil sampling was done using core sampler from 0-20 cm depth without disturbing the reduced condition as far as possible. Part of the sample was sealed as such and used for wet analysis.

3.1.1. Expression of results of wet analysis

To express the results of wet analysis, the moisture content of the sample were estimated gravimetrically. In order to find out the moisture percentage, an initially weighed soil (W1) sample was kept in the hot air oven at105°C. After drying, the sample was again weighed (W2). Percentage of moisture = [(W1-W2)/W1] x 100. Suppose a soil contains 80 % moisture, the actual percentage weight of the soil on wet basis is 20 %. Hence, if 5 g soil was taken for analysis, actual dry weight = 5 x 20/100= 1g.

Plate 1. Procedure for soil sampling in wet lands

3.1.2. Collection of soil samples

Representative soil samples were collected from 4 different rice growing acid saline and acid sulphate soils under different agro-ecological units (AEU) of Kerala. Soils included were i) *Kuttanad* soil (AEU-4), ii) *Pokkali* soil (AEU-5), iii) *Kole* lands (AEU-6), and iv) *Kaipad* lands (AEU7). A total of 25 samples from Kuttanad (*Kayal* 5, lower Kuttanad 5, upper Kuttanad 5, Vechur *kari*, 5, Purakkad *kari* 5) were collected. Five samples each from Thrissur and Ponnani *Kole* lands were also collected. Also, five samples each from Pokkali and Kaipad lands were collected. The details of sample location are presented in table 1.

3.1.3. Characterisation of soil samples

Soil samples collected before the cropping season were analysed for estimating pH, EC, total carbon, organic carbon, total N, available N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B and microbial biomass carbon. The procedures adopted for the characterisation of soil samples are detailed in table 2.

Table 1. Locations of soil sampling and agro-ecological units

Soil sample No	Soil type	Location	Agro-ecological unit
1	Vechoor Kari (1)	Poovathikkari,Vechoor, Vaikom N 09°41.026' E 076°26.666'	Kuttanad (AEU 4)
2	Vechoor Kari (2)	C.K.N Block, Thottakam, Vaikom N 09°43.691' E 076°25.582'	Kuttanad (AEU 4)

Soil sample No	Soil type	Location	Agro-ecological unit
3	Vechoor Kari (3)	Block 2, Poovathikkari, Vechoor, Vaikom N 09°41.032' E 076°26.682'	Kuttanad (AEU 4)
4	Vechoor Kari (4)	C.K.N Block, Thottakam, Vaikom N 09°43.691' E 076°25.582'	Kuttanad (AEU 4)
5	Vechoor Kari (5)	Block 4, Poovathikkari, Vechoor, Vaikom N 09°41.036' E 076°26.690'	Kuttanad (AEU 4)
6	Kayal lands (1)	Rajapuram Kayal N 09°29.410' E 076°26.829'	Kuttanad (AEU 4)
7	Kayal lands (2)	D Block Thekkearayiram N 09°30.395' E 076°26.116'	Kuttanad (AEU 4)

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Soil sample No	Soil type	Location	Agro-ecological unit
8	Kayal lands (3)	H Block Pazhepathinalayiram N 09°32.061’ E 076°26.131’	Kuttanad (AEU 4)
9	Kayal lands (4)	D Block Puthenarayiram N 09°31.621’ E 076°25.114’	Kuttanad (AEU 4)
10	Kayal lands (5)	Vadakkearayiram N 09°31.642’ E 076°25.871’	Kuttanad (AEU 4)
11	Purakkad Kari (1)	Valiyathuruthu N 09°22.832’ E 076°23.98’	Kuttanad (AEU 4)
12	Purakkad Kari (2)	Cheriyathuruthu N 09°22.841’ E 076°23.107’	Kuttanad (AEU 4)
13	Purakkad Kari (3)	Appathikari N 09°21.737’ E 076°23.912’	Kuttanad (AEU 4)

Soil sample No	Soil type	Location	Agro-ecological unit
14	Purakkad Kari (4)	Gracing Block N 09°21.403' E 076°23.147'	Kuttanad (AEU 4)
15	Purakkad Kari (5)	Malayathoduthekku N 09°20.181' E 076°23.633'	Kuttanad (AEU 4)
16	Upper Kuttanad (1)	Chathankari N 09°22.934' E 076°31.540'	Kuttanad (AEU 4)
17	Upper Kuttanad (2)	Mayankari N 09°22.957' E 076°31.514'	Kuttanad (AEU 4)
18	Upper Kuttanad (3)	Koorachalmanikathady N 09°22.957' E 076°31.514'	Kuttanad (AEU 4)
19	Upper Kuttanad (4)	Padavinakam B N 09°22.957' E 076°31.514'	Kuttanad (AEU 4)

Soil sample No	Soil type	Location	Agro-ecological unit
20	Upper Kuttanad (5)	Padavinakam A N 09°24.312' E 076°31.965'	Kuttanad (AEU 4)
21	Lower Kuttanad (1)	Mullapongambra N 09°27.327' E 076°25.237'	Kuttanad (AEU 4)
22	Lower Kuttanad (2)	Ezhukadu N 09°27.337' E 076°27.544'	Kuttanad (AEU 4)
23	Lower Kuttanad (3)	Moolappillikadu N 09°27.317' E 076°25.218'	Kuttanad (AEU 4)
24	Lower Kuttanad (4)	Padachal N 09°27.532' E 076°25.028'	Kuttanad (AEU 4)
25	Lower Kuttanad (5)	Nattayam N 09°25.531' E 076°25.028'	Kuttanad (AEU 4)

Soil sample No	Soil type	Location	Agro-ecological unit
26	Kaipad lands (1)	Ezhome 1 N 12°01.450' E 075°19.005'	Kaipad (AEU 7)
27	Kaipad lands (2)	Ezhome 2 N 12°01.507' E 075°19.106'	Kaipad (AEU 7)
28	Kaipad lands (3)	Ezhome 3 N 12°01.778' E 075°19.089'	Kaipad (AEU 7)
29	Kaipad lands (4)	Ezhome 4 N 12°01.721' E 075°18.814'	Kaipad (AEU 7)
30	Kaipad lands (5)	Ezhome 5 N 12°00.906' E 075°19.095'	Kaipad (AEU 7)
31	Pokkali lands (1)	Varappuzha N 10°03.333' E 076°14.986'	Pokkali (AEU 5)

Soil sample No	**Soil type**	**Location**	**Agro-ecological unit**
32	Pokkali lands (2)	Varappuzha N 10°03.454' E 076°14.929'	Pokkali (AEU 5)
33	Pokkali lands (3)	Varappuzha N 10°03.639' E 076°14.858'	Pokkali (AEU 5)
34	Pokkali lands (4)	Varappuzha N 10°03.854' E 076°14.789'	Pokkali (AEU 5)
35	Pokkali lands (5)	Varappuzha N 10°03.837' E 076°14.148'	Pokkali (AEU 5)
36	PonnaniKole (1)	Chembilakadavu N 10°44.650' E 076°00.525'	Kole (AEU 6)
37	PonnaniKole (2)	Manakadavu N 10°45.179' E 076°01.022'	Kole (AEU 6)

Soil sample No	Soil type	Location	Agro-ecological unit
38	PonnaniKole (3)	Chembilathazham N 10°44.598’ E 076°00.930’	Kole (AEU 6)
39	PonnaniKole (4)	Pangaduthiruth N 10°44.840’ E 076°00.250’	Kole (AEU 6)
40	PonnaniKole (5)	Pangadukundu N 10°44.845’ E 076°00.260’	Kole (AEU 6)
41	ThrissurKole (1)	Manalurthazham N 10°29.079’ E 076°07.680’	Kole (AEU 6)
42	ThrissurKole (2)	Vadakkekonchira N 10°30.554’ E 076°06.403’	Kole (AEU 6)
43	ThrissurKole (3)	Thekkekonchira(1) N 10°30.526’ E 076°06.391’	Kole (AEU 6)

Soil sample No	Soil type	Location	Agro-ecological unit
44	ThrissurKole (4)	Thekkekonchira(2) N 10°30.532' E 076°06.395'	Kole (AEU 6)
45	ThrissurKole (5)	Adattu N 10°30.549' E 076°06.395'	Kole (AEU 6)

Table 2. Methods of soil analysis

Sr. No.	Particulars	Method
1	pH	Potentiometric method using a pH meter in 1: 2.5 soil water suspension (Jackson, 1958)
2	EC	Estimated using a conductivity meter in the supernatant liquid used for pH determination (Jackson,1958)
3	Organic carbon	Wet digestion method (Walkley and Black, 1934)
4	Total C and N	Estimated by CHNS analyzer (Model: Elementar's vario EL cube)
5	Available nitrogen	Alkaline permanganate method (Subbiah and Asija, 1956)
6	Available phosphorus	Extracted (Bray and Kurtz, 1945) and estimated colorimetrically by reduced molybdate ascorbic acid blue colour method (Watanabe and Olsen, 1965)
7	Available potassium	Flame photometry (Jackson, 1958)

Sr No.	Particulars	Method
8	Available Ca and Mg	Atomic absorption spectrophotometry (Model: Analyst 400)
9	Available Sulphur	Extraction: Tabatabai, 1982 Estimation: Massoumi andCornfield, 1963
10	Available Fe, Mn, Cu and Zn	Atomic absorption spectrophotometry (Model: Analyst 400) (Sims and Johnson, 1991)
11	Available B	Hot water extraction method (Berger and Truog, 1939) and estimated colorimetrically by Azomethine H (modified by Gupta, 1972) using spectrophotometer
12	Microbial biomass carbon	Chloroform fumigation and extraction (Jenkinson and Powlson,1976)

Experiment 2

3.2. Fractionation of soil carbon

Representative samples of 4 different rice growing acid saline and acid sulphate soils of Kerala as detailed in table 1 and samples collected from experimental field during active tillering, flowering and harvest were subjected to fractionation of soil carbon. The procedure for the extraction and determination of soil carbon fractions is presented below.

3.2.1. Physical fractionation

Particle size fractionation of soil was carried out by dispersion, wet sieving and sedimentation processes (Cambardella *et al.*, 1993). Ten gram soil was dispersed using 0.5 % sodium hexametaphosphate (shaking period of 16h). After dispersion, the suspension was wet sieved to separate the sand sized (2.00-0.250 mm), silt sized (0.250-.053 mm) and clay sized (<0.053 mm) fractions using Yoder's apparatus. These particle size fractions were dried at 65° C. Carbon and nitrogen in the sand, silt and clay fractions were estimated by dry combustion method using CHNS analyser (Elementar's vario EL cube).

3.2.2. Chemical fractionation

3.2.2.1. Water soluble carbon (WSC)

Field moist soil samples were extracted with distilled water in the ratio 1:3 for 30 minutes on an end-over –end shaker and centrifuged for 20 minutes at 8000 rpm. The supernatant was filtered and the extract was estimated for water soluble carbon by dichromate oxidation method (Ghani *et al.*, 2003).

3.2.2.2. Hot water extractable carbon (HWEC)

To the soil left after water soluble carbon extraction, 30 ml distilled water was added and shaken for 30 minutes in a horizontal shaker. These centrifuge tubes were left in a hot water bath (80°C) for 16 hours. After shaking for 10 minutes on a horizontal shaker followed by centrifugation at 8000 rpm for 20 minutes, the supernatant was used to determine hot water extractable carbon by dichromate oxidation method (Ghani *et al.*, 2003).

3.2.2.3. Permanganate oxidizable soil carbon (POSC)

Field moist soil sample was extracted with 20 mM $KMnO_4$ in the ratio 1:10 for 30 minutes and centrifuged for 5 minutes at 2000 rpm. Two ml of the aliquot was made upto 50 ml and the absorbance was measured at 560 nm using spectrophotometer (Modified method of Blair *et al.*, 1995).

Experiment 3

3.3. Fractionation of soil nitrogen

Soil samples as detailed in table 1 were subjected to fractionation of soil nitrogen. The procedure for the extraction and determination of soil N fractions is presented below.

3.3.1. Organic fractions of nitrogen (Stevenson, 1996)

3.3.1.1. Preparation of hydrolysate

Five gram of soil was transferred to 500ml Erlenmeyer flask fitted with 24/40 ground glass joint and 20 ml of 6 N HCl was added. The suspension was digested for 12 h on an electric hot plate at 100° C under reflux. The hydrolysate mixture was filtered through Whatman No. 42 filter paper. The residue was washed with small portion of water for about 3 to 4 times. The pH of the extract was adjusted to 5.0 by dropwise addition and constant stirring with 5 N NaOH and finally pH was adjusted to 6.5± 0.1 with 0.5 N NaOH. The neutralized extract was transferred to a 100 ml volumetric flask and made to volume with distilled water.

3.3.1.2. Analysis of hydrolysate

3.3.1.2.1. Determination of total hydrolysable nitrogen

5 ml of the above neutralized extract was digested with 0.5 g of K_2SO_4-$CuSO_4$ digestion mixture and 2ml of concentrated H_2SO_4 in a 100 ml Kjeldahl digestion flask continuously for one hour. The digested material was cooled and distilled under alkaline conditions using 10 ml of 10 N NaOH. The distillate was absorbed in 5 ml of 2% boric acid and titrated with 0.02 N H_2SO_4.

3.3.1.2.2. Determination of amino acid nitrogen

5 ml of the above neutralized hydrolysate was taken in the 50 ml distillation flask. One ml of 0.5 N NaOH was added and the content of the flask was heated in waterbath (100° C) until the volume of the same reduced to half (20 minutes). After cooling, 500 mg of citric acid and 100 mg of ninhydrin were added to the flask and kept immersed in a water bath (100° C). After 1 minute, the flask was swirled for a few seconds, without removing it from water bath and then allowed to remain in the water bath for additional 9 minutes. The flask was then connected to the distillation set and the amount of NH_3 liberated by steam distillation was determined as described above.

3.3.2. Inorganic fractions of nitrogen

3.3.2.1. Exchangeable NH_4-N

The soil samples were extracted with 2 N KCl in a 1:10 soil to KCl ratio by shaking for 1 h and filtered off using Whatman No.1 filter paper. Leachate was collected and an aliquot of this was distilled with magnesium oxide (Keeney and Nelson, 1982).

3.3.2.1. Nitrate nitrogen NO_3-N

Further distillation of the above with Devarda's alloy.

Experiment 4. Nitrogen fertilization for rice

3.4.1. Field experiment

The field experiment to investigate the response of rice to nitogen was conducted in the field of Mr. Joby, *Puzhackalpadam* a *Kole* land in Adattu panchayat in Thrissur district, in the *mundakan* season of 2015. The field is located at N 10°30.549'latitude and E 076°06.395'longitude.

Soil sampling was done using core sampler from 0-20 cm depth without disturbing the reduced condition as far as possible. Part of the sample was sealed as such and used for wet analysis, while the remaining part was dried, processed, sieved through 2 mm sieve and analyzed by routine methods. The data on both wet and dry analysis of soil samples collected from the experimental soil is given in the table 3.

Table 3. Chemical properties of experimental soil

Parameter	Wet analysis	Dry analysis
pH (1:2.5)	5.94	4.54
EC (dS m^{-1})	0.046	0.052
Organic carbon (%)	2.35	2.92

Parameter	Wet analysis	Dry analysis
Total nitrogen (%)	0.12	0.24
C:N(OC:Total N) ratio	19.62	12.18
Available phosphorus (kg ha^{-1})	104.66	9.89
Available potassium (kg ha^{-1})	1233.78	367.71
Available calcium (mg kg^{-1})	382.45	435.73
Available magnesium (mg kg^{-1})	97.19	108.75
Available sulphur (mg kg^{-1})	2.27	4.54
Available iron (mg kg^{-1})	1307	242.66
Available manganese (mg kg^{-1})	35.83	38.24
Available copper (mg kg^{-1})	0.60	5.73
Available zinc (mg kg^{-1})	5.72	7.86
Available boron (mg kg^{-1})	1.30	1.36

The experiment was laid out in randomized block design with ten levels of nitrogen in 3 replications. The doses of nitrogen were based on soil fertility classes (0-9) (KAU, 2011). In the recommendation sited, the quantity of nitrogen was computed based on the organic carbon content. Suppose if OC is 1%, the N content is 0.1 % based on C:N ratio (10:1). This soil comes under the class no.4 (medium fertility). The N recommendation for this class is 91 % of POP recommendation. The C:N ratio of the field where experiment was laid out was 20:1. Hence, the N content is 1/20= 0.05 %. This comes under class No. 2 (low fertility). The corresponding nitrogen recommendation becomes 106% of POP. Thus, the quantity of nitrogen was modified in treatments as per the C:N ratio of experimental soil. The quantity of lime and fertilizers applied in different treatments are given in table 4.

10 levels of nitrogen

1) Absolute control
2) POP recommendation
3) Soil test based recommendation (Based on wet analysis)
4) Soil test based recommendation (Based on dry analysis)
5) C:N ratio based recommendation with addition of OM (Wet analysis)
6) C:N ratio based recommendation with addition of OM (Dry analysis)
7) Half of C:N ratio based recommendation (Based on wet analysis)
8) Half of C:N ratio based recommendation (Based on dry analysis)
9) Double of C:N ratio based recommendation (Based on wet analysis)
10) Double of C:N ratio based recommendation (Based on dry analysis)

Table 4. Rate of application of lime and fertilizer to the crop for field experiment

Treatment	Lime Kg ha^{-1}	Urea Kg ha^{-1}	Factomphos Kg ha^{-1}	MOP Kg ha^{-1}	$MgSO_4$ Kg ha^{-1}
T1	250	0	0	0	0
T2	250	141.00	224.991	75.00	0
T3	250	103.00	56.24775	18.74	80
T4	250	24.49	238.4905	18.74	80
T5	250	229.00	56.24775	18.74	80
T6	250	113.00	238.4905	18.74	80
T7	250	114.49	28.12388	18.74	80
T8	250	56.49	119.2452	18.74	80
T9	250	458.00	112.955	18.74	80
T10	250	226.00	476.9809	18.74	80

4.2. Variety

Uma, a medium duration variety of 115-120 days duration was used for the study.

4.3. Land preparation

The experimental area was ploughed well and plots of 5m x 4m were prepared by constructing bunds of 30 cm width and height. Irrigation and drainage channels were provided between each plot.

4.3.1. Crop culture

Seedlings, 18 days old were transplanted at a spacing of 20 cm x 10 cm. The magnesium deficiency was anticipated as is revealed by the initial soil test data. Magnesium sulphate was applied @ 80 kg ha^{-1} to correct the deficiency appeared in the field after the maximum tillering stage.

4.3.1.1. Biometric observations

The following observations were made in the field experiment.

4.3.1.1.1. Plant height

The plant height was recorded at active tillering, flowering and harvest stages.

4.3.1.1.2. Tiller production

The number of tillers per hill was recorded up to maximum tillering stage

4.3.1.1.3. Productive tillers

The number of productive tillers per hill was recorded at harvest stage

4.3.1.1.4. Number of branches per panicle

Number of branches per panicle was recorded at harvest stage

4.3.1.1.5. Number of grains per panicle

Number of grains per panicle was recorded at harvest stage

4.3.1.1.6. Thousand grain weight

One thousand grains were counted from the produce of each plot and their weight was recorded and expressed in grams.

4.3.1.1.7. Grain and straw weight

The crop harvested from each plot was threshed, winnowed and the weight of straw and grain was recorded separately and expressed as Mg ha^{-1}

4.3.2. Analysis of soil and plant samples

Soil samples were drawn at active tillering, flowering and harvest stage and analysed for nutrient content. Plant samples were drawn at flowering and harvest stage and analysed for nutrient content.

4.3.2.1. Soil analysis

Soil samples drawn from each plot and analysed for pH, EC,OC, and available nutrients as N, P, K, Ca, Mg, S and micronutrients Fe, Mn, Zn, Cu and available boron and microbial biomass carbon on wet basis as per the procedures detailed in table 2.

4.3.2.2. Fractionation of carbon

Fractionation of carbonin soil samples drawn from each plot were also done at 3stages as active tillering, flowering and harvest. The procedures adopted are detailed in 3.2.

4.3.2.3. Fractionation of nitrogen

Fractionation of nitrogen in soil samples drawn from each plot were also done at 3 stages as active tillering, flowering and harvest. The procedures adopted are detailed in 3.3.

4.3.2.4. Plant analysis

Plant samples were collected from each plot at flowering and harvest stage. The plant samples were oven dried at 70 ± 5°C, powdered and estimatedthe contents of total C, N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B.

Table 5. Methods of plant analysis

Sl. No.	Element	Method
1	Nitrogen	Estimated by CHNS analyzer (Model: Elementar'svario EL cube)
2	Phosphorus	Diacid digestion of leaf sample followed by filtration. Vanabdomolybdate phosphoric yellow colour in nitric acid system (Piper, 1966)
3	Potassium	Diacid digestion of leaf sample followed by filtration. Flame photometry determination (Jackson, 1973)
4	Calcium and magnesium	Diacid digestion of leaf sample followed by filtration. The filtrate was collected, analysed for Ca and Mg using Perkin-Elmer AAS (Piper, 1966)
5	Iron, manganese, zinc and copper	Diacid digestion of leaf sample followed by filtration. The filtrate was collected, analysed for Fe, Mn, Zn and Cu using Perkin-Elmer AAS (Piper, 1966)
6	Boron	Diacid digestion of leaf sample followed by filtration. The filtrate was collected, analysed for B using Perkin-Elmer ICP-OES (Piper, 1966)

4.4. Statistical analysis

Correlation studies of data were carried out by the method suggested by Panse and Sukatme (1978). Correlation and regression analysis of data generated in various experiments were carried out based on the method suggested by Cox (1987) using SPSS package. Path coefficient analysis was carried out in OPSTAT package. Analysis of variance in RBD was made in WASP package.

Plate 2. Field preparation

Plate 3. Layout of experimental field

Plate 4. Transplanted field

Plate 5. Fertilizer application

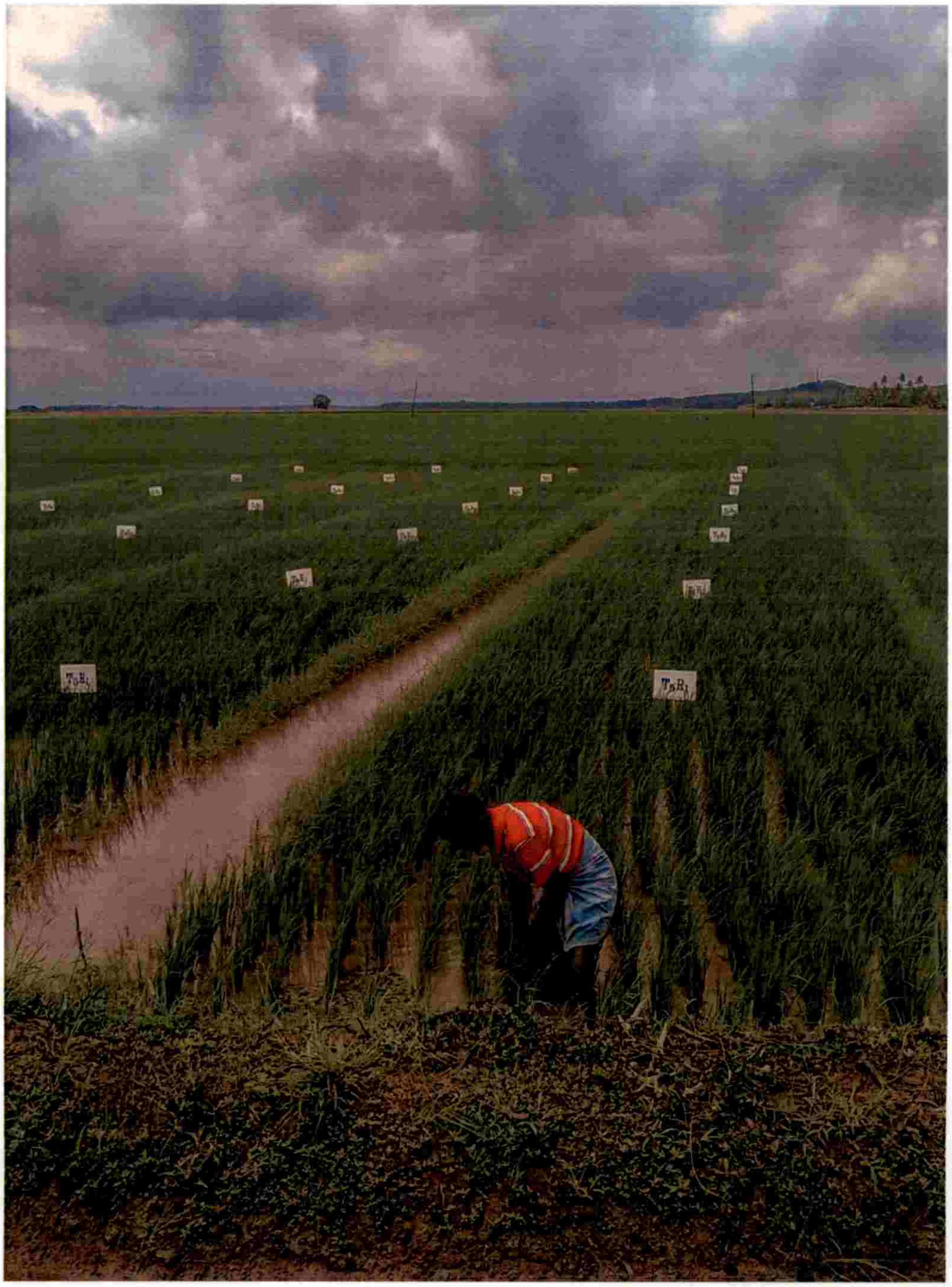

Plate 6. Weeding

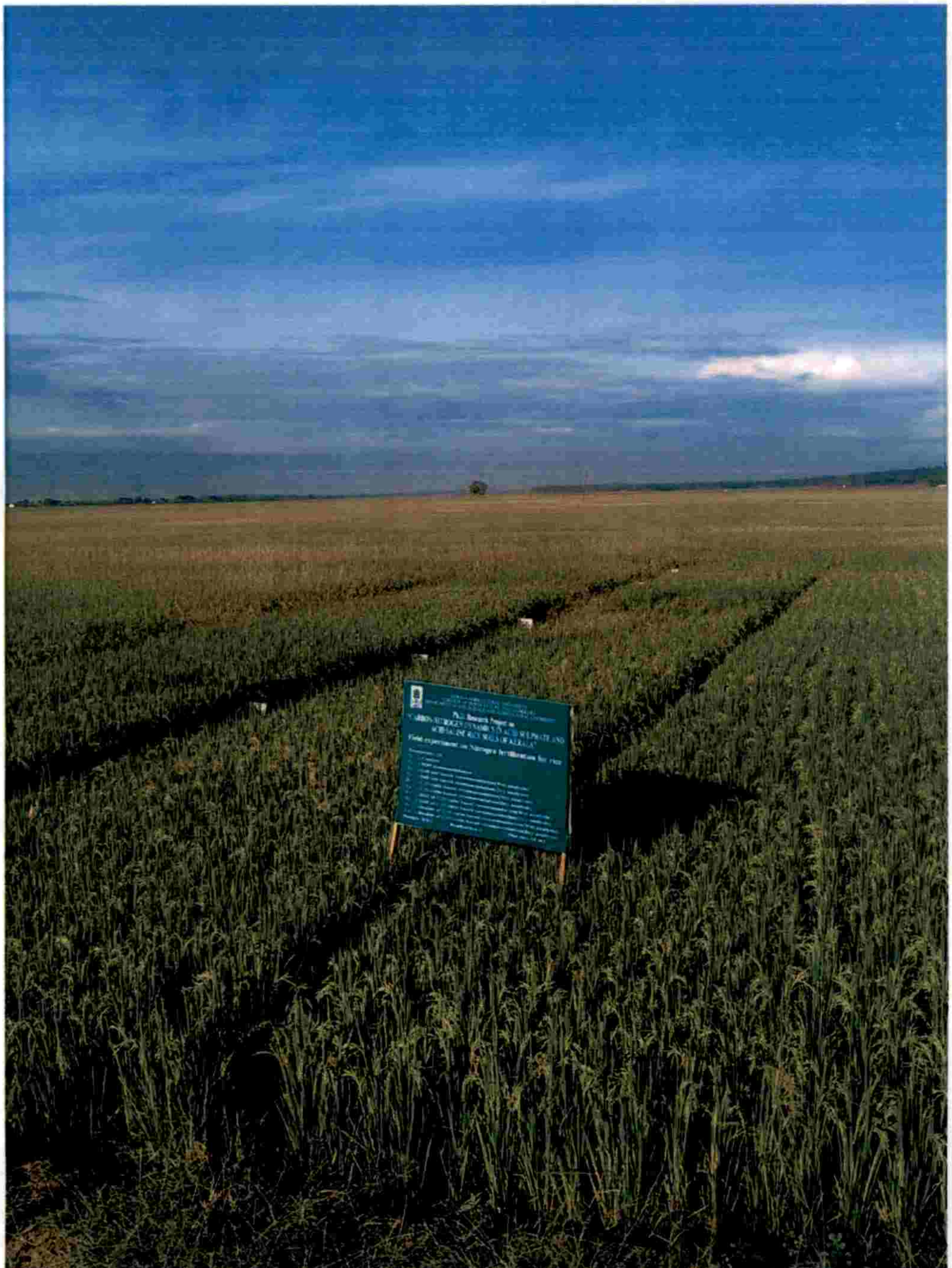

Plate 7. Field view of standing crop

Plate 8. Harvesting

Plate 9. Threshing.

Results

4. Results

The data generated from the various experiments conducted to realise the objectives of the study mentioned in the introduction are presented in this chapter.

Experiment 1

Characterization of soil samples

Representative soil samples (45 Nos.) of 4 different rice growing acid saline and acid sulphate soils of Kerala were collected, to characterise the soils keeping the moisture status as in field following wet analysis with respect to their physico-chemical characteristics in relation to carbon:nitrogen dynamics of the soils. The data are presented in the table No 6 and 7.

4.1 Electrochemical properties and available nutrient status

4.1.1 Soil pH

The pH of the soils ranged from 4.22 to 7.68. The lowest pH was recorded in the Purakkad *kari* of *Kuttanad (*AEU 4, sample No. 11) and the highest in the *Pokkali* soils (AEU 5, sample No. 31).

4.1.2 Electrical conductivity (EC)

The lowest electrical conductivity of 0.046 dSm^{-1} was recorded in the soils of Adattu *Kole* (AEU 6, sample No. 45) and the highest of 4.73 dSm^{-1} was recorded in *Pokkali* soils of AEU 5 (sample No. 33).

4.1.3 Available phosphorus

The available phosphorus ranged from as low as 0.30 to abnormally high value of 165.11 kg ha^{-1}. The highest available phosphorus was observed in *Pokkali* soils (AEU 5, sample No. 32) and the lowest in *Pokkali* (sample No. 31). Out of 45 samples collected and characterised, 9 samples were with P deficiency (<10 kg ha^{-1}), 14 samples were medium in P content (10-24 kg ha^{-1}) and the remaining samples were high (>24 kg ha^{-1}) in phosphorus content.

4.1.4 Available potassium

Available potassium was observed to range from 74.86 to 1233.78 kg ha^{-1}. The lowest available K was recorded in Thekkekonchira(1) of Thrissur *Kole* (AEU 6, sample No. 43) and the highest in Adattu *Kole* (sample No. 45).Out of 45 samples, 19 samples were with high K content (> 275 kg ha^{-1}).

Table 6. Electrochemical properties and available nutrient status of soils

Sr No.	pH	EC (dS/m)	Av P (kg ha^{-1})	Av K (kg ha^{-1})
Vechur Kari				
1	5.42	0.903	9.71	206.56
2	5.51	1.249	102.71	244.10
3	5.90	1.056	28.64	380.94
4	5.27	0.639	25.48	372.34
5	6.20	0.900	15.94	233.84
Kayal lands				
6	6.10	0.319	25.00	103.57
7	6.22	0.290	21.71	162.42
8	4.86	1.329	7.51	255.60
9	6.37	0.979	7.37	255.20
10	4.74	1.048	15.76	221.58
Purakkad Kari				
11	4.22	0.434	17.94	371.85
12	6.09	0.333	15.12	376.02
13	4.83	0.620	8.15	347.22
14	4.76	0.518	12.23	373.70
15	5.13	0.871	10.30	413.85

Sr No.	pH	EC (dS/m)	Av P (kg ha^{-1})	Av K (kg ha^{-1})
Upper Kuttanad				
16	5.45	0.069	23.66	288.27
17	5.30	0.254	25.73	380.77
18	5.25	0.214	24.77	336.31
19	6.02	0.377	21.62	354.77
20	6.48	0.266	25.78	527.48
Lower Kuttanad				
21	6.13	0.638	31.59	154.53
22	6.16	0.449	66.47	137.67
23	6.42	0.383	109.61	166.15
24	6.24	0.685	98.20	202.38
25	5.53	0.420	96.53	129.14
Kaipad lands				
26	6.28	1.690	10.42	384.58
27	6.92	0.670	24.38	142.39
28	7.07	0.094	10.58	85.74
29	6.57	0.460	5.15	160.02
30	6.82	0.100	1.34	100.41
Pokkali lands				
31	7.68	2.270	0.30	565.53
32	7.22	3.970	165.11	618.45
33	4.80	4.730	112.43	468.22
34	6.20	3.930	139.39	482.13
35	6.52	0.739	66.41	247.16

Sr No.	pH	EC (dS/m)	Av P (kg ha^{-1})	Av K (kg ha^{-1})
Ponnani Kole				
36	6.13	0.158	9.23	147.96
37	5.25	0.167	17.00	124.21
38	5.15	0.209	12.34	235.48
39	6.22	0.180	8.32	321.51
40	6.16	0.115	22.03	157.16
Thrissur Kole				
41	6.34	0.120	12.08	134.67
42	6.62	0.099	78.78	145.03
43	6.58	0.123	57.27	74.86
44	6.60	0.197	30.41	112.31
45	5.94	0.046	104.66	1233.78
Range	4.22-7.68	0.046-4.73	0.30-165.11	74.86-1233.78
Mean	5.90	0.43	21.79	239.93

4.1.5 Available calcium

Available calcium content of soils was found to range from 46.30 to 452 mg kg^{-1}. The lowest calcium status was observed in *Kayal* lands (AEU 4, sample 6). Soil from upper *Kuttanad* recorded the highest calcium status of 452 mg kg^{-1} (sample No. 20). Out of 45 samples, 41 were deficient ($<$ 300 mg kg^{-1}) in calcium.

4.1.6 Available magnesium

The available magnesium ranged from 5.16 to 296.31 mg kg^{-1}. The lowest available magnesium was recorded in *Kaipad* lands (AEU 7, sample No. 28) and the highest (296.31mg kg^{-1}) in Purakkad *Kari* (AEU 4, sample No. 14). Out of 45 samples, 35 were deficient ($<$120 mg kg^{-1}) in magnesium. Soils from Purakkad *Kari* and upper *Kuttanad* were sufficient ($>$120 mg kg^{-1}) in magnesium. All other samples were deficient in magnesium status.

4.1.7 Available sulphur

The lowest sulphur content of 0.98 mg kg^{-1} was recorded in the soils from Ponnani *Kole* (AEU 6, sample No. 38) and the highest of 996 mg kg^{-1} was found in soils of *Pokkali* (AEU 5, sample No. 33). Three samples from Ponnani *Kole* and one sample from Adattu *Kole* were deficient in available sulphur ($<$5 mg kg^{-1}).

4.1.8 Available iron

The available iron content of soils ranged from 360.90 to 4971 mg kg^{-1}. The lowest iron content was recorded in *Pokkali* (sample 33) and the highest in upper *Kuttanad* (sample 19). None of the samples were deficient in available Fe. Abnormally high values of iron were recorded in majority of the soils.

4.1.9 Available manganese

Available manganese was found to range from 0.22 to 35.83 mg kg^{-1}. Purakkad *Kari* (sample No. 15) of soils of AEU 4 recorded the lowest and soil from Adattu *Kole* (AEU 6, sample No.45) recorded the highest value. Soils from Vechoor *Kari*, Purakkad *Kari* and *Pokkali* were deficient in manganese ($<$1 mg kg^{-1}).

4.1.10. Available copper

The lowest available copper of 0.02 mg kg^{-1}was recorded in *Pokkali* (AEU 5, sample No. 31) and highest of 7.81 mg kg^{-1}in upper *Kuttanad* (sample No. 20). Out of 45 samples, 31 samples were deficient in copper. Soils of upper *Kuttanad* were sufficient in available copper.

4.1.11 Available zinc

The available zinc was found to vary from 1.35 to 157.78 mg kg^{-1}. The lowest available zinc was recorded in *Kaipad* soil (AEU 7, sample No. 27) and highest in *Pokkali* soil (AEU 5, sample No. 31).None of the samples were deficient in available zinc content.

4.1.12 Available boron

Available boron was observed to range from 0.027 to as high as 28.95mg kg^{-1} The lowest available boron was recorded in Purakkad *Kari* (AEU 4, sample No. 14) and the highest in *Pokkali* soil (AEU 5, sample No. 32). Out of 45 samples, 9 samples were deficient in boron content. Soils from Purakkad Kari and upper *Kuttanad* were deficient in available boron (<0.5 mg kg^{-1}).

Table 7. Available secondary and micronutrient nutrient status of soils

Sr No.	Av Ca	Av Mg	Av S	Av Fe	Av Mn	Av Cu	Av Zn	Av B
mg kg^{-1}								
Vechoor Kari								
1	52.59	17.61	91.82	1814.80	0.36	0.39	2.92	6.96
2	61.15	19.87	133.10	776.15	0.27	1.19	3.00	10.85
3	97.49	22.37	38.86	2507.49	0.28	0.14	1.99	8.15
4	89.32	20.83	40.78	1829.03	0.29	0.17	1.69	12.88
5	64.73	18.77	29.22	2845.70	0.27	0.11	1.84	5.99
Kayal lands								
6	46.30	12.52	26.98	1709.08	3.20	0.13	3.25	3.85
7	74.66	18.07	104.57	1168.08	1.79	0.56	3.90	3.71
8	47.87	18.06	49.74	702.89	1.04	0.14	5.58	5.16
9	112.85	18.40	28.85	2005.21	1.89	0.18	7.17	7.13
10	77.80	17.28	497.93	408.02	0.88	1.63	4.92	4.94
Purakkad Kari								
11	130.59	268.48	31.99	846.90	0.35	0.35	2.04	0.37
12	184.31	270.52	8.75	4216.38	0.51	0.51	2.17	0.53
13	387.84	273.48	156.29	375.40	0.32	0.32	2.56	0.27
14	365.61	296.31	122.59	1047.33	0.80	0.80	1.55	0.027
15	271.04	272.63	228.35	538.38	0.22	0.22	2.67	0.93

Sr No.	Av Ca	Av Mg	Av S	Av Fe	Av Mn	Av Cu	Av Zn	Av B
Upper Kuttanad								
16	222.54	248.49	6.50	1247.94	4.85	4.85	2.01	0.08
17	187.85	210.71	11.46	2052.61	3.12	3.12	4.82	0.20
18	244.60	228.36	8.04	1654.167	3.92	3.92	4.81	0.17
19	225.40	229.01	19.89	4971.01	2.75	2.75	4.36	0.08
20	451.83	281.31	13.17	4388.02	7.81	7.81	7.39	0.30
Lower Kuttanad								
21	53.86	15.40	93.80	431.91	1.43	2.71	3.25	5.20
22	52.66	14.99	125.16	813.67	0.79	0.88	3.33	2.87
23	75.68	17.70	30.65	557.12	0.64	2.35	3.15	3.37
24	57.09	17.68	54.65	792.87	0.90	3.47	3.70	3.16
25	70.17	15.50	26.22	822.98	0.58	2.43	3.57	4.86
Kaipad lands								
26	82.79	21.27	573.70	948.89	0.76	0.65	3.29	14.73
27	93.47	16.84	19.94	789.52	2.03	0.87	1.35	3.46
28	81.55	5.16	7.77	2245.58	1.53	0.60	2.92	3.77
29	62.11	17.12	79.79	2944.75	0.52	0.13	1.81	2.67
30	88.68	6.60	12.15	1717.54	1.43	2.75	2.20	1.87
Pokkali lands								
31	137.61	22.55	553.37	907.81	0.75	0.023	157.78	15.21
32	113.50	23.71	940.95	440.60	0.31	0.089	77.30	28.95
33	103.95	22.76	995.92	360.90	0.47	0.026	152.62	19.07
34	105.30	21.14	616.10	436.03	0.31	0.196	70.05	16.67
35	74.36	19.01	307.96	891.05	0.73	0.765	85.61	7.34

Sr No.	Av Ca	Av Mg	Av S	Av Fe	Av Mn	Av Cu	Av Zn	Av B
Ponnani Kole								
36	75.93	8.57	10.02	1990.35	2.60	0.16	1.73	1.96
37	78.86	7.52	1.02	1829.38	3.29	0.54	2.20	2.11
38	98.11	9.27	0.98	2207.11	1.40	0.58	2.32	1.75
39	100.25	12.19	2.97	1920.95	1.96	0.053	2.10	2.26
40	50.38	5.53	5.94	1586.79	0.75	0.24	2.007	1.92
Thrissur Kole								
41	166.74	12.79	9.93	1236.66	7.18	2.74	5.91	2.62
42	123.63	7.59	7.47	3482.00	2.25	0.21	4.09	4.344
43	96.42	6.24	12.95	2216.67	2.03	0.032	4.37	2.20
44	105.64	6.85	14.92	1349.81	1.95	2.67	4.31	4.17
45	382.45	97.19	2.27	1307.00	35.83	0.60	5.72	1.30
Range	**46.3 to 450.83**	**5.16 To 296.31**	**0.98 to 995.92**	**360.9 to 4971**	**0.22 to 35.83**	**0.02 to 7.81**	**1.35 to 157.78**	**0.027 to 28.95**
Mean	**107.22**	**27.78**	**35.49**	**1263.39**	**1.13**	**0.51**	**4.50**	**2.34**

4.2 Carbon status and C:N ratio's in soils

The organic carbon, total carbon, microbial biomass carbon, total nitrogen, available nitrogen and the C:N ratio's organic C:total N and total C:total N of the soils under study are presented in table 8.

4.2.1 Organic carbon

The organic carbon status of the soils varied from 0.81 to 7.58 per cent. Soils from *Kaipad* (AEU 7, sample No. 27) recorded the lowest and soils from Vechoor *Kari* of *Kuttanad* (AEU 4, sample No. 4) recorded the highest value.

4.2.2 Total carbon

The total carbon of the soils ranged from 0.92 to 7.52 per cent. The lowest total carbon was recorded in the soils of upper Kuttanad (AEU 4, sample 16) and highest in the Kari soils of Vechoor (AEU 4, sample 4). Out of the soils collected from *Kuttanad region*, soils from Vechoor *Kari* and upper *Kuttanad* recorded highest and lowest total carbon content respectively. The total carbon content in *Kaipad* ranged from 1.06 to 2.15 per cent.

4.2.3 Microbial biomass carbon

The lowest microbial biomass carbon of 126.63 $\mu g\ g^{-1}$was recorded in *Kaipad* soil(AEU 7, sample No. 27) and highest of 274.91$\mu g\ g^{-1}$ in Thekkekonchira of Thrissur *Kole* (AEU 6, sample No. 44).

4.2.4 Total nitrogen

The total nitrogen ranged from 0.05 to 0.42 per cent. The lowest total nitrogen was observed in soils of Upper *Kuttanad* (AEU 4, sample No. 16) and *Kaipad* lands (Sample27). Soils from Vechoor *Kari* (AEU 4, sample No. 4) recorded the highest total nitrogen status.

4.2.5 Available nitrogen

The highest available nitrogen content of 281.38 kg ha^{-1} was recorded in sample from Vechoor *Kari* (sample No. 4) and the lowest of 19.84 kg ha^{-1} in soil from Purakkad *Kari* (sample No. 13). Out of the total 45 samples, 44 samples were deficient($<$280 kg ha^{-1}) in nitrogen.

4.2.5 Carbon:nitrogen ratio

4.2.5.1 Organic carbon:total nitrogen ratio

The C:N ratio's Organic carbon:Total nitrogen and total carbon:total nitrogen ratio of the soils are presented in table 8.

4.2.5.1.1 Organic carbon : Total nitrogen (C:N) ratio

The C:N ratio varied from 13:1 to 24:1. Widest C:N ratio was recorded in soils of Upper *Kuttanad* (AEU 4, sample No. 20) and the lowest in samples from Thrissur Kole (AEU 6, sample 43 and 44).

4.2.5.1.2 Total carbon:Total nitrogen (C:N) ratio

The C:N ratio varied from 14:1 to 24:1. Highest C:N ratio was recorded in soils of Upper *Kuttanad* (AEU 4, sample No. 20) and the lowest in samples from Thrissur Kole (AEU 6, sample 41 and 43).

Table 8. Carbon and nitrogen status and C:N ratio's in soils

S No.	OC %	TC %	MBC µg g^{-1}	TN %	Av N kg ha^{-1}	C:N ratio OC:TN	C:N ratio TOTC/TN
Vechur Kari							
1	5.48	5.52	177.50	0.32	222.45	17:1	17:1
2	5.38	5.38	167.59	0.28	138.15	19:1	19:1
3	5.83	6.00	209.17	0.35	272.67	17:1	17:1
4	7.58	7.58	165.41	0.42	281.38	18:1	18:1
5	3.74	3.76	149.31	0.18	214.78	21:1	21:1
Kayal lands							
6	1.82	1.85	160.10	0.12	85.92	15:1	15:1
7	1.81	1.83	157.16	0.11	149.22	16:1	17:1
8	2.83	2.85	153.27	0.18	119.28	16:1	16:1
9	2.48	2.48	159.84	0.16	64.31	16:1	16:1
10	3.20	3.20	149.72	0.18	104.56	18:1	18:1
Purakkad Kari							
11	4.10	4.14	148.80	0.20	55.52	21:1	21:1
12	3.15	3.20	154.79	0.16	119.72	20:1	20:1
13	2.67	2.70	131.33	0.12	19.84	22:1	23:1
14	3.40	3.42	143.01	0.18	20.51	19:1	19:1
15	2.60	2.60	132.77	0.14	46.48	19:1	19:1

S No.	OC %	TC %	MBC $\mu g\ g^{-1}$	TN %	Av N $kg\ ha^{-1}$	C:N ratio OC:TN	C:N ratio TOTC/TN
Upper Kuttanad							
16	0.85	0.92	142.89	0.05	41.04	17:1	18:1
17	2.11	2.13	142.34	0.10	74.93	21:1	21:1
18	2.05	2.08	170.12	0.12	109.92	17:1	17:1
19	2.51	2.54	152.42	0.14	146.39	18:1	18:1
20	2.82	2.82	164.63	0.12	100.86	24:1	24:1
Lower Kuttanad							
21	3.40	3.40	148.80	0.18	179.99	19:1	19:1
22	1.74	1.78	153.28	0.12	154.20	15:1	15:1
23	2.93	3.02	167.15	0.14	145.38	21:1	22:1
24	2.82	2.85	189.87	0.16	169.61	18:1	18:1
25	2.27	2.27	168.64	0.14	197.23	16:1	16:1
Kaipad lands							
26	2.33	2.35	179.03	0.13	60.03	18:1	18:1
27	0.81	1.06	126.63	0.05	65.36	16:1	21:1
28	2.07	2.15	135.09	0.12	86.69	17:1	18:1
29	1.48	1.56	143.66	0.09	129.97	17:1	17:1
30	1.26	1.35	140.59	0.08	108.40	16:1	17:1
Pokkali lands							
31	3.54	3.75	185.39	0.20	53.16	18:1	19:1
32	3.29	3.36	208.73	0.18	64.13	18:1	19:1
33	3.16	3.21	198.53	0.18	93.92	18:1	18:1
34	4.60	4.68	168.20	0.22	94.35	21:1	21:1
35	1.31	1.43	154.58	0.09	35.30	15:1	16:1

S No.	OC %	TC %	MBC µg g^{-1}	TN %	Av N kg ha^{-1}	C:N ratio OC:TN	C:N ratio TOTC/TN
PonnaniKole							
36	2.00	2.05	145.01	0.14	136.95	14:1	15:1
37	2.09	2.12	156.45	0.14	140.52	15:1	15:1
38	2.10	2.16	140.56	0.12	108.20	18:1	18:1
39	2.44	2.51	140.80	0.16	108.29	15:1	16:1
40	1.68	1.68	140.24	0.10	81.24	17:1	17:1
Thrissur Kole							
41	1.67	1.68	148.20	0.12	131.46	14:1	14:1
42	1.85	1.92	255.58	0.10	159.66	19:1	19:1
43	1.02	1.08	248.42	0.08	89.34	13:1	14:1
44	2.15	2.18	274.91	0.16	180.74	13:1	14:1
45	2.35	2.38	257.72	0.12	110.83	20:1	20:1
Range	**0.81 to 7.58**	**0.92 To 7.58**	**126.63 to 274.91**	**0.5 to 0.42**	**19.84 to 281.38**	**13:1 to 24:1**	**14:1 to 24:1**
Mean	**2.72**	**2.77**	**166.84**	**0.15**	**117.17**	**17.28:1**	**17.5:1**

Experiment 2

Fractionation of soil carbon

Representative soil samples (45 Nos.) of 4 different rice growing acid saline and acid sulphate soils of Kerala were subjected to fractionation of soil carbon.

4.2.1 Physical fractionation

The data on soil carbon and nitrogen preferentially recovered in the sand, silt and clay size fractions are presented in table 9 and 10. The carbon content in macro size sand fraction varied from 0.0062 to 0.5 per cent. The maximum carbon in macro size sand fraction was estimated in soil from lower *Kuttanad* (sample No. 23) and the minimum in soil from upper *Kuttanad* (sample No. 16).

The nitrogen content in macro size sand fraction ranged from 0.00093 to 0.3 per cent. The lowest nitrogen in macro size sand fraction was recorded in soil from upper *Kuttanad* (sample No. 16) and the highest in lower *Kuttanad* (sample No. 23).

The carbon in micro sized sand fraction ranged from 0.012 in upper *Kuttanad* (sample 16) to 0.545 percent in Vechoor *Kari* (Sample 2). The highest nitrogen in micro sized sand fraction was recorded in *Kayal* lands (Sample 7) (0.039 per cent) and the lowest in upper *Kuttanad* (sample 16) (0.0011 per cent).

The carbon content in silt sized fraction varied from 0.041 in Ponnani *Kole* (sample 36) to 0.53 per cent in Vechoor *Kari (sample 3)*. The lowest nitrogen in silt sized fraction was observed in upper *Kuttanad (sample 16)* (0.0037 per cent) and the highest in Vechoor *Kari* (sample 3*)* (0.031 per cent).

The carbon content in the clay fraction ranged from 0.03 in *Kaipad* soil (sample 27) to 0.36 in Vechoor *Kari* (sample 3). The nitrogen content in clay fraction varied from 0.0033 to 0.028 percent. The highest nitrogen was recorded in Purakkad *Kari* (sample 12) soil and lowest in *Kaipad* soil (sample 30).

Table 9. Soil carbon recovered in the sand, silt and clay size fractions

Sr No.	Macro sand C %	Micro sand C %	Silt C %	Clay C %
Vechoor Kari				
1	0.30	0.407	0.261	0.212
2	0.35	0.545	0.328	0.222
3	0.34	0.438	0.535	0.362
4	0.41	0.422	0.47	0.358
5	0.32	0.312	0.376	0.181

Sr No.	Macro sand C %	Micro sand C %	Silt C %	Clay C %
Kayal lands				
6	0.14	0.249	0.146	0.117
7	0.11	0.147	0.127	0.113
8	0.21	0.264	0.16	0.124
9	0.06	0.196	0.185	0.132
10	0.15	0.272	0.269	0.136
Purakkad Kari				
11	0.16	0.234	0.133	0.154
12	0.27	0.251	0.185	0.125
13	0.09	0.263	0.311	0.206
14	0.23	0.328	0.370	0.188
15	0.037	0.081	0.183	0.180
Upper Kuttanad				
16	0.0062	0.012	0.046	0.066
17	0.083	0.275	0.218	0.155
18	0.074	0.138	0.120	0.148
19	0.044	0.112	0.156	0.159
20	0.041	0.06	0.088	0.079
Lower Kuttanad				
21	0.13	0.106	0.142	0.122
22	0.34	0.201	0.177	0.053
23	0.50	0.392	0.214	0.110
24	0.23	0.233	0.231	0.129
25	0.19	0.215	0.156	0.113

Sr No.	Macro sand C %	Micro sand C %	Silt C %	Clay C %
Kaipad lands				
26	0.18	0.212	0.074	0.046
27	0.028	0.061	0.113	0.031
28	0.23	0.058	0.107	0.048
29	0.25	0.132	0.225	0.065
30	0.064	0.084	0.059	0.030
Pokkali lands				
31	0.044	0.106	0.141	0.085
32	0.11	0.142	0.140	0.087
33	0.15	0.226	0.185	0.111
34	0.16	0.194	0.200	0.099
35	0.099	0.170	0.140	0.080
Ponnani Kole				
36	0.021	0.024	0.041	0.042
37	0.15	0.116	0.127	0.050
38	0.106	0.118	0.114	0.064
39	0.101	0.236	0.115	0.057
40	0.037	0.086	0.112	0.058
Thrissur Kole				
41	0.075	0.116	0.088	0.062
42	0.11	0.150	0.062	0.075
43	0.085	0.119	0.082	0.091
44	0.088	0.18	0.130	0.097
45	0.045	0.048	0.062	0.047
Range	**0.0062 to 0.5**	**0.012 to 0.545**	**0.041 to 0.535**	**0.03 to 0.36**
Mean	**0.114**	**0.155**	**0.149**	**0.099**

Table 10. Soil nitrogen recovered in the sand, silt and clay size fractions

Sr. No.	Macro Sand N %	Micro sand N%	Silt N%	Clay N%
Vechoor Kari				
1	0.018	0.026	0.0162	0.0146
2	0.021	0.032	0.0211	0.0153
3	0.016	0.020	0.0316	0.0218
4	0.019	0.018	0.0217	0.0189
5	0.018	0.016	0.0215	0.0109
Kayal lands				
6	0.011	0.019	0.0135	0.0118
7	0.010	0.039	0.0132	0.0117
8	0.013	0.024	0.0147	0.0108
9	0.005	0.016	0.0173	0.0131
10	0.012	0.023	0.0242	0.0133
Purakkad Kari				
11	0.0088	0.013	0.0079	0.0090
12	0.0093	0.014	0.0132	0.0287
13	0.0054	0.0086	0.0124	0.0083
14	0.0087	0.0079	0.0138	0.0069
15	0.0019	0.0047	0.0082	0.0082
Upper Kuttanad				
16	0.00093	0.0011	0.0037	0.0062
17	0.0060	0.0206	0.0190	0.0134
18	0.0072	0.013	0.0121	0.0143
19	0.0043	0.010	0.0174	0.0151
20	0.0035	0.0049	0.0076	0.0074

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Sr. No.	Macro Sand N %	Micro sand N%	Silt N%	Clay N%
Lower Kuttanad				
21	0.011	0.0088	0.0134	0.0127
22	0.029	0.019	0.0188	0.0088
23	0.03	0.030	0.02	0.0110
24	0.016	0.021	0.0228	0.0138
25	0.012	0.017	0.0162	0.0125
Kaipad lands				
26	0.0097	0.0190	0.0069	0.0060
27	0.0030	0.0041	0.0111	0.0046
28	0.015	0.0043	0.0181	0.0067
29	0.013	0.0076	0.0174	0.0066
30	0.0039	0.0058	0.0060	0.0033
Pokkali lands				
31	0.0039	0.0074	0.0118	0.0079
32	0.0093	0.011	0.0144	0.0083
33	0.014	0.018	0.0162	0.0113
34	0.015	0.017	0.0187	0.0105
35	0.0047	0.0052	0.0101	0.0076
Ponnani Kole				
36	0.0065	0.0048	0.0055	0.0072
37	0.011	0.012	0.0120	0.0058
38	0.011	0.010	0.0121	0.0078
39	0.0092	0.018	0.0128	0.0066
40	0.0039	0.0056	0.0115	0.0060

Sr. No.	Macro Sand N %	Micro sand N%	Silt N%	Clay N%
Thrissur Kole				
41	0.0069	0.01	0.0083	0.0060
42	0.012	0.0106	0.0069	0.00767
43	0.0083	0.0108	0.0083	0.0094
44	0.0097	0.0138	0.0120	0.0094
45	0.0101	0.0125	0.0113	0.0096
Range	**0.00093 to 0.03**	**0.0011 to 0.039**	**0.0037 to 0.031**	**0.0033 to 0.028**
Mean	**0.0088**	**0.0118**	**0.0129**	**0.0095**

4.2.3 Chemical fractionation

The data on various chemical fractions of carbon in above soils are given in the table 11.

4.2.3.1 Water soluble carbon (WSC)

The water soluble carbon content ranged from 0.02 to 0.59 per cent. The lowest WSC was recorded in the Vechoor *Kari* (sample No. 5) and the highest in upper *Kuttanad* (sample No. 18).

4.2.3.2 Hot water extractable carbon (HWEC)

The hot water extractable carbon varied from 0.0032 to 0.29 per cent. The lowest hot water extractable carbon was recorded in *Pokkali* soil (sample No. 35) and the highest in Vechoor *Kari* soil (sample No. 3).

4.2.3.3 Permanganate oxidizable carbon (POC)

Permanganate oxidizable carbon were in the range of 0.033 to 1.67 per cent. The lowest POC was recorded in Pokkali soil (sample No. 31) and the highest in soil from Purakkad Kari (sample No. 14).

Table 11. Fractions of carbon in soils

Sr. No.	WSC	HWEC	POC
	%		
Vechoor Kari			
1	0.023	0.051	0.434
2	0.226	0.071	0.691
3	0.024	0.291	0.860
4	0.067	0.124	0.329
5	0.021	0.145	0.612
Kayal lands			
6	0.067	0.013	0.501
7	0.022	0.013	0.233
8	0.065	0.019	0.193
9	0.088	0.013	0.127
10	0.108	0.019	0.160
Purakkad Kari			
11	0.258	0.019	0.962
12	0.109	0.0065	0.546
13	0.226	0.018	0.935
14	0.233	0.031	1.671
15	0.247	0.030	0.477
Upper Kuttanad			
16	0.531	0.006	0.566
17	0.338	0.006	0.540
18	0.592	0.013	0.500
19	0.541	0.022	0.402
20	0.044	0.006	0.164

Sr. No.	WSC	HWEC	POC
	%		
Lower Kuttanad			
21	0.129	0.058	0.711
22	0.043	0.009	0.752
23	0.135	0.020	0.334
24	0.143	0.064	0.434
25	0.045	0.071	0.685
Kaipad lands			
26	0.279	0.003	1.002
27	0.040	0.012	1.637
28	0.041	0.018	0.768
29	0.340	0.044	0.504
30	0.042	0.006	0.775
Pokkali lands			
31	0.354	0.021	0.033
32	0.274	0.007	0.969
33	0.048	0.007	0.264
34	0.135	0.013	0.080
35	0.219	0.003	0.701
Ponnani Kole			
36	0.212	0.006	0.835
37	0.546	0.026	0.935
38	0.420	0.025	0.952
39	0.210	0.006	0.608
40	0.147	0.006	1.450

Sr. No.	WSC	HWEC	POC
	%		
Thrissur Kole			
41	0.473	0.058	0.645
42	0.043	0.006	0.220
43	0.170	0.032	0.275
44	0.112	0.033	0.336
45	0.422	0.089	0.596
Range	**0.021-0.592**	**0.0032-0.291**	**0.033422-1.671123**
Mean	**0.130511**	**0.019303**	**0.483599**

Experiment 3

Fractionation of soil nitrogen

Representative soil samples (45 Nos.) of 4 different rice growing acid saline and acid sulphate soils of Kerala were subjected to fractionation of soil nitrogen.

4.3.1 Organic fractions

The data on various organic fractions of nitrogen in the above soils are given in the table 11.

4.3.1.1 Total hydrolysable nitrogen (THN)

The total hydrolysable nitrogen ranged from 0.0088 to 0.057 per cent. The lowest THN was recorded in Purakkad *Kari* soil (sample 13) and the highest in Vechoor *Kari* soil (sample 3).

4.3.1.2 Amino acid nitrogen (AAN)

The amino acid nitrogen was found to vary from 0.003 to 0.045 per cent. The lowest AAN was observed in lower *Kuttanad* (sample 23). Soil from *Pokkali* (sample 34) recorded the highest AAN of 0.045 per cent.

Table 12. Organic fractions of nitrogen in soils

Sr. No.	THN	AAN	TOT N
	%		
1	0.033	0.023	0.056
2	0.052	0.029	0.081
3	0.057	0.043	0.1
4	0.055	0.016	0.071
5	0.037	0.034	0.071
6	0.029	0.026	0.054
7	0.044	0.044	0.089
8	0.05	0.028	0.078
9	0.032	0.029	0.061
10	0.044	0.025	0.068
11	0.056	0.043	0.099
12	0.05	0.013	0.063
13	0.009	0.006	0.015
14	0.018	0.015	0.034
15	0.021	0.018	0.039
16	0.021	0.012	0.034
17	0.018	0.006	0.024
18	0.043	0.039	0.082
19	0.056	0.025	0.081
20	0.029	0.016	0.045
21	0.046	0.025	0.071
22	0.028	0.003	0.031
23	0.036	0.003	0.039
24	0.028	0.021	0.048
25	0.046	0.023	0.068

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Sr. No.	THN	AAN	TOT N
	%		
26	0.03	0.023	0.054
27	0.02	0.018	0.038
28	0.015	0.015	0.03
29	0.04	0.018	0.058
30	0.018	0.003	0.021
31	0.047	0.027	0.075
32	0.057	0.032	0.089
33	0.045	0.038	0.084
34	0.052	0.045	0.097
35	0.019	0.019	0.038
36	0.028	0.003	0.031
37	0.031	0.025	0.056
38	0.033	0.024	0.057
39	0.024	0.024	0.048
40	0.03	0.012	0.042
41	0.056	0.037	0.093
42	0.031	0.015	0.046
43	0.015	0.009	0.025
44	0.029	0.016	0.045
45	0.028	0.025	0.053
Range	**0.009 to 0.057**	**0.003 to 0.045**	**0.015 to 0.1**

4.3.2 Inorganic fractions

The data on various inorganic fractions of nitrogen in the above soils are given in the table 13.

4.3.2.1 Ammoniacal nitrogen (NH_4^+- N)

Ammoniacal nitrogen was observed to range from 7.4 to 162.00 mg kg^{-1}. The lowest NH_4^+- N was recorded in *Kaipad* soil (sample 28) and the highest in Vechoor *Kari* (sample 5).

4.3.2.2 Nitrate nitrogen (NO_3^--N)

The lowest NO_3^- -N of 7.4 mg kg^{-1}was recorded in *Kaipad* soil (sample 28) and the highest of 79.00 mg kg^{-1}was recorded in *Kayal* lands (sample 6) of *Kuttanad*.

Table 13. Inorganic fractions of nitrogen in soils

Sr. No.	NH_4^+-N (Mg kg^{-1})	NO_3^--N (Mg kg^{-1})
1	16.55	24.83
2	16.23	16.23
3	80.56	44.75
4	32.21	24.16
5	162.39	23.20
6	39.96	79.92
7	39.65	71.38
8	7.83	54.82
9	31.90	39.88
10	31.12	31.12
11	38.73	46.48
12	70.74	39.30
13	14.76	66.43
14	22.90	30.53
15	29.65	22.23
16	15.27	76.34

Sr. No.	NH_4^+-N (Mg kg-1)	NO_3^--N (Mg kg-1)
17	22.81	30.41
18	40.89	40.89
19	46.68	54.46
20	32.16	24.12
21	30.91	46.36
22	70.4	46.94
23	56.79	32.45
24	51.63	60.23
25	32.61	24.46
26	8.38	8.38
27	47.42	43.77
28	7.44	7.44
29	53.44	30.54
30	15.12	37.81
31	42.38	42.38
32	26.84	71.58
33	52.41	43.68
34	32.40	32.40
35	39.41	31.53
36	61.14	15.29
37	15.68	7.84
38	52.83	22.64
39	15.11	15.11
40	7.56	15.11
41	38.61	38.61
42	46.49	61.98
43	38.35	69.03
44	32.28	32.28
45	23.52	47.03

4.4 Correlation coefficient between electrochemical properties and nutrient status of soil

The correlation coefficient between electrochemical properties and nutrient status of soils are given in the table 14. Organic carbon had significant negative correlation with pH. Electrical conductivity, total C, total N, OC:tot N (C:N ratio), available nitrogen and boron had significant positive correlation with organic carbon and total carbon content.

Total nitrogen had significant positive correlation with electrical conductivity, total carbon, organic carbon, available nitrogen and boron content.

The C:N ratio's total C:total N and organic carbon:total nitrogen ratio had significant positive correlation with total carbon, OC, available K, Ca and Mg.

Total carbon, organic carbon, total nitrogen, available calcium and magnesium content had significant positive correlation with available nitrogen.

Table 14. Correlation coefficient between electrochemical properties and nutrient status of soil

	pH	EC	Tot C	OC	Tot N	Tot C: Tot N	OC: Tot N	Av N	Av P	Av K	Av Ca	Av Mg	Av S	Av Fe	Av Mn	Av Cu	Av Zn	Av B
pH	1																	
EC	0.025NS	1																
TotC	-0.277NS	0.359*	1															
OC	-0.295*	0.351*	0.999**	1														
Tot N	-0.263NS	0.317*	0.970**	0.970**	1													
Tot C: Tot N	-0.117NS	0.179NS	0.281 NS	0.275 NS	0.051 NS	1												
OC :Tot N	-0.234NS	0.187NS	0.385**	0.389**	0.165 NS	0.947**	1											
Av N	0.019NS	-0.141NS	0.506**	0.509**	0.587**	-0.194 NS	-0.116 NS	1										
Av P	0.138NS	0.535**	0.142 NS	0.140 NS	0.084 NS	0.166 NS	0.178 NS	0.066 NS	1									
Av K	-0.087NS	0.349*	0.273 NS	0.271 NS	0.179 NS	0.440**	0.478**	-0.198 NS	0.307*	1								
Av Ca	-0.217NS	-0.139NS	-0.064 NS	-0.058 NS	-0.174 NS	0.483**	0.511**	-0.388**	-0.089 NS	0.593 **	1							

	pH	EC	Tot C	OC	Tot N	Tot C: Tot N	OC: Tot N	Av N	Av P	Av K	Av Ca	Av Mg	Av S	Av Fe	Av Mn	Av Cu	Av Zn	Av B
Av Mg	-0.439 **	-0.177 NS	-0.009 NS	-0.001 NS	-0.130 NS	0.504 **	0.539 **	-0.407 **	-0.223 NS	0.355 *	0.803 **	1						
Av S	0.051 NS	0.916 **	0.195 NS	0.189 NS	0.158 NS	0.123 NS	0.135 NS	-0.291 NS	0.467 **	0.348 *	-0.084 NS	-0.142 NS	1					
Av Fe	0.214 NS	-0.389 **	-0.053 NS	-0.051 NS	-0.063 NS	0.067 NS	0.093 NS	0.256 NS	-0.321 *	-0.034 NS	0.209 NS	0.232 NS	-0.443 **	1				
Av Mn	0.037 NS	-0.218 NS	-0.171 NS	-0.168 NS	-0.193 NS	0.091 NS	0.097 NS	-0.050 NS	0.160 NS	0.668 **	0.484 **	0.110 NS	-0.185 NS	0.076 NS	1			
Av Cu	0.024 NS	-0.287 NS	-0.209 NS	-0.201 NS	-0.262 NS	0.229 NS	0.240 NS	0.012 NS	-0.011 NS	-0.014 NS	0.406 **	0.384 **	-0.252 NS	0.205 NS	0.157 NS	1		
Av Zn	0.218 NS	0.768 **	0.121 NS	0.105 NS	0.097 NS	0.057 NS	0.025 NS	-0.271 NS	0.367 *	0.340 *	-0.058 NS	-0.157 NS	0.781 **	-0.286 NS	-0.098 NS	-0.203 NS	1	
Av B	0.251 NS	0.874 **	0.436 **	0.427 **	0.435 **	0.030 NS	0.038 NS	0.050 NS	0.538 **	0.272 NS	-0.319 *	-0.417 **	0.834 **	-0.349 *	-0.211 NS	-0.339 *	0.676 **	1

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4.5 Correlation coefficient between fractions of carbon and nitrogen, electrochemical properties and nutrient status of soil

The correlation coefficient between electrochemical properties and nutrient status of soils are given in the table 15.

Water soluble carbon had significant negative correlation with available nitrogen

Hot water extractable carbon had significant positive correlation with total carbon, organic carbon, total nitrogen and available N content.

Carbon content in macro sized sand fraction had significant negative correlation with available calcium and water soluble carbon and positive correlation with total carbon, organic carbon, total nitrogen, available nitrogen, hot water extractable carbon, micro sized sand fraction's, silt sized fraction's and clay sized fraction's C content.

Total carbon, organic carbon, total nitrogen, available N, hot water extractable carbon, and carbon recovered from macro and micro sized sand fraction's, silt sized fraction and clay fraction had significant positive correlation with carbon content in micro sized sand fraction.

Carbon content in silt sized fraction had significant positive correlation with total carbon, organic carbon, total nitrogen, available nitrogen, hot water extractable carbon, and carbon recovered from macro and micro sized sand fraction's and clay sized fractions.

The carbon content in the clay sized fraction had significant positive correlation with total carbon, organic carbon, total nitrogen, available nitrogen, hot water extractable carbon and carbon recovered from macro sized and micro sized sand fraction's and silt fraction.

Among the organic fractions of nitrogen, total hydrolysable nitrogen had significant positive correlation with electrical conductivity, total carbon, organic carbon, total nitrogen, available nitrogen, boron, hot water extractable carbon and amino acid nitrogen. Amino acid nitrogen had positive correlation with electrical conductivity.

Among the inorganic nitrogen fractions, ammoniacal nitrogen had significant positive correlation with available nitrogen, iron, hot water extractable carbon and amino acid nitrogen.

Nitrogen recovered from macro sized sand fraction had positive correlation with total carbon, organic carbon, total nitrogen, available nitrogen, phosphorus, NH_4^+-N, nitrogen recovered from macro and micro sized sand fraction and clay fraction. It had negative correlation with water soluble carbon.

Nitrogen recovered from micro sized sand fraction had significant positive correlation with total carbon, organic carbon, tot C: tot N (C:N) ratio, available N, amino acid nitrogen, nitrogen recovered from macro sized sand fraction and clay sized fraction. It had negative correlation with water soluble carbon and permanganate oxidizable carbon content.

Water soluble carbon had significant negative correlation with N recovered in the silt sized fraction. Total carbon, organic carbon, total nitrogen, available nitrogen, hot water extractable carbon, total hydrolysable nitrogen, NH_4^+-N, nitrogen recovered from macro and micro sized sand fraction and clay sized fraction had significant positive correlation with the nitrogen recovered in silt sized fraction.

The nitrogen recovered in the clay fraction had significant positive correlation with total carbon, organic carbon, total nitrogen, available nitrogen, hot water extractable carbon, total hydrolysable nitrogen, amino acid nitrogen, NH_4^+-N, nitrogen recovered from macro sized and micro sized sand fraction and silt sized fraction.

Table 15. Correlation coefficient between fractions of carbon and nitrogen, electrochemical properties and nutrient status of soil

	WSC	HWEC	POC	THN	AAN	Amm N	Nit N	MacSa C	MicSa C	SiltC	ClayC	Macsa N	MicSa N	SiltN	ClayN
WSC	1														
HWEC	-0.171NS	1													
POC	0.117NS	0.038NS	1												
THN	0.136NS	0.413**	-0.215NS	1											
AAN	-0.062NS	0.115NS	-0.200NS	0.360*	1										
AmmN	-0.200NS	0.437**	-0.089NS	0.084NS	0.333*	1									
NitN	-0.003NS	-0.061NS	-0.214NS	0.112NS	0.024NS	0.061NS	1								
MacSaC	-0.378*	0.456**	-0.049NS	0.152NS	0.165NS	0.325*	-0.198NS	1							
MicSaC	-0.332*	0.464**	-0.070NS	0.268NS	0.142NS	0.156NS	-0.120NS	0.781**	1						
SiltC	-0.279NS	0.702**	0.035NS	0.315*	0.022NS	0.331*	-0.105NS	0.666**	0.800**	1					
ClayC	-0.187NS	0.674**	-0.103NS	0.411**	0.053NS	0.187NS	0.034NS	0.503**	0.743**	0.881**	1				
MacsaN	-0.373*	0.335*	-0.169NS	0.122NS	0.199NS	0.320*	-0.116NS	0.885**	0.627**	0.449**	0.277NS	1			
MicSaN	-0.310*	0.193NS	-0.354*	0.294NS	0.388**	0.073NS	0.060NS	0.569**	0.695**	0.368*	0.364*	0.639**	1		
SiltN	-0.306*	0.603**	-0.159NS	0.363*	0.166NS	0.335*	-0.096NS	0.664**	0.672**	0.787**	0.607**	0.633**	0.546**	1	
ClayN	-0.195NS	0.445**	-0.309*	0.309*	0.395**	0.296*	0.106NS	0.468**	0.567**	0.549**	0.665**	0.315*	0.471**	0.584**	1

4.6. Path analysis

Path coefficients of different fractions of carbon and nitrogen indicating the direct and indirect effects on total N are given in the table 17. Water soluble carbon had negative direct effect (-0.203) with total nitrogen in soil. Hot water extractable carbon had very high and positive direct effect (0.487) on total nitrogen in soil. The direct effect of total hydrolysable nitrogen (THN) on total nitrogen was medium (0.206).

Table 16. Correlation between carbon and nitrogen fractions and nutrient status of soil

	WSC	**HWEC**	**POC**	**THN**	**AAN**	**NH_4^+-N**	**NO_3^--N**
pH	NS	NS	NS	NS	NS	NS	NS
EC	NS	NS	NS	0.385**	0.412**	NS	NS
Tot C	NS	**0.576****	NS	**0.527****	NS	NS	NS
OC	NS	**0.570****	NS	**0.528****	NS	NS	NS
Tot N	NS	**0.612****	NS	**0.547****	NS	NS	NS
TotC:TotN	NS	NS	NS	NS	NS	NS	NS
OC:TotN	-NS	NS	NS	NS	NS	NS	NS
Av N	**-0.286***	**0.667****	NS	**0.391***	NS	**0.408****	NS

Table 17. Path coefficients of different fractions of carbon and nitrogen to total nitrogen in soil

	WSC	HWEC	THN	AmmN	Correlation coefficient
WSC	**-0.203**	-0.083	0.028	-0.027	-0.286
HWEC	0.034	**0.487**	0.085	0.059	0.667
THN	-0.027	0.201	**0.206**	0.011	0.391
AmmN	0.040	0.213	0.017	**0.137**	0.408

Table 18. Path coefficients of different fractions of carbon and nitrogen to available nitrogen in soil

	HWEC	THN	Correlation coefficient
HWEC	**0.465**	0.146	0.611
THN	0.191	**0.355**	0.547

Experiment 4

Field experiment

The field experiment was laid out in randomized block design as detailed in chapter 3 materials and methods in section 3.

4.4.1 Biometric observations

4.1.1 Plant height

Plant height was significantly influenced by the nitrogen application at different growth stages. The data on plant height at active tillering stage is given in table 19. The plant height was significantly higher in all the treatments in comparison with absolute control.

The data on plant height at flowering stage is given in Table 19. The maximum plant height was produced in T10 (Double of C:N ratio recommendation (based on dry analysis) and the treatments T2(POP recommendation), T3 (Soil test based recommendation (wet analysis), T4 (Soil test based recommendation (dry analysis), T5 (C:N ratio recommendation (based on wet analysis), T7 (Half of C:N ratio recommendation (wet analysis), T8 (Half of C:N ratio based recommendation) (dry analysis) and T9 (Double of C:N ratio recommendation (wet analysis) were on par.

The data on plant height at harvest stage is given in Table 19. The maximum plant height was produced in T10 (Double of C:N ratio recommendation (based on dry analysis) and the treatments T5, T7, T8 and T9 were on par with T10.

Table 19. Effects of treatments on plant height at various stages

Treatments	AT	Flowering	Harvest
T1	54	90	93.33
T2	64.33	95.66	103
T3	66.33	99	107.66
T4	66	96.33	106.33
T5	67	97.33	111
T6	64	95.33	103.33
T7	62.66	96	109.33
T8	64.33	99	109.33

Treatments	AT	Flowering	Harvest
T9	67.33	97.66	108
T10	66.66	100.33	112
CD	4.885	4.786	4.001

4.1.2 Tiller production

The data on the number of tillers produced at active tillering stage is given in table 20. The maximum number of tillers was produced in T9 receiving nitrogen dose double the C:N ratio recommendation (based on wet analysis) and the treatments T4, T5, T6, T8 and T10 were on par with T9.

The total number of tillers was highest in T10 at flowering stage. However, treatments T4, T5 and T9 were on par with T10 (Table 20).

The total number of tillers and productive tillers observed at harvest is given in table 22. The treatments could not produce any significant effect on the total number of tillers. The number of productive tillers was significantly higher in all the treatments except in absolute control.

4.1.3. Number of branches per panicle

The maximum number of branches per panicle was observed in the treatment receiving nitrogen dose double the C:N ratio recommendation (based on dry analysis) (T10) and was on par with T5 and T9 (Table 21).

4.1.4. Number of grains per panicle

The number of grains per panicle was highest in treatment T9 receiving nitrogen dose double the C:N ratio based recommendation (wet analysis). However, treatments T5 and T10 were on par with T9 (Table 21).

4.1.4. Thousand grain weight

Data in table 21 shows that the maximum of 30.71 g thousand grain weight was recorded in T9 and it was superior to all the treatments. T5 were on par with T9.

4.1.5. Grain yield

Grain yield recorded in each treatment in kg $plot^{-1}$ and Mg ha^{-1} is presented in table 22. The maximum grain yield of 8.22 Mg ha^{-1} was recorded in the treatment which received the application of nitrogen based on C:N ratio recommendation (wet analysis) (T5). However, the treatments T7 and T9 were on par with T5.

4.1.6. Straw yield

The straw yield recorded in each treatment are presented in the table 22. The highest straw yield of 17.47 Mg ha^{-1} recorded in T9 and the minimum in T1 (10.67 Mg ha^{-1}).

Table 20. Effect of levels of nitrogen on number of tillers in rice at active tillering and flowering stage

Treatment	Total tillers	Total tillers
T1	19.66	14.00
T2	29.33	16.33
T3	28.00	17.00
T4	32.33	18.33
T5	32.66	18.00
T6	35.33	16.33
T7	31.00	16.33
T8	31.33	16.33
T9	36.00	18.33
T10	35.00	20.00
CD (0.05)	5.712	2.89

Table 21. Effect of different levels of nitrogen on total tillers, productive tillers, number of branches per panicle, grains per panicle and thousand grain weight of rice at harvest stage

Treatment	Total tillers	Productive tiller	No. of branches per panicle	No. of grains per panicle	Thousand grain weight
T1	11.33	9.00	7.33	95.00	26.30
T2	17.00	15.00	8.33	98.00	28.25
T3	18.00	16.00	8.66	110.00	29.03
T4	17.33	14.00	8.33	110.33	27.15
T5	18.00	14.66	9.66	117.00	30.46
T6	15.66	13.33	9.66	113.00	26.87
T7	16.33	14.00	8.66	109.33	28.12
T8	18.33	14.33	9.00	110.00	28.53
T9	18.33	15.00	10.33	117.66	30.71
T10	18.00	15.33	11.66	116.33	28.57
CD (0.05)	NS	3.426	1.373	2.576	1.036

Table 22. Effect of different levels of nitrogen on straw and grain yield

Treatments	Straw yield (kg plot^{-1})	Straw yield (Mg ha^{-1})	Grain yield (kg plot^{-1})	Grain yield (Mg ha^{-1})
T1	21.35	10.67	12.28	6.14
T2	33.55	16.77	14.75	7.37
T3	26.85	13.42	14.73	7.36
T4	25.63	12.81	14.15	7.07
T5	34.65	17.32	16.45	8.22
T6	25.38	12.69	15.44	7.72
T7	32.13	16.06	15.95	7.97

Treatments	Straw yield (kg plot^{-1})	Straw yield (Mg ha^{-1})	Grain yield (kg plot^{-1})	Grain yield (Mg ha^{-1})
T8	29.03	14.51	14.78	7.39
T9	34.93	17.46	15.78	7.89
T10	29.91	14.95	15.52	7.76
CD (0.05)	6.934	3.468	0.698	0.349

4.2. Soil and plant analysis

4.2.1. Effect of different treatments on electrochemical properties, nutrient content and C:N ratio in soil at active tillering stage

The data on the effect of different treatments on electrochemical properties and nutrient content in soil at active tillering stage is presented in the table 23.

The application of different levels of nitrogen had no significant effect on pH, EC and available N content of the soil, while the organic carbon and total nitrogen contents varied significantly with the different levels of nitrogen application.

The organic carbon content in treatment T3 (Soil test based recommendation) (wet analysis), T4 (Soil test based recommendation) (dry analysis) T5 (C:N ratio based recommendation) (wet analysis), T7 (Half of C:N ratio based recommendation (wet analysis), and T9 (Double of C:N ratio based recommendation (wet analysis) were on par. The organic carbon in these treatments were significantly higher in soil than that in other treatments.

The total nitrogen content in the treatments T10 was significantly higher than that in other treatments. The treatments T5 and T7 were on par with T10.

With respect to C:N ratio, the ratio in treatment T3 (Soil test based recommendation) (wet analysis) was significantly higher than that in other treatments. The treatments T1, T2 and T4 were on par with T3.

The primary and secondary nutrient status of the experimental site was influenced by the application of different treatments are presented in the table 24. The maximum available P content was recorded in T10. The available P in treatment T2 (POP recommendation), T4 (Soil test based recommendation) (dry analysis), T5 (C:N ratio based recommendation) (wet analysis) and T6 (C:N ratio based recommendation) (dry analysis) were on par with T10 and were found to be significantly higher than that in other treatments.

The available potassium status of 104.72 kg ha^{-1} observed in T6 (C:N ratio based recommendation) (dry analysis) was found to be significantly higher from that in all other treatments.

The available calcium content recorded in T9, T6, T3, T2 and T7 were on par and found to be significantly higher than that in other treatments.

The available magnesium content recorded in T6 (C:N ratio based recommendation) (dry analysis) was found to be significantly higher from that in other treatments. The available sulphur content recorded in T4 (Soil test based recommendation) (dry analysis), T6, T5, T2 and T3 were on par and found to be significantly higher from that in other treatments.

The micronutrient status as influenced by different levels of nitrogen is presented in the Table 25. The application of different levels of nitrogen had significant influence in the available zinc and boron content of the soil. The available zinc content recorded in T3 (Soil test based recommendation) (wet analysis) and T7 (Half of C:N ratio based recommendation) (wet analysis) were on par and significantly higher than that from all other treatment. The hot water extractable B recorded in T4, T5, T6, T7, T8, T9, T10 were on par and was significantly higher from all other doses. The available Fe, Mn and Cu were not significantly influenced by the treatments.

Table 23. Effect of C:N ratio based N application on electrochemical properties, nutrient content and C:N ratio in soil at active tillering stage

Treatment	pH	EC (dSm^{-1})	OC (%)	Av N ($kg\ ha^{-1}$)	Tot N (%)	C:N ratio
Initial	**5.94**	**0.046**	**2.35**	**112.80**	**0.12**	**19.62**
T1	6.70	0.048	1.60	106.20	0.120	13.94
T2	6.52	0.058	1.84	118.60	0.130	14.25
T3	6.63	0.036	1.97	136.17	0.127	15.62
T4	6.55	0.042	1.94	113.12	0.133	14.63
T5	6.67	0.043	2.07	131.62	0.153	13.51
T6	6.593	0.059	1.83	119.44	0.143	12.78
T7	6.647	0.048	2.03	121.80	0.150	13.57
T8	6.703	0.031	1.61	122.37	0.127	12.74
T9	6.593	0.037	1.92	115.98	0.143	13.43
T10	6.593	0.041	1.88	128.09	0.157	12.00
CD (0.05)	NS	NS	0.186	NS	0.012	1.909

Table 24. Effect of C:N ratio based N application on primary and secondary nutrient content in soil at active stage

Treatment	Av P ($kg\ ha^{-1}$)	Av K ($kg\ ha^{-1}$)	Av Ca ($mg\ kg^{-1}$)	Av Mg ($mg\ kg^{-1}$)	Av S ($mg\ kg^{-1}$)
Initial	**104.66**	**1233.78**	**382.45**	**97.19**	**0.727**
T1	9.48	52.48	474.33	63.10	3.95

Treatment	Av P (kg ha^{-1})	Av K (kg ha^{-1})	Av Ca (mg kg^{-1})	Av Mg (mg kg^{-1})	Av S (mg kg^{-1})
T2	14.00	102.76	565.44	70.04	12.95
T3	11.57	49.92	588.82	74.33	12.25
T4	12.88	49.11	521.81	72.35	15.80
T5	14.16	65.81	469.88	64.90	14.60
T6	14.81	104.72	590.27	87.99	14.62
T7	9.33	48.98	537.28	64.52	10.14
T8	10.59	56.01	504.93	66.68	11.18
T9	9.14	54.08	631.08	69.75	14.69
T10	15.73	73.27	487.52	70.42	11.38
CD (0.05)	3.129	11.463	100.44	10.29	4.285

Table 25. Effect of C:N ratio based N application on micro nutrient content in soil at active tillering stage

Treatment	Av Fe	Av Mn	Av Cu	Av Zn	Av B	MBC mg kg^{-1}
	mg kg^{-1}					
Initial	**1307**	**35.83**	**0.60**	**5.72**	**1.30**	
T1	366.64	44.48	4.91	9.70	0.61	269.76
T2	289.25	46.02	2.71	9.24	0.89	268.89
T3	504.40	49.01	6.36	10.04	0.93	260.43

Treatment	Av Fe	Av Mn	Av Cu	Av Zn	Av B	MBC
	mg kg^{-1}					mg kg^{-1}
T4	281.62	51.15	3.32	8.73	1.002	263.70
T5	277.47	42.81	7.11	8.47	1.222	273.14
T6	243.23	47.80	6.82	8.03	1.195	274.34
T7	374.70	48.03	5.62	11.20	1.107	261.10
T8	385.79	75.18	7.91	7.75	1.045	252.53
T9	452.34	43.21	12.06	8.08	1.008	258.71
T10	294.12	50.79	5.53	9.08	1.009	257.65
CD (0.05)	NS	NS	NS	1.594	0.236	NS

4.2.2. Fractions of carbon at active tillering stage

The different fractions of soil carbon estimated in the soils of treatment plot are presented in the table 26. The treatment T10 (Double of C:N ratio based recommendation) (dry analysis) recorded highest water soluble carbon (WSC) of 0.88 % and was found to be significantly higher from that in other treatments.

The hot water extractable carbon (HWEC) recorded in treatments T5, T6, T7, T8 and T10 were on par and was found to be significantly higher than that in other treatments.

The permanganate oxidizable carbon (POC) in treatments T3, T5 and T6 were on par and significantly higher than that in other treatments.

The application of different levels of nitrogen could not produce any significant influence on the microbial biomass carbon content in the experimental plot.

Table 26. Effect of nitrogen on fractions of carbon in soil at active tillering stage

Treatment	WSC (%)	HWEC (%)	POC (%)
T1	0.088^{e}	0.011^{c}	0.157c
T2	0.374^{cd}	0.035^{bc}	0.365b
T3	0.101^{e}	0.037^{b}	0.533a
T4	0.628^{b}	0.037^{b}	0.177c
T5	0.542^{bc}	0.06^{ab}	0.532a
T6	0.281^{de}	0.069^{a}	0.426ab
T7	0.391^{bcd}	0.052^{ab}	0.186c
T8	0.498^{bcd}	0.050^{ab}	0.218c
T9	0.341^{cde}	0.039^{b}	0.209c
T10	0.889^{a}	0.052^{ab}	0.204c
CD	**0.254**	**0.025**	**0.113**

4.2.3. Fractions of nitrogen at active tillering stage

4.2.3.1. Organic fractions of nitrogen

The different organic fractions of soil nitrogen as influenced by different treatments are presented in the table 27. The organic fractions (Total hydrolysable N and amino acid N) were not significantly affected by the treatment application in the experimental plot.

Table 27. Effect of nitrogen on organic fractions of nitrogen in soil at active tillering stage

Treatment	THN (%)	AAN (%)
T1	0.027	0.023
T2	0.022	0.023
T3	0.050	0.032
T4	0.020	0.027

Treatment	THN (%)	AAN (%)
T5	0.025	0.036
T6	0.030	0.023
T7	0.029	0.032
T8	0.025	0.037
T9	0.043	0.03
T10	0.024	0.032
CD (0.05)	NS	NS

4.2.3.2. Inorganic fractions of nitrogen

The different inorganic fractions of soil nitrogen estimated in the soils of treatment plots are presented in the table 28. The application of different levels of nitrogen produced significant influence on the nitrate fraction of nitrogen. The nitrate nitrogen content in treatments T5, T8 and T10 were on par and were significantly higher than that in other treatments. However, ammoniacal nitrogen fraction was not significantly influenced by the treatment application.

Table 28. Effect of nitrogen on inorganic fractions of nitrogen in soil at active tillering stage

Treatment	NH_4^+-N	NO_3^--N
T1	0.003	0.006
T2	0.004	0.005
T3	0.004	0.003
T4	0.003	0.002
T5	0.003	0.008
T6	0.003	0.003
T7	0.003	0.004
T8	0.004	0.006

Treatment	NH_4^+-N	NO_3^--N
T9	0.003	0.003
T10	0.003	0.006
CD (0.05)	NS	**0.003**

Table 29. Corelation between fractions of carbon, organic carbon, total nitrogen, available nitogen and C:N ratio at active tillering stage

	WSC	HWEC	POC	OC	Av N	Tot N	C:N ratio
WSC	1						
HWEC	0.387*	1					
POC	-0.244	0.313	1				
OC	0.052	0.148	0.313	1			
Av N	-0.041	0.253	0.536**	0.436*	1		
Tot N	0.469**	0.471**	0.144	0.494**	0.175	1	
C:N ratio	-0.415*	-0.353	0.138	0.429*	0.247	-0.570**	1

Table 30. Path coefficients of WSC and HWEC on total N in soil at active tillering stage

	WSC	HWEC	Correlation coefficients
WSC	**0.337**	0.131	0.468
HWEC	0.130	**0.340**	0.471

Table 31. Path coefficients of POC and OC on available N in soil at active tillering stage

	POC	OC	Correlation coefficients
POC	**0.443**	0.092	0.535
OC	0.138	**0.297**	0.435

4.2.4. Effect of different treatments on electrochemical properties, nutrient content and C:N ratio in soil at flowering stage

The data on the effect of different treatments on electrochemical properties, nutrient content and C:N ratio in soil at flowering stage is presented in the table 32.

The application of different levels of nitrogen had no significant effect on pH, EC and available N content of the soil, while the organic carbon and total nitrogen contents varied significantly with the different levels of nitrogen application.

The organic carbon recorded in T3 (Soil test based recommendation) (wet analysis), T5 (C:N ratio based recommendation (wet analysis), T9 (Double of C:N ratio based recommendation (wet analysis) and T10 (Double of C:N ratio based recommendation (dry analysis) were on par and were significantly higher than that in other treatments.

The highest total N content of 0.143 % was recorded in T5 (C:N ratio-based recommendation) (wet analysis) and the treatments T2, T4, T6, T8 and T10 were on par with T5.

The C:N ratio recorded in T9 (Double of C:N ratio-based recommendation) (wet analysis) and in treatment T10 (Double of C:N ratio based recommendation) (dry analysis) were on par and significantly wider from that in other treatments.

The primary and secondary nutrient status as influenced by the different levels of nitrogen are presented in the table 33. The available P content recorded in T3, T4, T5, T6, T7, T9 and T10 were on par and significantly higher than that in other treatments.

The available potassium status in treatments T2, T4, T7, T8, T9 and T10 were on par and were significantly higher from that in other treatments.

The application of different levels of nitrogen could not produce any significant influence on the available calcium and magnesium status.

The available sulphur status in the treatments T2, T4 and T5 were on par and were significantly higher than that in other treatments.

The micronutrient status as influenced by different levels of nitrogen is presented in the Table 34. The application of different levels of nitrogen had significant influence in the available iron, manganese, copper, zinc and boron content of the soil. The available iron content recorded in T4, T5, T6, T7, T8 and T9 were on par and significantly higher than that in all other treatments.

The highest available manganese content of 71.37 mg kg^{-1} was recorded in T6 and it was on par with T8. The available copper content recorded in T2, T3 and T5 were on par and were significantly higher than that in all other treatments.

The maximum available zinc content was recorded in T10 (10.21 mg kg^{-1}) and it was on par with T9. The hot water extractable B recorded in T2, T4, T5, T6, T7, T9 and T10 were on par and significantly higher than that in all other treatments.

Table 32. Effect of C:N ratio based N application on electrochemical properties, nutrient content and C:N ratio in soil at flowering stage

Treatment	pH	EC	OC	Tot N	Av N	C:N ratio
T1	6.42	0.042	1.777	0.117	141.083	15.23
T2	6.318	0.05	1.994	0.130	138.704	15.38
T3	6.314	0.045	2.182	0.123	134.075	17.84

Treatment	pH	EC	OC	Tot N	Av N	C:N ratio
T4	6.434	0.047	1.786	0.130	140.991	13.78
T5	6.213	0.069	2.118	0.143	133.153	14.77
T6	6.252	0.058	1.907	0.140	128.466	13.62
T7	6.554	0.072	1.549	0.123	127.046	12.57
T8	6.306	0.085	1.964	0.133	130.76	14.72
T9	6.396	0.042	2.199	0.123	132.523	17.85
T10	6.409	0.082	2.086	0.13	134.6	16.04
CD (0.05)	**NS**	**NS**	**0.149**	**0.014**	**NS**	**1.815**

Table 33. Effect of C:N ratio based N application on primary and secondary nutrient content in soil at flowering stage

Treatment	Av P (kg ha^{-1})	Av K (kg ha^{-1})	Av Ca (mg kg^{-1})	Av Mg (mg kg^{-1})	Av S (mg kg^{-1})
T1	5.79	36.88	341.76	57.61	4.46
T2	10.99	55.06	414.90	63.09	15.78
T3	14.70	48.64	406.89	62.05	7.83
T4	15.32	59.44	519.71	74.35	15.61
T5	15.44	49.20	455.83	68.71	13.74
T6	14.62	45.04	364.48	65.93	7.58
T7	16.47	56.79	446.49	62.70	5.37
T8	12.26	63.06	407.35	72.62	11.44
T9	16.20	55.64	459.85	64.94	11.58
T10	15.27	68.66	427.85	62.66	10.92
CD (0.05)	**2.683**	**13.596**	NS	NS	**2.114**

Table 34. Effect of C:N ratio based N application on micro nutrient content in soil at flowering stage

Treatment	Av Fe	Av Mn	Av Cu	Av Zn	Av B	MBC
	mg kg^{-1}					
T1	130.39	43.21	4.74	7.69	0.461	253.81
T2	189.35	40.71	9.34	9.01	1.001	260.60
T3	208.81	42.03	7.68	8.70	0.823	259.03
T4	321.11	51.64	3.17	7.56	1.02	269.38
T5	479.65	53.83	10.29	8.57	1.03	270.11
T6	519.06	71.37	4.47	8.53	0.93	265.49
T7	370.40	45.44	2.84	8.92	0.93	257.97
T8	509.20	58.54	4.67	7.32	0.87	268.80
T9	359.57	52.51	3.75	9.41	0.89	259.40
T10	222.49	38.32	5.44	10.21	0.99	254.03
CD (0.05)	226.289	17.138	3.055	1.653	0.150	NS

4.2.2. Fractions of carbon at flowering stage

The different fractions of soil carbon estimated in the soils of treatment plot are presented in the table 35. The water soluble carbon (WSC) recorded in T3, T4, T5, T6, T7, T9 and T10 were on par and were significantly higher than that in other treatments.

The hot water extractable carbon (HWEC) recorded in T2, T5, T6, T7 and T10 were on par and were significantly higher than that in other treatments.

The permanganate oxidizable carbon (POC) in treatment T9 and T10 were on par and were significantly higher than that in other treatments.

The microbial biomass carbon was not significantly influenced by the treatments.

Table 35. Effect of nitrogen on fractions of carbon in soil at flowering stage

Treatments	WSC	HWEC	POC
T1	0.10	0.015	0.141
T2	0.12	0.086	0.126
T3	0.33	0.041	0.163
T4	0.44	0.020	0.156
T5	0.31	0.075	0.190
T6	0.42	0.089	0.179
T7	0.30	0.088	0.146
T8	0.25	0.062	0.183
T9	0.42	0.078	0.251
T10	0.27	0.064	0.197
CD (0.05)	**0.167**	**0.023**	**0.057**

4.2.3. Fractions of nitrogen at flowering stage

4.2.3.1. Organic fractions of nitrogen

The different organic fractions of soil nitrogen estimated in the soils of treatment plots as influenced by the N application are presented in the table 36. The application of different levels of nitrogen produced significant influence on the amino acid fraction of nitrogen. The amino acid nitrogen fraction recorded in T6 was on par with T9 and were significantly higher than that in all other treatments. The total hydrolysable nitrogen was not influenced significantly by the different treatment application.

Table 36. Effect of nitrogen on organic fractions of nitrogen in soil at flowering stage

Treatments	THN (%)	Aa N (%)
T1	0.029	0.020
T2	0.024	0.014
T3	0.027	0.012

Treatments	THN (%)	Aa N (%)
T4	0.021	0.019
T5	0.028	0.012
T6	0.038	0.033
T7	0.029	0.012
T8	0.027	0.014
T9	0.020	0.026
T10	0.024	0.016
CD (0.05)	NS	**0.012**

4.2.3.2. Inorganic fractions of nitrogen

The different inorganic fractions of soil nitrogen estimated in the soils of treatment plots are presented in the table 37. The application of different levels of nitrogen could not produce any significant influence on the ammoniacal and nitrate fraction of nitrogen.

Table 37. Effect of nitrogen on inorganic fractions of nitrogen in soil at flowering stage

Treatments	NH_4^+(%)	NO_3^-(%)
T1	0.003	0.004
T2	0.002	0.005
T3	0.004	0.004
T4	0.004	0.003
T5	0.003	0.003
T6	0.003	0.004
T7	0.003	0.006

Treatments	NH_4^+(%)	NO_3^-(%)
T8	0.004	0.003
T9	0.003	0.004
T10	0.003	0.004
CD (0.05)	NS	NS

4.2.4. Nutrient content in plant at flowering stage

The primary and secondary nutrient content estimated in plant samples at flowering are presented in the table 38 and 39. Highest nitrogen content of 0.80 % was recorded in T10 and it was significantly higher than that in other treatments. Total phosphorus content in rice was not significantly influenced by the levels of nitrogen, but the total potassium content in plant was significantly influenced by the treatments. The total potassium content in T5, T6, T7 and T10 were on par and were significantly higher than that in other treatments.

The application of different treatments could not produce any significant influence on the total calcium, magnesium and sulphur contents in the plant at flowering stage.

Table 40 shows the micronutrient content of plant samples at flowering stage. Iron, zinc, copper and boron varied significantly with respect to different levels of treatments. With respect to total iron content, treatments T1, T5 and T10 were on par and were significantly higher than that in all other treatments. The total copper content in T1, T5, T6, T7 and T10 were on par and significantly higher than that in other treatments. The maximum total zinc content was recorded in T2 and it was on par with T10. The total boron content in treatment T5 was significantly higher than that in other treatments.

Table 38. Effect of treatments on primary nutrient content in plant at flowering stage

Treatments	Tot N	Tot P	Tot K
T1	0.353	0.013	1.247
T2	0.430	0.010	1.347
T3	0.520	0.009	0.883
T4	0.537	0.012	1.173
T5	0.637	0.014	1.457
T6	0.563	0.013	1.473
T7	0.457	0.018	1.547
T8	0.677	0.003	0.863
T9	0.737	0.013	1.023
T10	0.800	0.017	1.617
CD (0.05)	**0.043**	**NS**	**0.207**

Table 39. Effect of treatments on secondary nutrient content in plant at flowering stage

Treatments	Tot Ca (%)	Tot Mg (%)	Tot S (%)
T1	0.88	0.10	0.18
T2	0.68	0.08	0.14
T3	0.65	0.07	0.14
T4	0.77	0.11	0.16
T5	0.78	0.12	0.17
T6	0.84	0.10	0.14
T7	0.82	0.11	0.15
T8	0.87	0.03	0.19
T9	0.82	0.10	0.23
T10	0.90	0.14	0.17
CD (0.05)	**NS**	**NS**	**NS**

Table 40. Effect of treatments on micronutrient content at flowering stage

Treatment	Tot Fe	Tot Mn	Tot Cu	Tot Zn	Tot B
	mg kg^{-1}				
T1	637.10	54.13	8.56	46.13	18.63
T2	403.43	41.76	3.56	56.83	17.66
T3	419.03	39.36	4.20	46.43	16.31
T4	474.73	51.90	5.90	39.16	24.86
T5	685.60	64.16	9.10	39.63	33.86
T6	513.76	50.90	5.93	35.96	20.86
T7	544.86	47.86	9.23	41.23	21.51
T8	406.30	36.00	4.73	24.20	19.69
T9	340.50	35.50	3.90	28.16	19.60
T10	723.80	52.46	8.40	50.56	25.43
CD	**106.808**	**NS**	**3.696**	**7.574**	**6.358**

Table 41. Corelation between fractions of carbon, organic carbon, total nitrogen, available nitrogen C:N ratio and plant nitrogen content at flowering stage

	WSC	HWEC	POC	OC	Tot N	C: N ratio	Av N	Plant N
WSC	1							
HWEC	0.092	1						
POC	0.524**	0.181	1					
OC	0.136	0.135	0.484**	1				
TotN	0.299	0.304	0.02	0.257	1			
C:N ratio	-0.058	-0.075	0.443*	0.757**	-0.432*	1		
AvN	-0.162	-0.372*	-0.085	0.073	0.051	0.026	1	
PlantN	0.392*	0.264	0.648**	0.559**	0.318	0.298	-0.158	1

Table 42. Path coefficients of organic carbon, water soluble carbon and permanganate oxidizable carbon on total N in plant at flowering stage

	OC	WSC	POC	Correlation coefficients
OC	**0.339**	0.017	0.201	0.558
WSC	0.046	**0.127**	0.218	0.391
POC	0.164	0.066	**0.416**	0.647

4.2.4. Effect of different treatments on electrochemical properties, nutrient content and C:N ratio in soil at harvest stage

The data on the effect of different treatments on electrochemical properties and nutrient content in soil at harvest stage is presented in the table 43.

The application of different levels of nitrogen had no significant effect on pH and EC of the soil, while the organic carbon and total nitrogen contents varied significantly with the different levels of treatment application.

The organic carbon status of 2.43 % observed in T5 (C:N ratio based recommendation) (wet analysis) was found to be significantly higher than that in all other treatments. The treatments T2 (POP recommendation) and T3 (Soil test based recommendation) (wet analysis) were found to be on par with T5.

The total N content recorded in T5, T7, T9 and T10 were on par and were significantly higher than that in other treatments.

With respect to C:N ratio, the treatments T2 (POP recommendation), T3(Soil test based recommendation (dry analysis), T4 (Soil test based recommendation (dry analysis), T5 (C:N ratio based recommendation)(wet analysis) ,T6 (C:N ratio based recommendation)(dry analysis) T8 (Half of C:N ratio based recommendation (dry analysis) were on par and were significantly wider than that in other treatments.

The available nitrogen content recorded in T2, T4, T5, T6, T8 and T9 were on par and significantly higher than that in other treatments.

The primary and secondary nutrient status of the experimental site was influenced by the application of different treatments are presented in the table 44. The maximum available P content was recorded in T5. The treatments T7 and T8 were on par with T5 and were found to be significantly higher than that in other treatments.

The available potassium status observed in T2, T3 and T8 were on par and were found to be significantly higher from that in other treatments.

The available calcium content recorded in T2, T7 and T8 were on par and found to be significantly higher from that in other treatments.

The available magnesium status of 104.76 mg kg^{-1} observed in T2 (POP recommendation) was found to be significantly higher than that in other treatments.

The available sulphur content recorded in T4, T6, T9 and T10 were on par and found to be significantly higher than that in other treatments.

The micronutrient status as influenced by different levels of nitrogen is presented in the Table 45. The application of different levels of nitrogen had significant influence in the available copper and boron content of the soil. The available copper content recorded in T2 (POP recommendation) and T3 (Soil test based recommendation) (wet analysis) were on par and significantly higher than that from all other treatment. The hot water extractable B recorded in T2, T3 and T5 were on par and were significantly higher than that from all other treatments. Available Fe, Mn and Zn were not significantly influenced by the levels of treatments.

Table 43. Effect of treatments on electrochemical properties, nutrient content and C:N ratio in soil at harvest stage

Treatment	pH	EC (dSm^{-1})	OC (%)	Tot N (%)	Av N (kg ha^{-1})	C:N ratio
T1	4.72	0.091	1.14	0.133	127.53	8.54
T2	5.27	0.126	2.25	0.153	197.74	14.68

Treatment	pH	EC (dSm^{-1})	OC (%)	Tot N (%)	Av N (kg ha^{-1})	C:N ratio
T3	6.01	0.119	2.25	0.150	175.22	15.04
T4	6.01	0.115	2.08	0.147	189.21	14.33
T5	4.70	0.111	2.34	0.167	202.67	14.07
T6	5.19	0.121	2.15	0.157	202.35	13.77
T7	5.84	0.114	2.10	0.170	169.33	12.40
T8	5.31	0.107	2.09	0.153	181.38	14.26
T9	4.71	0.109	2.24	0.190	191.01	11.82
T10	4.53	0.129	2.24	0.187	222.76	12.028
CD (0.05)	NS	NS	0.095	0.025	50.593	2.41

Table 44. Effect of treatments on primary and secondary nutrient content in soil at harvest stage

Treatment	Av P (kg ha^{-1})	Av K (kg ha^{-1})	Av Ca (mg kg^{-1})	Av Mg (mg kg^{-1})	Av S (mg kg^{-1})
T1	7.83	59.62	444.47	64.56	3.58
T2	13.84	146.43	679.12	104.73	30.41
T3	17.19	113.28c	464.98	81.75	28.96
T4	10.12	94.05	506.62	78.04	39.89
T5	23.99	95.53	551.24	92.87	27.02
T6	14	61.88	548.06	67.91	45.04
T7	18.38	106.45	660.95	76.25	24.46
T8	17.83	162.39	668.46	65.38	27.67
T9	15.18	84.61	564.29	85.38	33.65
T10	13.51	55.5	563.37	79.51	42.26
CD (0.05)	**6.414**	**53.939**	**67.831**	**16.186**	**13.467**

Table 45. Effect of C:N ratio based N application on micro nutrient content in soil at harvest stage

Treatment	Av Fe	Av Mn	Av Cu	Av Zn	Av B	MBC
	mg kg^{-1}					
T1	59.23	51.85	12.12	6.90	0.61	246.34
T2	97.91	67.83	18.71	10.35	1.10	288.35
T3	63.53	45.71	16.25	9.51	1.06	272.72
T4	66.18	48.08	12.08	7.77	0.99	259.49
T5	97.06	41.97	9.56	8.05	1.19	255.50
T6	65.04	37.19	11.03	7.32	0.97	248.26
T7	65.82	34.30	12.68	7.68	0.95	244.57
T8	91.24	56.90	13.52	8.22	0.89	249.90
T9	89.63	53.47	11.62	9.98	1.04	261.86
T10	50.52	42.45	10.43	7.09	0.99	254.84
CD (0.05)	**NS**	**NS**	**4.372**	**NS**	**0.128**	**NS**

4.2.5. Fractions of carbon at harvest stage

The different fractions of soil carbon estimated in the soils of treatment plot at harvest are presented in the table 46. The treatment T2 (POP recommendation) recorded water soluble carbon (WSC) of 0.579 % and was found to be significantly higher from that in other treatments.

The hot water extractable carbon (HWEC) recorded in T4, T5, T8, T9 and T10() were on par and were significantly higher than that in other treatments.

The permanganate oxidizable carbon (POC) recorded T3, T7 and T8 were on par and were significantly higher than that in other treatments.

The application of different levels of nitrogen could not produce any significant influence on the microbial biomass carbon content in the experimental plot.

Table 46. Effect of nitrogen on fractions of carbon in soil at harvest stage

Treatments	WSC %	HWEC %	POC %
T1	0.112	0.019	0.127
T2	0.579	0.064	0.140
T3	0.324	0.058	0.178
T4	0.237	0.080	0.126
T5	0.405	0.066	0.166
T6	0.278	0.063	0.157
T7	0.473	0.054	0.180
T8	0.318	0.068	0.198
T9	0.267	0.080	0.171
T10	0.226	0.083	0.180
CD (0.05)	**0.105**	**0.017**	**0.020**

4.2.3. Fractions of nitrogen at harvest stage

4.2.3.1. Organic fractions of nitrogen

The different organic fractions of soil nitrogen as influenced by different treatments are presented in the table 47. The amino acid nitrogen fraction in treatments T5 and T6 were significantly higher than that in other treatments and were on par.

The total hydrolysable nitrogen fraction was not significantly influenced by different levels of treatment application in the experiment plot.

4.2.3.2. Inorganic fractions of nitrogen

The different inorganic fractions of soil nitrogen estimated in the soils of treatment plots are presented in the table 48. The application of different levels of nitrogen produced significant influence on the ammoniacal fraction of nitrogen. The ammoniacal nitrogen fractions in treatments T6, T8 and T10 were significantly higher than that in other treatments and were on par. With respect to nitrate fraction, treatments T4, T7 and T9 were on par and were significantly higher than that in other treatments.

Table 47. Effect of nitrogen on organic fractions of nitrogen in soil at harvest stage

Treatments	THN	AAN
T1	0.025	0.023bc
T2	0.021	0.013c
T3	0.027	0.022bc
T4	0.033	0.032b
T5	0.024	0.054a
T6	0.029	0.054a
T7	0.029	0.022bc
T8	0.048	0.02bc
T9	0.026	0.02bc
T10	0.03	0.025bc
CD (0.05)	NS	**0.015**

Table 48. Effect of nitrogen on inorganic fractions of nitrogen in soil at harvest stage

Treatments	NH_4^+ (%)	NO_3^- (%)
T1	0.002	0.003
T2	0.006	0.011
T3	0.004	0.012
T4	0.004	0.014
T5	0.006	0.010
T6	0.010	0.004
T7	0.003	0.015

Treatments	NH_4^+ (%)	NO_3^- (%)
T8	0.010	0.006
T9	0.007	0.016
T10	0.008	0.003
CD (0.05)	**0.003**	**0.003**

4.2.4 Nutrient content in straw at harvest

The data on primary, secondary and micro nutrient contents estimated in straw samples are given in table 49, 50 and 51. Highest content of nitrogen was noticed in T9 (1.53 %) and lowest in T1(1.08 %). Though T9 recorded highest it was on par with T10.

The treatment application could not significantly influence the total P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B content of straw at harvest stage.

Table 49. Effect of treatments on primary content in straw at harvest stage

Treatment	Tot N (%)	Tot P (%)	Tot K (%)
T1	1.08	0.013	2.53
T2	1.18	0.010	2.02
T3	1.29	0.009	1.50
T4	1.20	0.012	1.84
T5	1.38	0.014	2.05
T6	1.26	0.013	2.21
T7	1.23	0.018	2.37
T8	1.39	0.003	0.56
T9	1.53	0.013	1.83
T10	1.48	0.017	2.43
CD	**0.135**	**NS**	**NS**

Table 50. Effect of treatments on secondary content in straw at harvest stage

Treatment	Tot Ca (%)	Tot Mg (%)	Tot S (%)
T1	0.993	0.108	0.187
T2	0.688	0.087	0.149
T3	0.658	0.074	0.14
T4	0.986	0.114	0.162
T5	1.031	0.124	0.178
T6	0.948	0.109	0.146
T7	0.823	0.110	0.157
T8	0.389	0.038	0.195
T9	0.680	0.106	0.238
T10	0.892	0.141	0.173
CD	**NS**	**NS**	**NS**

Table 51. Effect of treatments on micronutrient content in straw at harvest stage

Treatment	Tot Fe	Tot Mn	Tot Cu	Tot Zn	Tot B
	mg kg^{-1}				
T1	637.10	54.13	8.56	45.40	18.63
T2	523.03	41.76	4.83	46.70	12.60
T3	331.36	29.36	3.26	26.23	16.31
T4	421.26	51.90	5.90	33.86	17.00
T5	440.00	52.00	7.26	32.10	22.20
T6	452.50	50.90	5.93	32.93	15.70
T7	438.83	47.86	7.30	33.933	16.03
T8	181.76	19.60	2.23	15.20	16.22
T9	431.53	35.50	3.90	24.96	14.13
T10	593.50	52.467	8.40	43.10	22.13
CD (0.05)	**NS**	**NS**	**NS**	**NS**	**NS**

4.2.5. Analysis of nutrients in grain

The primary, secondary and micronutrients estimated in the grain samples are given in table 52, 53 and 54. The total nitrogen content recorded in the treatments T5, T9 and T10 were on par and were significantly higher than that in all other treatments. The application of treatments could not produce any significant effect on the total phosphorus, potassium, calcium and magnesium contents in the grain. Total S content in grain varied significantly with respect to the treatment application. Highest S content was noticed in T3 and was significantly higher than that in other treatments. Micronutrient content in grain except B did not vary significantly with respect to application of different treatments. The total B content in T2, T3, T4, T8, T9 and T10 were on par and were significantly higher than that in all other treatments.

Table 52. Effect of treatments on primary content in grain at harvest stage

Treatments	Tot N (%)	Tot P (%)	Tot K (%)
T1	0.24	0.028	0.343
T2	0.42	0.055	0.600
T3	0.34	0.046	0.510
T4	0.45	0.035	0.550
T5	0.57	0.043	0.547
T6	0.52	0.044	0.477
T7	0.53	0.043	0.530
T8	0.52	0.045	0.477
T9	0.73	0.039	0.543
T10	0.72	0.052	0.607
CD 0.05	**0.194**	**NS**	**NS**

Table 53. Effect of treatments on secondary content in grain at harvest stage

Treatment	Tot Ca (%)	Tot Mg (%)	Tot S (%)
T1	0.460	0.124	0.215
T2	0.852	0.226	0.203
T3	0.701	0.195	0.418
T4	0.808	0.201	0.208
T5	0.799	0.202	0.208
T6	0.491	0.180	0.197
T7	0.692	0.195	0.190
T8	0.617	0.181	0.201
T9	0.759	0.207	0.282
T10	0.761	0.226	0.236
CD (0.05)	**NS**	**NS**	**0.051**

Table 54. Effect of treatments on micronutrient content in grain at harvest stage

Treatment	Tot Fe	Tot Mn	Tot Cu	Tot Zn	Tot B
	mg kg^{-1}				
T1	382.60	40.70	12.96	25.56	10.63
T2	505.93	46.63	15.63	23.33	16.36
T3	344.23	35.76	12.40	21.26	12.46
T4	463.66	48.26	14.40	24.26	12.60
T5	465.36	32.00	9.80	47.16	6.06
T6	796.16	35.00	11.86	33.16	6.76
T7	577.36	34.03	13.70	23.56	8.20
T8	687.50	36.56	14.66	24.80	13.16
T9	642.03	41.40	13.96	60.16	11.46
T10	446.46	38.93	15.13	31.96	11.13
CD (0.05)	NS	NS	NS	NS	**5.67**

4.3. Correlation coefficient between biometric observations, total nitrogen in soil and nitrogen in grain and straw during harvest stage

The correlation coefficient between biometric observations, total nitrogen in soil and nitrogen in grain and straw during harvest stage are given in the table 55.

Plant height had significant positive correlation with plant height (0.785**), thousand grain weight (0.593**), number of branches per panicle (0.656**), total number of tillers (0.647**), number of productive tillers (0.655**), straw yield (0.497**), grain yield (0.736**), grain N (0.585**), straw N (0.648**) and total N in soil (0.618**).

Number of grains per panicle was significantly and positively correlated with thousand grain weight (0.584**), number of branches per panicle (0.731**), total number of tillers (0.476**), number of productive tillers (0.445**), straw yield (0.356**), grain yield (0.756**), grain N (0.705**), straw N (0.761**) and total N in soil (0.637**).

Test weight had significant positive correlation with number of branches per panicle (0.452**), total number of tillers (0.505**), number of productive tillers (0.482**), straw yield (0.640**), grain yield (0.626**), grain N (0.547**), straw N (0.697**) and total N in soil (0.515**).

Number of branches per panicle was significantly and positively correlated with total number of tillers (0.424*), number of productive tillers (0.459**), grain yield (0.576**), grain N (0.790**), straw N (0.722**) and total N in soil (0.724**).

The total number of tillers was significantly and positively correlated with number of productive tillers (0.927**), straw yield (0.413**), grain yield (0.520**), and straw N (0.460**).

The number of productive tillers had significant positive correlation with straw yield (0.423*), grain yield (0.537**) and straw N (.391*) content.

Table 55. Corelation between biometric observations, total nitrogen in soil and nitrogen in grain and straw during harvest stage

	Plant Ht	No Grain	Test Wt	No Branches	Tot tillers	Prod Tillers	Straw Yield	Grain Yield	Grain N	Straw N	Tot N
Plant Ht	1										
No Grain	0.785**	1									
Test Wt	0.593**	0.584**	1								
No Branches	0.656**	0.731**	0.452*	1							
Tot tillers	0.647**	0.476**	0.505**	0.424*	1						
Prod Tillers	0.655**	0.445*	0.482**	0.459*	0.927**	1					
Straw Yield	0.497**	0.356	0.640**	0.341	0.413*	0.423*	1				
Grain Yield	0.736**	0.756**	0.626**	0.576**	0.520**	0.537**	0.558**	1			
Grain N	0.585**	0.705**	0.547**	0.790**	0.27	0.216	0.468**	0.611**	1		
Straw N	0.648**	0.761**	0.697**	0.722**	0.460*	0.391*	0.498**	0.571**	0.812**	1	
Tot N	0.618**	0.637**	0.515**	0.724**	0.23	0.277	0.562**	0.554**	0.744**	0.682**	1

Table 56 Correlation between nutrient status in soil, carbon and nitrogen fractions and plant N in grain and straw during harvest stage.

	OC	Tot N	C:N ratio	Av N	WSC	HWEC	POC	THN	AAN	Amm N	Nit N	Grain N	Straw N
OC	1												
Tot N	0.465**	1											
C:N ratio	0.704**	-0.291	1										
Av N	0.676**	0.489**	0.31	1									
WSC	0.537**	0.034	0.530**	0.15	1								
HWEC	0.729**	0.501**	0.413*	0.637**	0.136	1							
POC	-0.273	-0.201	-0.083	-0.297	-0.344	-0.215	1						
THN	-0.006	-0.022	0.085	-0.132	-0.07	0.146	0.308	1					
AAN	0.166	-0.02	0.152	0.26	-0.134	0.041	-0.325	0.032	1				
Amm N	0.450*	0.329	0.253	0.461*	0.06	0.500**	0.072	0.336	0.248	1			
Nit N	0.396*	0.19	0.28	0.02	0.381*	0.32	-0.104	-0.189	-0.243	-0.35	1		
GrainN	0.508**	0.744**	0.005	0.457*	-0.045	0.634**	-0.145	0.017	0.075	0.425*	0.178	1	
StrawN	0.545**	0.682**	0.09	0.443*	-0.041	0.588**	0.131	0.119	-0.004	0.406*	0.125	0.812**	1

4.4. Corelation between nutrient status in soil, carbon and nitrogen status and plant N in grain and straw during harvest stage

The correlation coefficient between nutrient status in soil, carbon and nitrogen status and plant N in grain and straw during harvest stage are given in the table 56.

Water soluble carbon had significant positive correlation with organic carbon (.537**), C:N ratio (.530**), and nitrate nitrogen (0.381*) content in soil.

Hot water extractable carbon had significant positive correlation with organic carbon (0.729**), total nitrogen (0.413*) and available N (0.637**), ammoniacal nitrogen (0.500**), grain N (0.634**) and straw N (0.588**) content.

No significant correlations were obtained between permanganate oxidizable carbon and fractions of nitrogen with total nitrogen in soil, grain and straw yield, straw N and grain N contents.

4.5. Path analysis

The path coefficients showing the direct and indirect effects of fractions of carbon and nitrogen on nitrogen content in grain at harvest are presented in table 57. Hot water extractable carbon had very high and positive direct effect on grain nitrogen content (0.562). Ammoniacal nitrogen content had low and positive direct effect on grain nitrogen content (0.143).

The path coefficients showing the direct and indirect effects of carbon and nitrogen fractions on content of nitrogen in straw are presented in table 58. The direct effect of hot water extractable carbon on straw nitrogen content was positive and very high (0.51).

The path coefficients explaining the direct as well as indirect effects of water soluble carbon and ammoniacal nitrogen on straw yield are presented in table 59. The direct effect of straw yield through water soluble carbon was very high and positive (0.534). The direct effect of ammoniacal nitrogen was negligible.

Path coefficients of different fractions of carbon and nitrogen and indicating the direct and indirect effects on grain yield are given in the table 60.

The direct effect of water soluble carbon was high and positive (0.428). The direct effect of grain yield through hot water soluble carbon was also very high (0.401). The direct effects of ammoniacal (0.20) was low and positive

Table 57. Path coefficients of different fractions of carbon and nitrogen to grain N

	HWEC	AmmN
HWEC	**0.562**	0.0716
AmmN	0.281	**0.1433**

Table 58. Path coefficients of different fractions of carbon and nitrogen to straw N

	HWEC	AmmN
HWEC	**0.512**	0.074
AmmN	0.256	**0.149**

Table 59. Path coefficients of different fractions of carbon and nitrogen to straw yield

	WSC	AmmN
WSC	**0.534**	0.004
AmmN	0.032	**0.074**

Table 60. Path coefficients of different fractions of carbon and nitrogen to grain yield

	WSC	HWEC	AmmN
WSC	**0.428**	0.054	0.012
HWEC	0.058	**0.401**	0.102
AmmN	0.025	0.2	**0.202**

4.6. Cost of cultivation

The cost of cultivation incurred in various treatments are given in table 61. The net returns are provided in table 62.

Table 61. Cost of cultivation of field experiment

Cost of cultivation									
Treatments	Factomphos (Rs 18 kg^{-1})	Urea (Rs 6 kg^{-1})	MOP (Rs 15 kg^{-1})	$MgSO_4$ (Rs 20 kg^{-1})	CaO (Rs 9 kg^{-1})	Total	Labour Charges Rs.	Plant Protection Rs.	Total Rs. (a)
T1	0	0	0	0	2250	0	20000	1500	21500
T2	4049.838	845.9662	1124.955	0	5400	11420.76	20000	1500	32920.76
T3	1012.46	617.9753	281.2388	1600	2250	5761.67	20000	1500	27261.67
T4	4292.828	146.9941	281.2388	1600	2250	8571.06	20000	1500	30071.06
T5	1012.46	1373.945	281.2388	1600	2250	6517.64	20000	1500	28017.64
T6	4292.828	677.9729	281.2388	1600	2250	9102.04	20000	1500	30602.04
T7	506.2298	686.9725	281.2388	1600	2250	5183.82	20000	1500	26824.44
T8	2146.414	338.9864	281.2388	1600	2250	6476.02	20000	1500	28116.64
T9	2024.919	2747.89	281.2388	1600	2250	9185.28	20000	1500	30404.05
T10	8585.657	1355.946	281.2388	1600	2250	14354.08	20000	1500	35572.84

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Table 62. Gross and net returns from the treatments under field experiment

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Returns price/grain Rs. 20 kg^{-1} (b)	Returns price/straw Rs. 3 kg^{-1} (c)	Gross return Rs. d = (b+c)	Net return (Rs.) e = (d-a)
T1	6142	10670	122840	32010	154850	133350
T2	7377	16770	147540	50310	197850	164929
T3	7367	13420	147340	40260	187600	160338
T4	7075	12810	141500	38430	179930	149859
T5	8225	17320	164500	51960	216460	188442
T6	7720	12690	154400	38070	192470	161868
T7	7975	16060	159500	48180	207680	180856
T8	7392	14510	147840	43530	191370	163253
T9	7893	17460	157860	52380	210240	179836
T10	7760	14950	155200	44850	200050	164477

Discussion

5. Discussion

Forty-five representative samples from 4 different rice growing acid saline and acid sulphate rice soils of Kerala have been characterized initially keeping the moisture status as in field and wet analysis being followed. All these samples were subjected to fractionation for soil carbon and nitrogen as detailed in chapter 3. A field experiment was also conducted based on initial C:N ratio to optimize the best treatment for rice nutrition with respect to nitrogen. In this chapter, the results of all these experiments are discussed critically with supporting studies from the literature wherever possible.

Experiment 1

5.1 Electro chemical properties and available nutrient status

The data on the electrochemical properties and available nutrient status are presented in table 6 and 7.

5.1.1 Soil pH

The soil pH ranged from 4.22 to 7.68. The pH was lowest in Purakkad *Kari* (sample 11) of *Kuttanad.* This is as expected since the soil is potentially acid sulphate in nature and the soil sample being collected during pre-monsoon period (May) which in turn resulted in extremely acidic (3.5 to 4.4) reaction. Partial decomposition of organic matter resulting in production of organic acids also might have contributed to acidity. The highest pH was observed in *Pokkali* region (sample 31) where sample was collected in post monsoon period (first week of August). Washing out of active acidity during monsoon followed by submergence might have increased the pH to near neutral level in this soil. Most of the samples from *Pokkali* and *Kaipad* showed near neutral pH supporting the above argument (table 6).

A total of 25 samples were collected from Kuttanad (5 samples each from Vechur *Kari*, *Kayal* lands, Purakkad *Kari*, Upper *Kuttanad* and Lower *Kuttanad*). The pH values estimated in Vechur *Kari* and Purakkad *Kari* indicated that majority of these samples were strongly acidic (5.1-5.5) in reaction. This is due to the acid sulphate nature of these soils. The pH was slightly acidic (6.1-6.5) in *Kayal* lands due to continuous submergence. Similarly, the soils from Upper *Kuttanad* were also slightly acidic in reaction.

A total of ten samples from Kole lands (5 each from Ponnani and Thrissur *Kole*) were characterised. The pH was slightly to moderately acidic (5.6 to 6.5) in reaction. This is as expected since soil sample was collected just before cultivation (September). Washing away of active acidity during monsoon, liming and continuous submergence during cropping season resulted in slightly to moderately acidic reaction.

A perusal of data on pH showed that majority of soils from *Kuttanad* could be included in strongly acidic category (5.1-5.5) and *Kole* lands in moderately to slightly acidic (5.6-6.5) in reaction. Both *Pokkali* and *Kaipad* tracts were near neutral (6.6-7.3) in reaction (table 6).

5.1.2 Electrical conductivity

The electrical conductivity of the soils of 4 different rice growing acid saline and acid sulphate soils ranged from 0.046 to 4.73 dSm^{-1}. The highest EC of 4.73 dS m^{-1} was recorded in *Pokkali* soils of AEU 5 (sample No. 33). As in the case of pH, the salts were also washed out due to monsoon which might have reduced the EC to the present level which may go as high as ~ 8 dSm^{-1} during the saline phase (Anilkumar and Annie, 2010). However, the acid saline soils of *Pokkali* and *Kaipad* have still shown comparatively higher EC indicating the effect of sea water inundation. Vechur *Kari* and *Kayal* lands recorded comparatively higher values of EC than other regions of Kuttanad. This is due to saline water intrusion into these areas during the summer months (table 6).

It can be concluded that the electrical conductivity was highest in *Pokkali*, followed by *Kaipad* area which were already classified as acid saline. Vechur *Kari* soils recorded higher EC values among soils of *Kuttanad* region. Low EC values were recorded in *Kole* lands. (Bhindhu, 2017) where sea water intrusion was effectively checked.

5.1.3 Available phosphorus

The highest available P of 165.11 kg ha^{-1} (sample 32) and lowest of 0.30 kg ha^{-1} were recorded in soils from *Pokkali*. The data on available P was consistently high when analysed as such on wet basis. This is because when the soil is submerged, reduction occurs, pH increases in acid soils attaining near neutrality; availability of P being maximum at near neutral pH. This is clearly depicted by higher available P values when analysed on wet basis maintaining the anaerobic situation in the field (Ponnamperuma, 1972).

Among the various groups of soil collected, Vechur *Kari*, Lower *Kuttanad* and *Pokkali* recorded very high values for available P. The available P status was sufficient in Upper *Kuttanad* area. The available P was low to medium (<10- 24 kg ha^{-1}) in other areas.

Available P was significantly and positively correlated with electrical conductivity (0.535*) and available K (0.307*), indicating the existence of soluble P salts like that of phosphates of potassium (Table No. 13). At near neutral pH, there is every possibility of increase in available P status enhancing the electrolytic concentration in the soil solution where soluble salts of P might have also contributed to electrical conductivity. Thus, higher electrical conductivity values along with high K status in *Pokkali* and *Kaipad* areas have contributed to higher available P status.

One sample from Vechur *Kari* and two from *Kayal* lands were low in available P content. Available P was negatively correlated with available Fe content (-0.321*) (Table 14). The acidic reaction with high status of iron resulted in precipitation of different species of iron phosphates reducing the availability of phosphorus (Table 6 and 7). The available P status in Ponnani *Kole* region were medium.

5.1.4 Available potassium

Available potassium was observed to range from 74.86 to 1233.78 kg ha^{-1}. The high potassium content in various locations can be substantiated by significant positive correlation (0.349*) between electrical conductivity and available K status. High EC values have contributed to soluble salts which caused an increase in available K status (table 6).

Potassium deficiency was reported only in 2 samples, one each from Thrissur *Kole* (sample 43) and *Kaipad* lands (sample 28).

Among the various locations, available K status was high in *Kuttanad*, *Pokkali* and Thrissur *Kole*. It was medium in *Kaipad* and Ponnani *Kole* area.

5.1.5 Available calcium

Available calcium content of soils was found to range from 46.30 to 452 mg kg^{-1}. Out of 45 samples, 41 were deficient (< 300 mg kg^{-1}) in calcium. The available Ca status was less than 100 mg kg^{-1} in Vechur *Kari* and *Kayal* lands. This is due to the low pH in these locations where Ca is too soluble to be retained in soil (table 7).

The available Ca status was less than 100 mg kg^{-1} in Lower *Kuttanad* and *Kaipad* lands also. In these locations, dominance of sodium ion (Na^{+}) in exchange complex resulted in low Ca^{2+} ions resulting in low available Ca status.

5.1.6 Available magnesium

A perusal of the data of magnesium status reported in various acid sulphate and acid saline rice soils reveals 78 per cent deficiency of magnesium in the collected samples (table 7). The deficiency of Mg reported in these soils is attributed to the low pH of these soils.

Soils from Purakkad *Kari* and upper *Kuttanad* were sufficient (>120 mg kg^{-1}) in magnesium. All other locations in *Kuttanad* as well as in *Kaipad, Pokkali and*

Kole lands recorded very lower values of magnesium (<50 mg kg^{-1}). This is due to the presence of high sodium content in the exchangeable complex in these soils.

5.1.7 Available sulphur

The lowest sulphur content of 0.98 mg kg^{-1} was recorded in the soils from Ponnani *Kole* (AEU 6, sample No. 38) and the highest of 996 mg kg^{-1} was found in soils of *Pokkali* (AEU 5, sample No. 33). High level of available sulphur is as expected in various other locations, being acid sulphate/saline in nature. Only three samples from Ponnani *Kole* and one sample from Thrissur *Kole* (Adattu *Kole)* were deficient in available sulphur (<5 mg kg^{-1}) the reason being unknown (table 7).

5.1.8 Available iron

The data on 0.1 M HCl extractable micronutrients (Fe, Mn, Cu and Zn) (table 7) in soils shows very high values of iron. This is as expected due to acid sulphate/saline nature of these soils where iron toxicity is reported for rice. George (2011) also reported high Fe status in soils of *Kuttanad*, *Pokkali* and *Kole*.

5.1.9 Available manganese

Available manganese was found to range from 0.22 to 35.83 mg kg^{-1}. Soils from Vechoor *Kari*, Purakkad *Kari*, Lower Kuttanad and *Pokkali* were deficient in manganese (<1 mg kg^{-1}). These soils have higher exchangeable sodium and magnesium (only in Purakkad *Kari*) which might have caused low retention ofMn^{2+} in the exchangeable sites. This could be the reason for low levels of Mn in these soils. Further, water soluble Mn might have precipitated as manganese sulphide prior to precipitation of iron sulphide. Available manganese was high in soils from all other locations.

5.1.10 Available copper

The lowest available copper of 0.02 mg $kg^{-1}$was recorded in *Pokkali* (AEU 5, sample No. 31) and highest of 7.81 mg kg^{-1}in Upper *Kuttanad* (sample No. 20). Out of 45 samples, 31 samples were deficient in copper. This is due to precipitation of solubilised copper as CuS. (Das, 1996). The formation of insoluble complexes with organic compounds also must have resulted in low available copper among the 45 locations, the soils being rich in organic matter.

5.1.11 Available zinc

The available zinc was found to vary from 1.35 to 157.78 mg kg^{-1}. The lowest available zinc was recorded in *Kaipad* soil (AEU 7, sample No. 27) and highest in *Pokkali* soil (AEU 5, sample No. 31). None of the samples were deficient in available zinc content. Toxic concentration of Zn was observed in *Pokkali*.

5.1.12 Available boron

The hot water extractable boron recorded higher values in various soils. Out of 45 samples, only 9 samples were found to be deficient in available boron.

In general, it is observed by many workers that pH has negative correlation with available B (Santhosh, 2013). So, when pH get reduced higher values of available B was obtained and vice-versa especially in soils rich in organic matter (table 7).

5.2 Carbon and nitrogen status and C:N ratio's in soils

The organic carbon, total carbon, microbial biomass carbon, total nitrogen, available nitrogen and the C:N ratio organic C:total N and total C:total N of the soils under study are presented in table 8.

5.2.1 Organic carbon

The organic carbon status of the soils varied from 0.81 to 7.58 per cent. Soils from *Kaipad* (AEU 7, sample No. 27) recorded the lowest and soils from Vechoor *Kari* of *Kuttanad* (AEU 4, sample No. 4) recorded the highest value. The *Kuttanad* soils in general were high in organic matter content and are expected to have high carbon content. The lowest organic carbon was recorded in soils from *Kaipad* region. A general trend of decline in organic matter with increase in pH was observed which is supported by the significant negative correlation obtained between pH and organic carbon (-0.295*) (table 14).

Among the soils collected from *Kuttanad*, *Kari* soils from Vechur and Purakkad recorded the highest organic carbon status. These soils are unusually black and very rich in organic matter with deeply buried partially burned out timber specimens of ancient period. Such remnants of ancient forest vegetation were quite rare in the Upper *Kuttanad* and *Kayal* lands. The organic carbon status of Upper *Kuttanad* and *Kayal* lands were lower than *Kari* soils.

Among the acid saline rice soils of *Pokkali* and *Kaipad*, *Pokkali* soils recorded higher values of organic carbon than *Kaipad*. The status of organic carbon was high in Ponnani *Kole* than in Thrissur *Kole* (table 8).

The organic carbon was significantly and positively correlated with total nitrogen (0.970**) and available nitrogen (0.509**) status in these soils (table 14). The regression equation including all the parameters having significant correlation with organic carbon yielded the following single equation obtained with total nitrogen as the dominant independent variable that could explain 94 per cent variability.

OC= -0.095+18.308 Total N** (R^2=0.94) ....(1)

The step up regression analysis including all the parameters correlated for organic carbon yielded the following relations:

OC= -0.095+18.308 Total N** (R^2=0.94) ....(2)

OC=-2.352+17.575 Total N**+0.135 OC:TN ratio (R^2=0.995)….(3)

Thus, total nitrogen content of the soil is closely related to the organic carbon of the soil.

5.2.2 Total carbon

The total carbon of the soils ranged from 0.92 to 7.52 per cent. The lowest total carbon was recorded in the soils of upper *Kuttanad* (AEU 4, sample 16) and highest in the *Kari* soils of Vechoor (AEU 4, sample 4) (table 8). The trend of total carbon status in *Kuttanad* and all other locations followed the same trend as that of organic carbon and the data are so close that it could be inferred that the carbon in the soils of present study is in organic form and the inorganic forms such as carbonates and bicarbonates were negligibly small. This is as expected since under acidic soil reaction these inorganic forms cannot exist. This result is further supported by the very high correlation coefficient between organic carbon and total carbon (0.99) (table 13).

The regression equation including all the parameters having significant correlation with total carbon yielded the following single equation obtained with organic carbon as the dominant independent variable that could explain 99.8 per cent variability.

Total C= 0.057+0.018 OC (R^2=0.998)..............................(4)

5.2.3 Microbial biomass carbon

The lowest microbial biomass carbon of 126.63 $\mu g\ g^{-1}$ was recorded in *Kaipad* soil (AEU 7, sample No. 27) and highest of 274.91$\mu g\ g^{-1}$ in Thekkekonchira of Thrissur *Kole* (AEU 6, sample No. 44). Mishra *et al.*, 2003 have established that both the acetotrophic and hydrogenotrophic methanogens are inhibited by increasing NaCl concentration while the methylotrophic methanogens appear to tolerate high NaCl concentrations. This is the reason of low microbial biomass carbon in acid saline soils of *Kaipad.* Thus, the reason for low microbial biomass carbon in Kaipad soil is attributed to the high salt content (table 8).

While in case of *Pokkali* despite of higher salinity than Kaipad region the microbial biomass carbon was higher than *Kaipad* which requires further detailed study. Low electrical conductivity values were recorded in *Kole* lands (Bhindhu, 2017) where sea water intrusion was effectively checked which resulted in increase of microbial biomass carbon in Thrissur *Kole*.

5.2.4 Total nitrogen

The total nitrogen ranged from 0.05 to 0.42 per cent (table 8). The lowest total nitrogen was observed in soils of Upper *Kuttanad* (AEU 4, sample No. 16) and

Kaipad lands (Sample 27). Soils from Vechoor *Kari* (AEU 4, sample No. 4) recorded the highest total nitrogen status. More than 95 % of nitrogen in soils exists in organic form associated with organic matter This is clear from the significant positive correlation of total nitrogen with organic carbon (0.97**) content. The step up regression analysis including all the parameters correlated for total nitrogen yielded the following relations

Total N= 0.014+0.051 OC (R^2=0.94).................................(5)

Total N=0.006+0.048 OC+0.001Av. N (R^2=0.951)................(6)

Thus, organic carbon is the most contributing single factor for total nitrogen in soil. However, fractions of organic carbon, hot water extractable carbon correlates significantly to total nitrogen.

The lowest total nitrogen content was observed in soils from Upper *Kuttanad* and *Kaipad.* This can be attributed to the lower organic carbon in these soils. The trend of total nitrogen status in *Kuttanad* and all other locations followed the same trend as that of organic carbon.

5.2.5 Available nitrogen

The highest available nitrogen content of 281.38 kg ha^{-1} was recorded in sample from Vechoor *Kari* (sample No. 4) and the lowest of 19.84 kg ha^{-1} in soil from Purakkad *Kari* (sample No. 13) (table 8). Available nitrogen was significantly and positively correlated with total carbon (0.506**), organic carbon (0.509**), total nitrogen (0.587**) and hot water extractable carbon (0.676**) content (Table 14 and 16). The highest total carbon, organic carbon and total nitrogen was recorded in Vechur *Kari* resulted in higher available nitrogen status in these soils.

The available nitrogen status was low in all other locations. The mineralizable nitrogen estimated by alkaline permanganometry largely depends on mineralization rate in the soil which in turn is a function of microbial population as well as the total nitrogen status. The nitrifying microbial activity might have reduced due to low pH and submergence. This is the reason for reduced available nitrogen in these locations despite acid sulphate/saline nature. However, higher organic carbon as well as total N resulted in higher mineralizable (available) N.

5.2.6 Carbon:nitrogen ratio

The C:N ratio expressed as Organic carbon:Total nitrogen and Total carbon:Total nitrogen ratio of the soils are presented in table 8.

5.2.6.1 Organic carbon: Total nitrogen (C:N) ratio

The C:N ratio varied from 13:1 to 24:1. Widest C:N ratio was recorded in soils of Upper *Kuttanad* (AEU 4, sample No. 20) and the lowest in samples from Thrissur Kole (AEU 6, sample 43 and 44).

In submerged soils, the decomposition of organic matter is almost entirely the activity of facultative and obligate anaerobes. Since anaerobic bacteria operate at a much lower energy than aerobic organisms, both decomposition and assimilation are much slower in submerged soils than in aerobic soils especially in absence of O_2. In general, this would be the reason for wider C:N ratio's in these soils.

The C:N ratio was between 12-15:1 in 9 locations. Majority of samples from Thrissur and Ponnani Kole were included in this category. It was between 15-20:1 in 29 locations. Majority of samples from *Kuttanad*, *Pokkali* and *Kaipad* fall under this category. The C:N ratio was above 20:1 in 7 locations. Two samples each from Purakkad *Kari* and Upper *Kuttanad* and one each from Vechur Kari, Purakkad Kari and Pokkali were included here (table 8).

5.2.6.2. Total carbon:Total nitrogen (C:N) ratio

The C:N ratio varied from 14:1 to 24:1. Highest C:N ratio was recorded in soils of Upper *Kuttanad* (AEU 4, sample No. 20) and the lowest in samples from Thrissur Kole (AEU 6, sample 41 and 43).

A perusal of the data on C:N ratio (both Organic C:total N and total carbon:total N) clearly shows the same trends and hence it could be concluded that the total carbon is almost the same as organic carbon in these acidic soils with absence of carbonates and bicarbonates (inorganic carbon fractions).

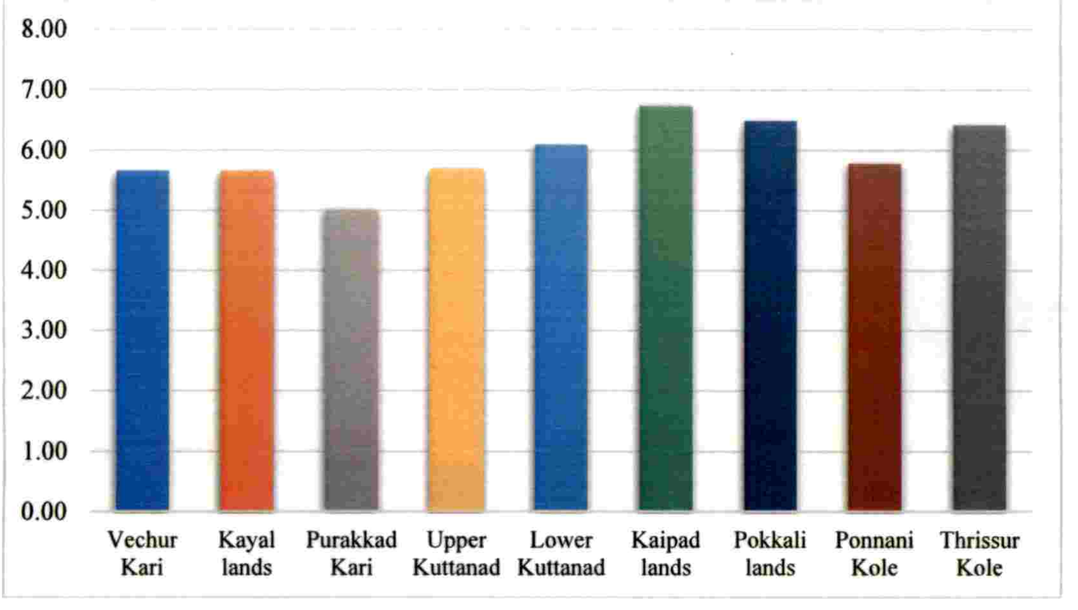

Figure 1. Changes in pH.

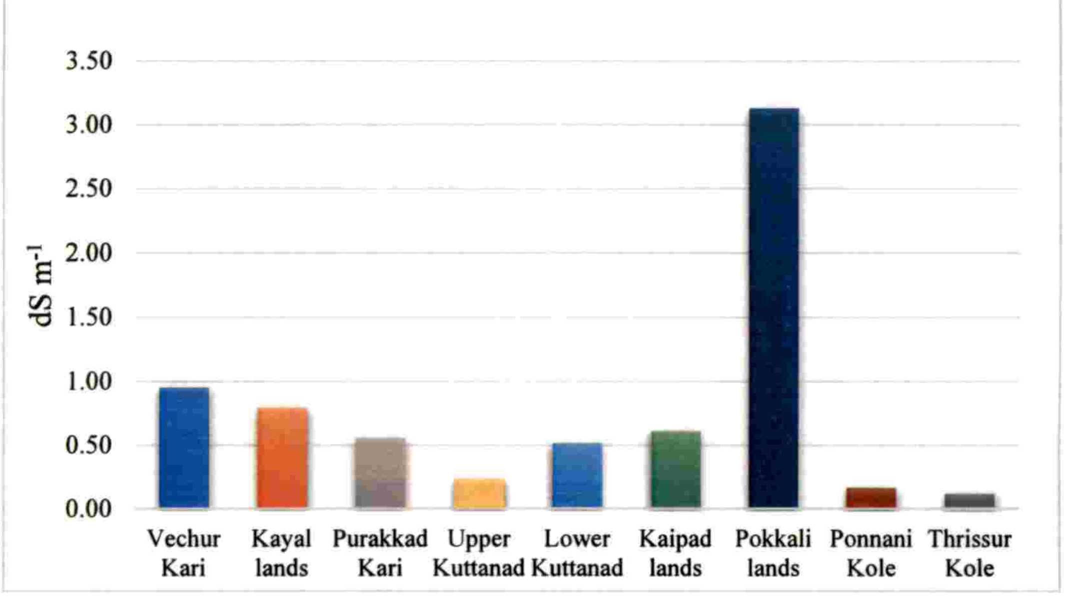

Figure 2. Changes in Electrical conductivity (dS m^{-1})

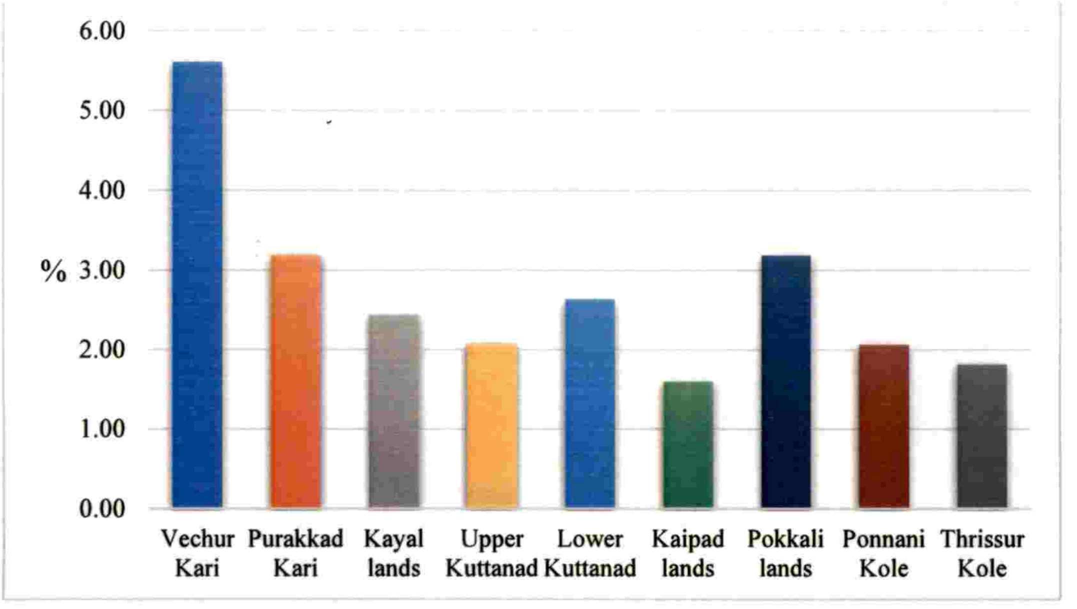

Figure 3. Organic carbon status in soils.

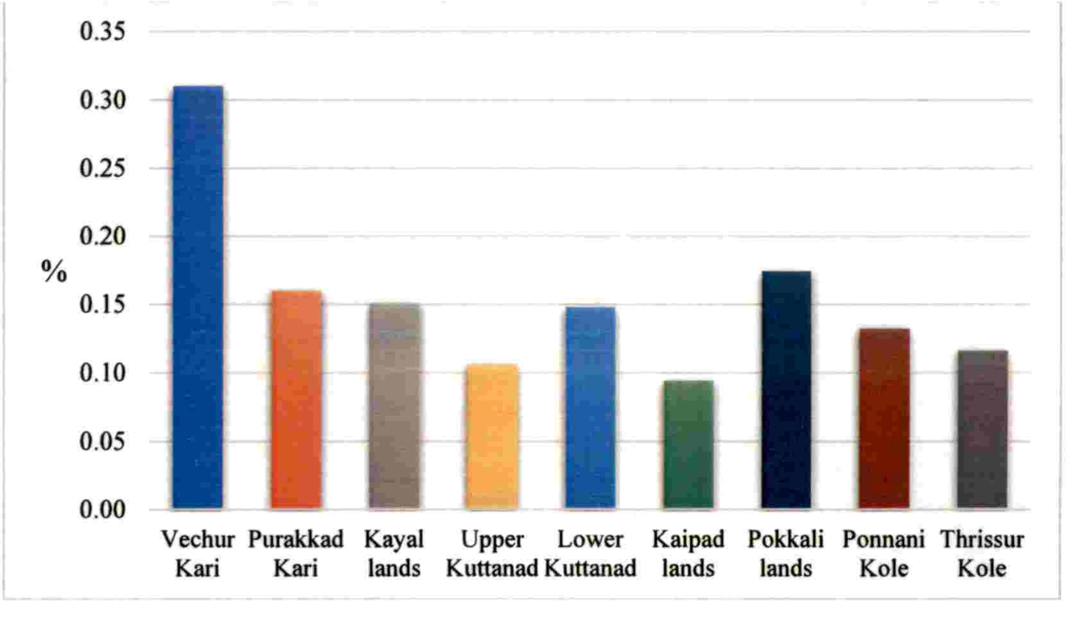

Figure 4. Total Nitrogen percentage status in soils.

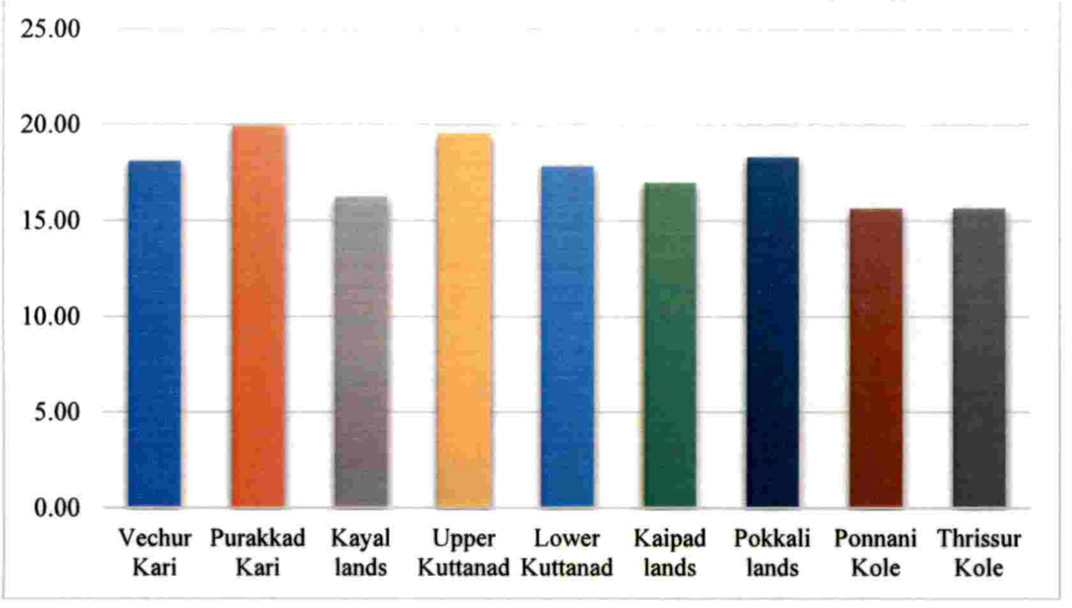

Figure 5. C:N ratio in soils.

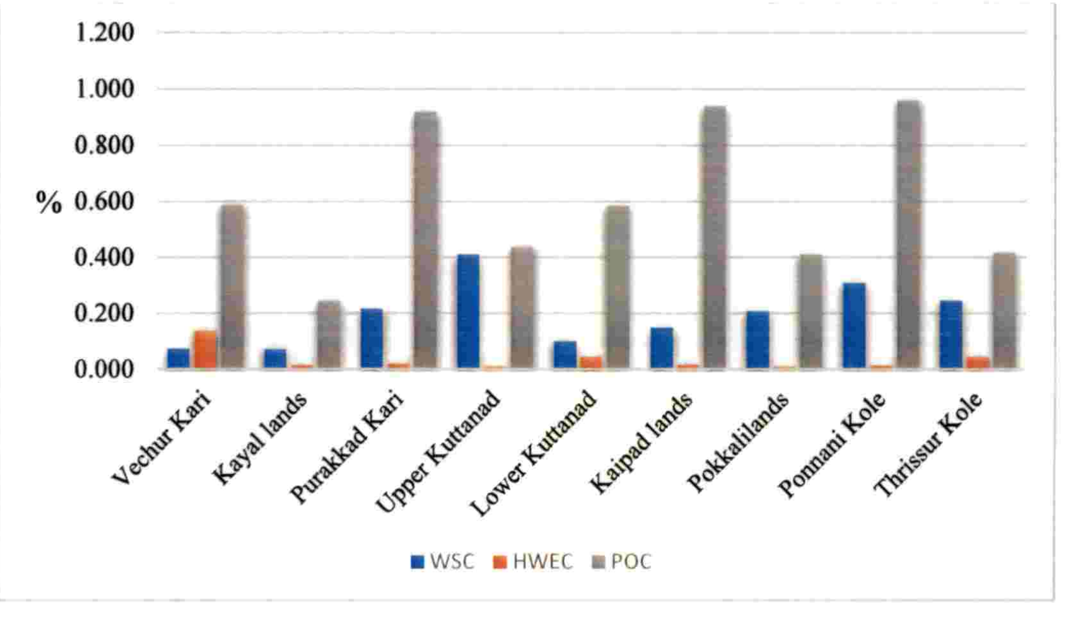

Figure 6. Fractions of carbon in soils

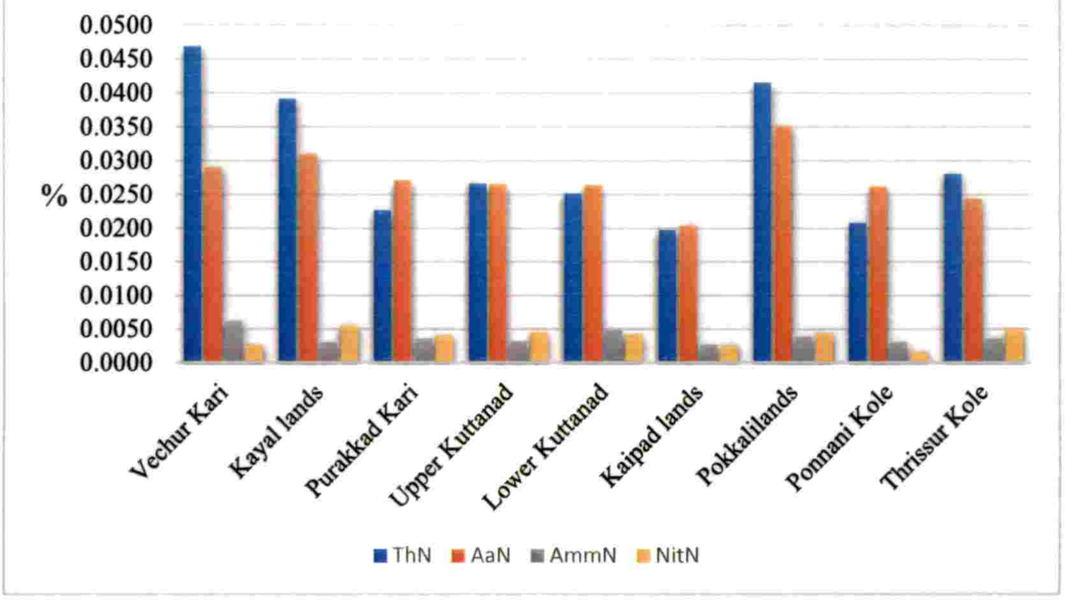

Figure 7. Fractions of nitrogen in soils

The trend of wider C:N ratio's obtained in these soils is due to the same reason as explained in case of OC:tot N ratio.

Experiment 2

Fractionation of soil carbon

Representative soil samples (45 Nos.) of 4 different rice growing acid saline and acid sulphate soils of Kerala were subjected to fractionation of soil carbon.

5.3.1 Physical fractionation

The data on soil carbon and nitrogen preferentially recovered in the sand, silt and clay size fractions are presented in table 9 and 10.

The carbon content in macro size sand fraction varied from 0.0062 to 0.5 per cent. The maximum carbon in macro size sand fraction was estimated in soil from lower *Kuttanad* (sample No. 23) and the minimum in soil from upper *Kuttanad* (sample No. 16).

The lowest total carbon content was recorded in soils from upper *Kuttanad.* This resulted in proportionate lower carbon content recovered in macro size sand fraction also. The Upper *Kuttanad* region is situated along waterways and rivers. They lie in the interior of the villages on the Eastern and Southern periphery of *Kuttanad* subjected to leaching losses of macro sized soil fractions and hence the carbon content.

The nitrogen recovered in macro sand fraction followed the same trend as that of carbon recovered in this fraction, once again substantiating the close association of carbon and nitrogen.

The maximum carbon recovered in micro sand fraction was recorded in Vechoor Kari (sample 2). The lowest carbon and nitrogen content was recorded in upper *Kuttanad* (sample 16).

The carbon content in silt sized fraction varied from 0.041 in Ponnani *Kole* (sample 36) to 0.53 per cent in Vechoor *Kari (sample 3)*. The lowest nitrogen in silt

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sized fraction was observed in upper *Kuttanad (sample 16)* (0.0037 per cent) and the highest in Vechoor *Kari* (sample 3*)* (0.031 per cent).

The carbon content in the clay fraction ranged from 0.03 in *Kaipad* soil (sample 27) to 0.36 in Vechoor *Kari* (sample 3). The nitrogen content in clay fraction varied from 0.0033 to 0.028 percent. The highest nitrogen was recorded in Purakkad *Kari* (sample 12) soil and lowest in *Kaipad* soil (sample 30).

The SOC can be subdivided into fractions with different rates of decomposability, i.e. the labile carbon fraction and the non-labile carbon (stable carbon fraction). The stable SOC is largely bound to clay particles. Therefore, SOC values are highly site dependent and show a strong correlation with clay content (Weigel et al., 2011).

The regression equation including all the parameters having significant correlation with organic carbon yielded the following single equation obtained with carbon recovered from clay fraction as the dominant independent variable that could explain 64.6 per cent variability.

The step up regression analysis including all the parameters correlated for organic carbon yielded the following relations:

OC= 0.978+14.980 clay C (R^2=0.646)......................................(7)

OC=0.557+13.713clay C+53.675 Macrosand N (R^2=0.704).............(8)

Thus, it becomes clear that carbon recovered from clay sized fraction contributed to a major share of organic carbon status in soil (64.6 per cent) which is non-labile pool of SOC. An improvement of R^2 value by 6 % with inclusion of macro sand points to the fact that macro sand carbon also contributes to the stable carbon pool. In addition, N content recovered from macro sand fraction is also closely associated to organic carbon.

The step up regression analysis including all the parameters correlated for total nitrogen yielded the following relations

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Total N= 0.062+0.786 clay C (R^2=0.634)..(9)

Total N=0.039+0.717 clay C+ 2.924 Macro Sand N (R^2=0.695).........(10)

It can be concluded from the above regression equations that carbon recovered from clay sized fraction is the single dominant independent variable for predicting organic carbon and total nitrogen content in soil.

Organic matter of recent plant origin is believed to be preferentially recovered in the sand size fraction (2.00-0.053 mm) whereas more microbially processed material can be found in the silt and clay size (<0.053 mm) fractions (Cheshire and Mundie, 1981). Carbon in the sand fraction is generally more labile than carbon in clay and silt fractions (Tiessen and Stewart, 1983). The labile pool is composed of relatively recent plant residues, root exudates and the microbial biomass (Tisdall and Oades, 1982).

5.3.2. Chemical fractionation

The data on various chemical fractions of carbon in above soils are given in the table 11.

5.3.2.1 Water soluble carbon (WSC)

The term water soluble organic carbon (WSC) is defined as the entire pool of water soluble carbon either sorbed on soil or sediment particles or dissolved in interstitial pore water (Tao and Lin, 2000). The water soluble carbon content ranged from 0.02 to 0.59 per cent among soils. The lowest WSC was recorded in the Vechoor *Kari* (sample No. 5) and the highest in upper *Kuttanad* (sample No. 18). Soil water-soluble organic matter (WSOM) is the most labile and mobile form in soil organic matter pools (Zhao et al., 2012). Being water soluble leaching losses might have resulted in lower values of water-soluble carbon in Vechoor Kari.

The path coefficient showed that water soluble carbon (WSC) had a low direct effect on total nitrogen (-0.203) (table 17).

5.3.2.2. Hot water extractable carbon (HWEC)

The hot water extractable carbon (HWEC) as described by Schulz (1990) consists of a chemical extraction using hot distilled water to represent 'near to nature' conditions of ongoing mineralisation processes. The extracted fraction contains soil microbial biomass, simple organic compounds, and compounds which are hydrolysable under the given extraction conditions (Weigel et al., 2011).

The hot water extractable carbon varied from 0.0032 to 0.29 per cent. The lowest hot water extractable carbon was recorded in *Pokkali* soil (sample No. 35) and the highest in Vechoor *Kari* soil (sample No. 3) (table 11).

. The amounts of C extracted by hot water procedure also strongly correlate with soil micro-aggregate characteristics (Ghani *et al*., 2003). Weigel et al. (2011) reported a strong correlation between hot water extractable carbon and organic carbon. They considered it to confirm that hot water extractable fraction was more related to labile carbon and thus reflected carbon changes as affected by land management.

Hot water extractable carbon had significant positive correlation with total carbon (0.576**), organic carbon (0.570**), total nitrogen (0.612**) and available N (0.667**) content (Table 16). The hot water extraction method can be applied for determining the easily available pool of mineralisable N. Hot water extractable carbon was significantly and positively correlated with total hydrolysable nitrogen (0.413**) and ammoniacal nitrogen (0.437**) (Table 15). Significant correlation obtained between HWEC and total N and available N indicates its influence on mineralisation process. The HWEC being the most labile pool of carbon, the path coefficient showed very high and positive direct effect of HWEC on total nitrogen (+0.487) and available nitrogen (0.465) in these soils supporting the above fact (Table 17 and 18).

5.3.2.3 Permanganate oxidizable carbon (POC)

The measurement of POC is based on chemical oxidation of organic matter by a weak potassium permanganate solution (Weil et al., 2003). In a comparison of

POC and other more established measures of active organic matter, Culman *et al.*, (2012b) found that POC was closely related with smaller and heavier particulate organic C fractions, indicating that POC reflects a relatively processed or stabilized pool of active soil carbon.

Permanganate oxidizable carbon was in the range of 0.033 to 1.67 per cent. The lowest POC was recorded in *Pokkali* soil (sample No. 31) and the highest in soil from Purakkad *Kari* (sample No. 14) (table 11). No significant correlations were obtained between permanganate oxidizable carbon, total nitrogen and available nitrogen content in soil (table 16). The permanganate oxidizable carbon being a stabilized pool might not undergo further decomposition to release nitrogen, this being the reason for no contribution to nitrogen pool from this fraction.

Experiment 3

Fractionation of soil nitrogen

5.4.1 Organic fractions

Approximately 90% of total soil N is composed of soil organic nitrogen N (ON), which plays an important role in N retention and transformation. Nitrogen availability, which is important for the growth of plants, is closely associated with the mineralization of soil organic nitrogen and the depolymerization of the N-containing constituents, namely, amino acid and amino sugar (Liu *et al.*,2018). The data on various organic fractions of nitrogen in the above soils are given in the table 12.

5.4.1.1 Total hydrolysable nitrogen (THN)

The total hydrolysable nitrogen ranged from 0.0088 to 0.057 per cent. The lowest THN was recorded in Purakkad *Kari* soil (sample 13) and the highest in Vechoor *Kari* soil (sample 3). Total hydrolysable nitrogen had significant positive correlation with total carbon (0.527**), organic carbon (0.528**), total nitrogen (0.547**), available nitrogen (0.349*), hot water extractable carbon (0.413**) and amino acid nitrogen (0.360*) (table 14 and 15).

The organic forms of soil N occur in various stages of humification and decomposition and are closely related to the microbial activity. This in turn contributes to the net release of N from the organic reserve as mineral N (Gotoh et al., 1986). The total hydrolysable nitrogen contributed about 80 per cent of total nitrogen (Mini, 1992).

The direct effect of total hydrolysable nitrogen (THN) on total nitrogen was low (+0.206) among soils. Total hydrolysable nitrogen had a positive and very high direct effect on available nitrogen (+0.355) (Table 17 and 18). Thus, THN contributed significantly to mineralizable nitrogen.

5.4.1.2 Amino acid nitrogen (AAN)

The amino acid nitrogen was found to vary from 0.003 to 0.045 per cent. The lowest AAN was observed in lower *Kuttanad* (sample 23). Soil from *Pokkali* (sample 34) recorded the highest AAN of 0.045 per cent. The amino acid nitrogen was significantly and positively correlated with total hydrolysable nitrogen (0.360*) and ammoniacal nitrogen (0.33*) (Table 15).

Typically, about one-third of the fertilizer N applied immobilized and retained in organic forms at the end of the growing season. This newly immobilized nitrogen is less available to microbes and plants than the native humus nitrogen. Also, the stabilization processes involving polymerization of amino compounds and polyphenols, result in incorporation of N into humic substances causing concurrent reduction in N availability (Kelley and Stevenson, 1995). This is clear from the negligible direct effect of AAN on total nitrogen and available nitrogen in soils.

5.4.2 Inorganic fractions

The data on various inorganic fractions of nitrogen in the above soils are given in the table 13.

5.4.2.1 Ammoniacal nitrogen (NH_4^+- N)

Ammoniacal nitrogen was observed to range from 7.4 to 162.00 mg kg^{-1}. The lowest NH_4^+- N was recorded in *Kaipad* soil (sample 28) and the highest in Vechoor

Kari (sample 5). Ammoniacal nitrogen had significant positive correlation with available nitrogen (0.408**), hot water extractable carbon (0.437**) and amino acid nitrogen (0.333*) (table 15 and 16). NH_4^+-N had a low direct effect on total nitrogen (0.137) (Table 17).

5.4.2.2 Nitrate nitrogen (NO_3^--N)

The lowest NO_3^- -N of 7.4 mg $kg^{-1}$was recorded in *Kaipad* soil (sample 28) and the highest of 79.00 mg $kg^{-1}$was recorded in *Kayal* lands (sample 6) of *Kuttanad.* No significant correlations were obtained between nitrate nitrogen content, organic carbon, total nitrogen, available nitrogen and fractions of carbon and nitrogen. This is because NO_3^-N is water soluble and is removed by uptake or leaching losses. It is also clear from the data that the ammoniacal nitrogen fraction is more contributing to available pool.

Experiment 4

Field experiment

The field experiment was laid out in randomized block design as detailed in chapter 3.

5.5. Biometric observations

5.5.1 Plant height

Plant height was significantly influenced by the nitrogen application at different growth stages. The data on plant height at active tillering stage is given in table 19. The plant height was significantly higher in all the treatments in comparison with absolute control. Significant positive correlation was obtained between plant height and total N in soil (0.421*).

The data on plant height at flowering stage is given in table 19. The maximum plant height was produced in T10 (Double of C:N ratio recommendation (based on dry analysis) and the treatments T2, T3, T4, T5, T7, T8 and T9 were on par. The plant height was significantly and positively correlated with plant N content

(0.600**) at this stage indicating the positive influence of nitrogen on vegetative growth which is already well established. The quantity of nitrogen applied in T8 (Half of C:N ratio based recommendation (based on dry analysis) is the lowest (50 kg ha^{-1}) dose of nitrogen applied among the treatments T2, T3, T4, T5, T7, T8 and T9. Hence, with respect to increase in plant height, application of T8 (Half of C:N ratio based recommendation (dry analysis) was sufficient to influence plant height when compared to absolute control.

The data on plant height at harvest stage is given in table 19. The maximum plant height was produced in T10 (Double of C:N ratio recommendation (based on dry analysis) and the treatments T5, T7, T8 and T9 were on par with T10. Plant height was significantly and positively correlated with total N (0.618**) in soil and content in straw (0.648**). It is clear from this that total N in soil as well as N content in straw directly influenced the height of plant at harvest stage. So, treatment T8 was enough for increasing plant height in comparison with absolute control where the nitrogen applied was the lowest.

5.5.2. Tiller production

The data on the number of tillers produced at active tillering stage is given in table 20. The maximum number of tillers was produced in T9 receiving nitrogen dose double the C:N ratio recommendation (based on wet analysis) (233.2 kg ha^{-1})and the treatments T4 (Soil test based recommendation) (Based on dry analysis) (59.4 kg ha^{-1}), T5(C:N ratio based recommendation (based on wet analysis) (116.6 kg ha^{-1}), T6(C:N ratio based recommendation (based on dry analysis) (100 kg ha^{-1}), T8 (Half of C:N ratio based recommendation (based on dry analysis) (50 kg ha^{-1}) and T10 (Double of C:N ratio recommendation (based on dry analysis) (200 kg ha^{-1}) were on par with T9. Hence, with respect to tiller production the lowest quantity of nitrogen required was as in T8 (50 kg ha^{-1}).

The application of nitrogen (N) fertilizer enhance the tiller population. This is due to increase in the cytokinin content within tiller nodes, which further enhances the germination of the tiller primordium (Liu et al. 2011). This is clear from the significant positive correlation obtained between number of tillers and total N in soil (0.590**) at active tillering stage.

The data on the number of tillers produced at flowering stage is given in table 20. The maximum number of tillers was produced in T10 receiving nitrogen dose at the rate of double the C:N ratio recommendation (based on dry analysis) and the treatments T4, T5 and T9 were on par with T10. Hence, treatment T4 (Soil test-based recommendation) (Based on dry analysis) (59.4 kg ha^{-1}) was enough with respect to maximum tiller production.

Nitrogen evokes a significant effect on the promotion of tiller development (Sakakibara *et al.*, 2006). This became clear from the significant positive correlation obtained between number of tillers and plant N content (0.610**) during flowering stage.

The total number of tillers and productive tillers observed at harvest is given in table 21. The treatments could not produce any significant effect on the total number of tillers. The number of productive tillers rather than total number of tillers contributes more to enhance productivity of rice plant.The number of productive tillers was significantly higher in all the treatments in comparison with absolute control. Significant positive correlations were obtained between number of productive tillers and nitrogen content in straw (0.391*) (table 55).

5.5.3. Number of branches per panicle

The data on the number of branches per panicle, number of grains per panicle and thousand grain weight are presented in the table 21. The maximum number of branches per panicle was observed in the treatment receiving nitrogen dose double the C:N ratio recommendation (based on dry analysis) (T10) and was on par with T5(C:N ratio based recommendation (based on wet analysis) and T9(double of C:N ratio recommendation (based on wet analysis). Hence, the nitrogen as per treatment T5 was enough to obtain maximum number of branches per panicle.

5.5.4. Number of grains per panicle

The maximum number of grains per panicle was recorded in treatment receiving nitrogen dose double the C:N ratio recommendation (based on wet analysis) (T9). Since, treatments T5 and T10 were on par with T9, treatment T5 (C:N ratio based recommendation (based on wet analysis) (116.6 kg ha^{-1}) was sufficient for getting maximum number of grains per panicle (table 21).

Higher number of grains per panicle at higher nitrogen rate favoured formation of higher number of branches per panicle (Haque and Haque, 2016). Significant positive correlations were obtained between number of branches and total N in soil (0.724**), grain N (0.790**) and straw N (0.722**) content (Table 55).

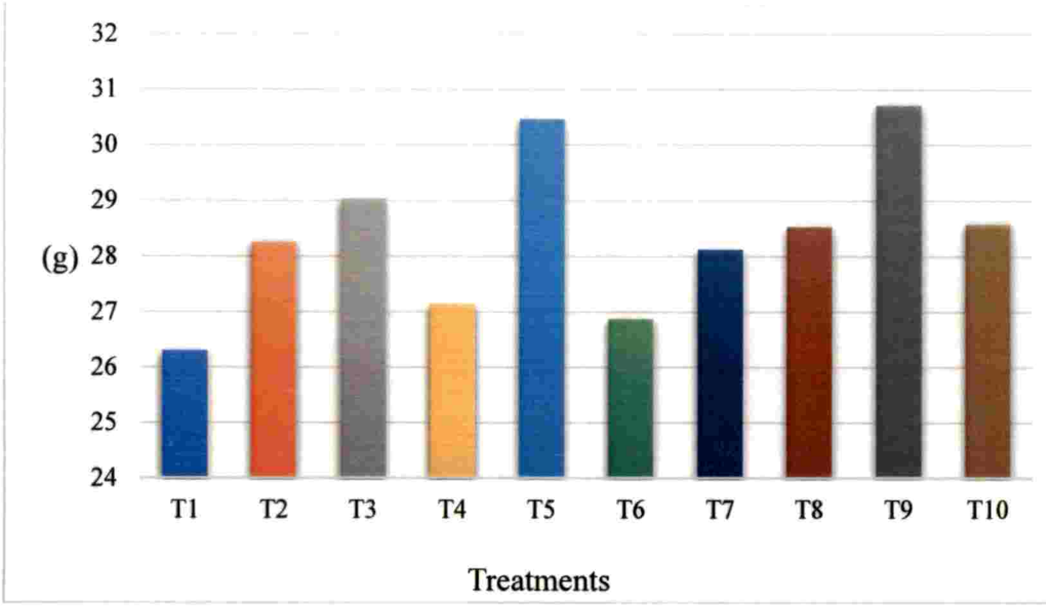

Figure 8. Effect of treatments on thousand grain weight

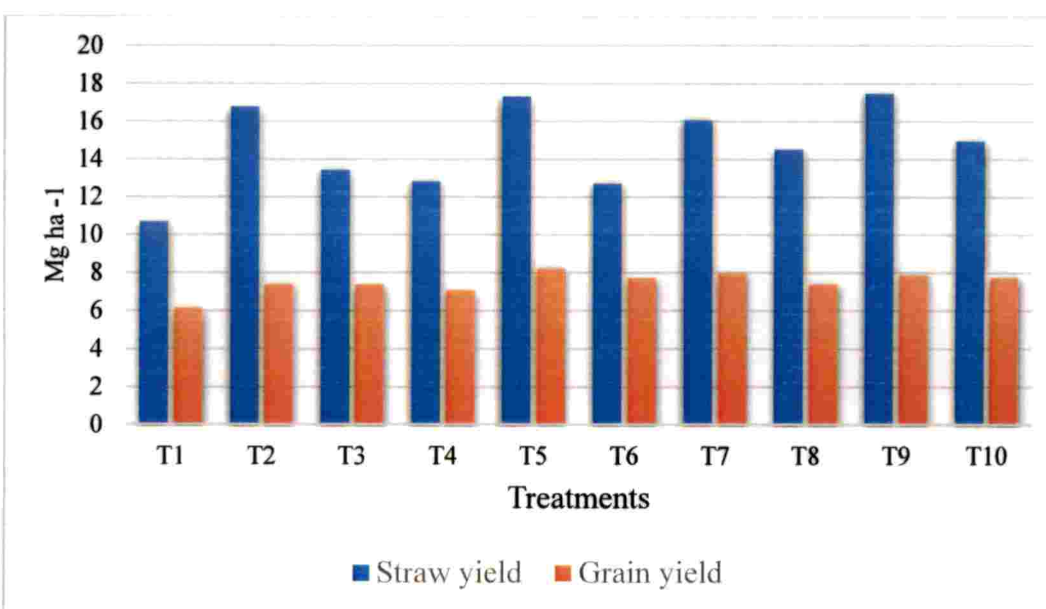

Figure 9. Effect of different treatments on straw and grain yield.

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5.5.5. Thousand grain weight

Data in table 21 show that the maximum of 30.71 g thousand grain weight was recorded in T9(double the C:N ratio recommendation (based on wet analysis). However, T5 (C:N ratio based recommendation (based on wet analysis) was on par with T9. So, treatment T5 was enough for with respect to increase in thousand grain weight. Significant positive correlations were obtained between thousand grain weight, with N content in grain (0.547**), straw (0.697**), number of grains per panicle (0.584**) and number of branches per panicle. (0.452*) (Table 55).

5.5.6. Grain yield

Grain yield recorded in each treatment in kg $plot^{-1}$ and Mg ha^{-1} is presented in table 22. The maximum grain yield of 8.22 Mg ha^{-1} was recorded in the treatment which received the application of nitrogen based on C:N ratio recommendation (wet analysis) (T5) (116.6 kg N ha^{-1}). The grain yield in treatment T4 (Soil test based recommendation)(dry analysis) was 7.07 Mg ha^{-1}. However, the treatments T7 (half of C:N ratio based recommendation (wet analysis) (58.3 kg N ha^{-1}) and T9 (double of C:N ratio based recommendation (wet analysis) (233.2 kg N ha^{-1}) were on par with T5. The quantity of nitrogen applied in treatment T4 (Soil test based recommendation) (wet analysis) was 59.4 kg N ha^{-1}. Moreover, it is clear from the above data a difference of 1.15 Mg ha^{-1} of grain yield was observed between T5(C:N ratio based recommendation) (wet analysis) and T4 (Soil test based recommendation)(dry analysis). The net returns from T5, T7 and T9 are 188,44, 180,855 and 179,836 rupees respectively. The net returns from C:N ratio based treatments (T5, T7 and T9) were higher than T2 (POP recommendation) (1,64,929 rupees) and T4 (soil test based recommendation (dry analysis) (1,49,858 rupees). Hence, treatment T5 could be recommended for getting maximum grain yield.

Grain yield of rice plant is highly relying on the number of spike-bearing tillers produced by each plant, filled grains and grain weight. The increment of grain yield in this study at higher nitrogen levels is due to efficient absorption of nitrogen and other elements which raise the production and translocation of the dry matter from source to sink. Significant positive correlations was obtained between grain yield and plant height (0.736**), number of grains per panicle (0.756**), thousand grain weight (0.626**), number of branches per panicle (0.576**), total number of tillers (0.520**), number of productive tillers (0.537**) and straw yield (0.558*) and total nitrogen in soil (0.554**) (Table 55). The total nitrogen in soil was highest in T10 followed by T5 and T7 (table 43).

5.5.7. Straw yield

The straw yield recorded in each treatment are presented in the table 23. The highest straw yield of 17.47 Mg $ha^{-1}$was recorded in T9 (Double of C:N ratio based recommendation) (wet analysis) and the minimum in T1 (Absolute control) (10.67 Mg ha^{-1}). The treatments T2, T5, T7, T8 and T10 were on par withT9.The straw yield of 17.32 Mg $ha^{-1}$was recorded in T5 (C:N ratio based recommendation) (wet analysis) and 12.81 Mg $ha^{-1}$was recorded in T4 (Soil test based recommendation) (dry analysis). A difference of 4.51 Mg $ha^{-1}$of straw yield was observed between T4 and T5.

The net returns from T5, T7, T8 and T10 were 188,442, 180,855, 163,253 and 164,477 rupees respectively. The net returns from C:N ratio based treatments (T5, T7) were higher than T2 (POP recommendation) (164,929 rupees) and T4 (soil test based recommendation (dry analysis) (1,49,858 rupees). The treatment T5 (C:N ratio based recommendation (wet analysis) (58.3 kg ha^{-1}) could be recommended for application for getting higher straw yield also.

Significant positive correlations were obtained between straw yield and plant height (0.497**), total number of tillers (0.413*), number of productive tillers (0.423*) and grain yield (0.558**) (Table 55).

5.6. Soil and plant analysis

5.6.1. Effect of different treatments on electrochemical properties, nutrient content and C:N ratio in soil at active tillering stage

The data on the effect of different treatments on electrochemical properties and nutrient content in soil at active tillering stage is presented in the table 23.

The application of different levels of nitrogen had no significant effect on pH, EC and available N content of the soil, while the organic carbon and total nitrogen contents varied significantly with the different levels of nitrogen application. The highest organic carbon was recorded in T5(C:N ratio based recommendation) (wet analysis) (2.05 %).

In general, N fertilization leads to an increase in SOC concentration (Alvarez, 2005). The organic carbon content in treatment T3 (Soil testbased recommendation) (wet analysis)(59.4 kg N ha^{-1}), T4 (Soil test based recommendation) (dry analysis) (59.4 kg Nha^{-1}) T5 (C:N ratio based recommendation)(wet analysis)(116.6 kg N ha^{-1}), T7 (Half of C:N ratio based recommendation (wet analysis) (58.3 kg N ha^{-1}), and T9 (Double of C:N ratio based recommendation (wet analysis)(233.2 kg N ha^{-1}) were on par with respect to organic carbon. The organic carbon in these treatments were significantly higher than that in other treatments. So, with respect to increase in organic carbon content, among the treatments, treatment T7 (58.3 kg N ha^{-1}) was enough to have the same organic carbon content.

The total nitrogen content in the treatments T10 was significantly higher than that in other treatments. The treatments T5 and T7 were on par with T10. So, T7 (58.3 kg ha^{-1}) is the best treatment combination for increasing total nitrogen in soil.The total nitrogen content was significantly and positively correlated with plant height (0.421*) and number of tillers (0.590*) at active tillering stage. At the same time the total N could be deduced as a function of water soluble carbon (WSC) (0.469**) and hot water extractable carbon (0.471**) which had significant positive correlation with total nitrogen (table 29). The path coefficient analysis also indicated that water soluble carbon (0.337) and hot water extractable carbon (0.340) had very high and positive direct effect on total nitrogen content in soil (table 30) indicating the release of N during decomposition of organic matter. It becomes clear that application of treatment T10 (Double of C:N ratio recommendation (dry analysis) (200.2 kg ha^{-1}) is not required since it is on par with T7 (Half of C:N ratio recommendation (wet analysis) (58.3kg ha^{-1}) for increasing total nitrogen content in active tillering stage.

Soil C:N ratio is a sensitive indicator of soil quality and is often considered as a sign of soil nitrogen mineralization capacity. With respect to C:N ratio, the treatments T3 (Soil test based recommendation) (wet analysis) was significantly higher than that in other treatments. However, the treatments, T1 (Absolute control), T2 (POP recommendation) and T4 (Soil test based recommendation) (dry analysis) were on par with T3 with respect to C:N ratio. Wider soil C:N ratio in these treatments resulted in slow decomposition rate of organic matter and organic nitrogen by limiting the soil microbial activity, whereas narrow soil C:N ratio in C:N ratio based treatments (T5, T6, T7, T8, T9 and T10) accelerated the process of microbial decomposition of organic matter and nitrogen, which is not conducive for carbon sequestration (Sunfeng *et al.*, 2013). This resulted in increase in total N status in C:N ratio based treatments than POP and soil test based treatments.

The primary and secondary nutrient status of the experimental site as influenced by the application of different treatments are presented in the table 24. The maximum available P content of 15.73kg $ha^{-1}$was recorded in T10 (Double of C:N ratio based recommendation (dry analysis). The treatments T2, T4, T5 and T6 were on par with T10 and were found to be significantly higher than that in other treatments. The available P status in T2 was 14 kg ha^{-1}, T4 (12.88kg ha^{-1}), T5 (14.16 kg ha^{-1}) and T6 was 14.81 kg P_2O_5 ha^{-1} respectively.

Several forms of phosphate that are coprecipitated with ferric oxide are released as a result of reduction of ferric oxide in the soil. These reactions result in a larger amount of phosphate becoming available to a flooded rice crop than an upland crop (Patrick and Mahapatra, 1968).

The available potassium status of 104.72 kg ha^{-1} observed in T6 (C:N ratio based recommendation) (dry analysis) was found to be significantly higher from that in all other treatments. Hence, T6 is the best treatment combination with respect to increasing available potassium status in soil.

The available calcium content recorded in T9 (Double of C:N ratio based recommendation) (wet analysis), T6 (Half of C:N ratio based recommendation) (dry analysis), T3 (Soil test based recommendation) (250 kg $CaCO_3$ ha^{-1}), T2 (POP recommendation) and T7 (Half of C:N ratio based recommendation (wet analysis) were on par and found to be significantly higher than that in other treatments.This would suggest that soil test based recommendation of 250 kg ha^{-1}was sufficient to improve the available Ca content as against the treatments T2 where calcium carbonate were applied @600 kg ha^{-1}.

The available magnesium content recorded in T6 (C:N ratio based recommendation) (dry analysis) was found to be significantly higher from that in other treatments. The available sulphur content recorded in T4 (Soil test based recommendation) (dry analysis) (25 kg S ha^{-1}), T6, T5, T2 and T3 were on par and found to be significantly higher from that in other treatments.

The micronutrient status as influenced by different levels of nitrogen is presented in the Table 25. The application of different levels of nitrogen had significant influence in the available zinc and boron content of the soil. The available zinc content recorded in T3 (Soil test based recommendation) (wet analysis) and T7 (Half of C:N ratio based recommendation) (wet analysis) were on par and significantly higher than that from all other treatment. The hot water extractable B recorded in T4, T5, T6, T7, T8, T9, T10 were on par and was significantly higher from all other doses. The available Fe, Mn and Cu were not significantly influenced by the treatments.

5.6.2. Effect of different treatments on carbon fractions in soil at active tillering stage

The highest water soluble carbon was recorded in T10 (0.88 %). (table 26). The hot water extractable carbon in treatments T5, T6, T7, T8 and T10 were on par and significantly higher than that of other treatments. Significant positive correlation coefficients were obtained between WSC (0.469**), HWEC (0.471**) and total nitrogen in soil. The direct effect of water soluble carbon (0.33) and that of hot water extractable carbon on total nitrogen in soil was very high and positive (table 30). Hence, labile and mobile fractions of carbon viz., water soluble carbon and hot water extractable carbon contributed significantly to the total nitrogen status than active and stable fraction viz., permanganate oxidizable carbon. Permanganate oxidizable carbon had significant positive correlation with available nitrogen (0.536**) at active tillering stage (table 29). The path coefficient analysis of POC on available N indicated very high and positive direct effect (0.443) (table 31).

5.6.3. Effect of different treatments on organic and inorganic fractions of nitrogen in soil at active tillering stage

The organic fractions (total hydrolysable nitrogen and amino acid nitrogen) and the inorganic ammoniacal nitrogen fraction were not significantly influenced by the treatments (table 27). The nitrate nitrogen fractions in T5, T8 and T10 were on par and were significantly higher than that in other treatments. It is clear from the data that the higher nitrate nitrogen fraction was obtained in C:N ratio based treatments (T5, T8 and T10) than POP (T2) and soil test based (T4) treatments (table 28).

5.6.4. Effect of different treatments on electrochemical properties, nutrient content and C:N ratio in soil at flowering stage

The data on the effect of different treatments on electrochemical properties, nutrient content and C:N ratio in soil at flowering stage is presented in the table 32.

The application of different levels of nitrogen had no significant effect on pH, EC and available N content of the soil, while the organic carbon and total nitrogen contents varied significantly with the different levels of nitrogen application.

The organic carbon recorded in T3 (Soil test based recommendation)(wet analysis) (59.4 kg N ha^{-1}), T5 (C:N ratio based recommendation (wet analysis) (116.6 kg N ha^{-1}), T9 (Double of C:N ratio based recommendation (wet analysis) (233.2 kg N ha^{-1}) and T10(Double of C:N ratio based recommendation (dry analysis) (200.2 kg N ha^{-1})were on par and were significantly higher than that in other treatments. The highest plant N content of 0.80 % was recorded in T10 (table 39). The plant N content in T3 was 0.52 %. The plant N content in C:N ratio based recommendation treatments viz., T5 (0.637 %), T9 (0.737 %) and T10 (0.80 %) were higher than soil test based recommendation (wet analysis) (0.52 %). Hence, it could be concluded that increased N application resulted in an increase in organic carbon status of soil especially when it was based on C:N ratio.

Organic carbon had significant positive correlation with plant N (0.559**) content in flowering stage. Besides, significant positive correlation was obtained between permanganate oxidizable carbon fraction (0.484**) and organic carbon status in soil (table 41). The direct effect of permanganate oxidizable carbon on total nitrogen content in plant is high and positive as indicated by partial coefficient of 0.41(table 42).

The highest total N content of 0.143 % was recorded in T5 (C:N ratio based recommendation) (wet analysis) (116.6 kg N ha^{-1}). The treatments T2 (POP recommendation) (110 kg ha^{-1}), T4 (Soil test based recommendation (dry analysis) (59.4 kg ha^{-1}),T6(C:N ratio based recommendation)(dry analysis) (100 kg ha^{-1}), T8 (Half of C:N ratio based recommendation) (dry analysis) (50 kg ha^{-1})and T10(Double of C:N ratio based recommendation) (dry analysis) (200.2 kg ha^{-1}) were on par with T5. The plant N content was highest in T10 (Double of C:N ratio based recommendation) (dry analysis) (0.80 %). The quantity of N applied is also higher in this treatment (200.2 kg ha^{-1}). The plant N content in T2 (0.43 %), T4 (0.54 %), T6 (0.56 %) T8 (0.67 %) respectively (table 39). It is clear from the data that the total N content in soil as well as in plant during flowering stage was higher in C:N ratio based treatments(T5, T6, T8 and T10) than package of practices based (T2) and soil test based recommendation based(T4) treatments.

Significant positive correlations were obtained between plant N and organic carbon (0.559*), water soluble carbon (0.392*) and permanganate oxidizable carbon (0.648**) (table 42). The path coefficient analysis indicated that the direct effect of water soluble carbon on total N in plant is low (0.12) whereas that of permanganate oxidizable carbon is positive and high (0.41) at flowering stage. The direct effect of soil organic carbon on plant N content is also high and positive (0.33) (table 43).

The C:N ratio recorded in T9 (Double of C:N ratio based recommendation)(wet analysis) and in treatment T10 (Double of C:N ratio based recommendation)(dry analysis) were on par and significantly wider from that in other treatments.

The primary and secondary nutrient status as influenced by the different levels of nitrogen are presented in the table 33. The available P content recorded in T3 (14.7kg ha^{-1}), T4 (15.32kg ha^{-1}), T5 (15.32 kg ha^{-1}),T6 (14.62kg ha^{-1}), T7 (16.47 kg ha^{-1}), T9 (16.20kg ha^{-1}) and T10 (16.20kg ha^{-1}) were on par and significantly higher than that in other treatments. Hence, T7 (Half of C:N ratio based recommendation) (wet analysis) is sufficient for increasing P content in soil.

The available potassium status in treatments T2 (55.06 kg ha^{-1}), T4 (59.44kg ha^{-1}), T7 (56.79kg ha^{-1}), T8 (63.06kg ha^{-1}), T9 (55.64 kg ha^{-1}) and T10 (68.66 kg ha^{-1}) were on par and were significantly higher from that in other treatments. The highest K content in plant was recorded in T10 (1.61 %). The plant K content in T2 (1.34 %) and T4 (1.14 %) respectively (table 39).

The application of different levels of nitrogen could not produce any significant influence on the available calcium and magnesium status in soils.

The available sulphur status in the treatments T2 (POP recommendation), T4 (Soil test based fertilizer recommendation (dry analysis) and T5 (C:N ratio based recommendation (wet analysis) were on par and were significantly higher than that in other treatments.

The micronutrient status as influenced by different levels of nitrogen is presented in the Table 34. The application of different levels of nitrogen had significant influence in the available iron, manganese, copper, zinc and boron content of the soil. The available iron content recorded in T4, T5, T6, T7, T8 and T9were on par and significantly higher than that in all other treatments.

The highest available manganese content of 71.37 mg $kg^{-1}$was recorded in T6 and it was on par with T8. The available copper content recorded in T2, T3 and T5 were on par and were significantly higher than that in all other treatments.

The maximum available zinc content was recorded in T10 (10.21 mg kg^{-1}) and it was on par with T9. The hot water extractable B recorded in T2, T4, T5, T6, T7, T9 and T10 were on par and significantly higher than that in all other treatments. Significant positive correlation was obtained between available B in soil and B in plant (0.429*).

5.6.5. Effect of different treatments on carbon fractions in soil at flowering stage

The water soluble carbon recorded in treatments T3, T4, T5, T6, T7, T9 and T10 were on par and were significantly higher than that in other treatments (table 35). The hot water extractable carbon recorded in treatments T2, T5, T6, T7 and T10 were on par and significantly higher than other treatments. Significant positive correlations were obtained between water soluble carbon (0.392*), permanganate oxidizable carbon (0.648**) and N content in plant (table 41). This is also supported by the very high direct effect of permanganate oxidizable carbon on total nitrogen content in plant (0.41) (table 42).

5.6.6. Effect of different treatments on organic and inorganic fractions of nitrogen in soil at flowering stage

The amino acid nitrogen in treatments T6 and T9 were on par and were superior than that in other treatments. The total hydrolysable nitrogen was not significantly influenced by the treatments. The inorganic nitrogen fractions (ammoniacal and nitrate) also were not significantly influenced by the treatment at flowering stage (table 36 and 37).

5.6.7. Nutrient content in plant at flowering stage

Highest nitrogen content in plant was recorded in T10 (Double of C:N ratio recommendation) (dry analysis) (0.80 %) where N applied was 200 kg ha^{-1} (table 39). Content of nitrogen in plant was significantly and positively correlated with organic carbon content in soil (0.559**) (table 41).

Total P, total Ca, total Mg, total S and total Zn content in rice were not significantly influenced by the treatments.

The total potassium content in T5, T6, T7 and T10 were on par and were significantly higher than that in other treatments (table 38). The total boron content in T5 was significantly higher than that in other treatments. Available B in soil had significant correlation with plant boron content (0.429*) in flowering stage.

5.6.8. Effect of different treatments on electrochemical properties, nutrient content and C:N ratio in soil at harvest stage

The data on the effect of different treatments on electrochemical properties and nutrient content in soil at harvest stage is presented in the table 43.

The application of different levels of nitrogen had no significant effect on pH, EC of the soil, while the organic carbon, total nitrogen and available nitrogen contents varied significantly with the different levels of nitrogen application.

The organic carbon status of 2.343 % observed in T5 (POP recommendation) was found to be significantly higher than that in all other treatments.Significant positive correlations were obtained between organic carbon and total nitrogen (0.465**), available N (0.676**) water soluble carbon (0.537*), hot water extractable carbon (0.729*), ammoniacal nitrogen (0.450*) and nitrate nitrogen (0.396*) fractions (table 56)

The total N content recorded in T5, T7, T9 and T10 were on par and were significantly higher than that in other treatments.

The straw and grain N content in T9 and T10 were highest among the treatments. It is clear from the data that the total N content in plant during harvest stage was higher in C:N ratio based treatments(T9 and T10) than package of practices based (T2) and soil test based recommendation based(T4) treatments.

The total N in soils had significant and positive correlation with organic carbon (0.465**), available N (0.489**), hot water extractable carbon(0.501**) and grain N (0.744**) and straw N (0.682**) content (table 55).

The available N content recorded in T2(110 kg N ha^{-1}), T4(59.4 kg N ha^{-1}), T5(116.6 kg N ha^{-1}), T6(100 kg N ha^{-1}), T8(50 kg N ha^{-1}) and T9(233.2 kg N ha^{-1}) were on par and were significantly higher than that in other treatments. Significant positive correlations were obtained between available N and organic carbon (0.676*), total N (0.489**), hot water extractable carbon (0.637**) and ammoniacal N (0.461**) (table 56).

With respect to C:N ratio, the treatmentsT2, T4, T8 and T9 were on par and were significantly wider than that in other treatments.

The primary and secondary nutrient status of the experimental site was influenced by the application of different treatments are presented in the table 45. The maximum available P content was recorded in T5 (24 kg ha^{-1}). The treatments T7 (18.38 kg ha^{-1}) and T8 (17.83 kg ha^{-1}) were on par with T5 and were found to be significantly higher than that in other treatments. Hence, treatment T7 is enough for increasing available P content in soil.

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The available potassium status observed in T2 (146.43kg ha^{-1}), T3 (113.28 kg ha^{-1}) and T8 (162.39kg ha^{-1}) were on par and were found to be significantly higher from that in all other treatments. Hence, with respect to available K status T8 becomes sufficient.

The available calcium content recorded in T2, T7 and T8 ()were on par and found to be significantly higher from that in other treatments.

The available magnesium status of 104.76 mg kg^{-1}observed in T2 (POP recommendation) was found to be significantly higher than that in other treatments.

The available sulphur content recorded in T4, T6, T9 and T10 were on par and found to be significantly higher than that in other treatments.

The micronutrient status as influenced by different levels of nitrogen is presented in the Table 46. The application of different levels of nitrogen had significant influence in the available copper and boron content of the soil. The available copper content recorded in T2 (POP recommendation) and T3 (Soil test based recommendation) (wet analysis) were on par and significantly higher than that from all other treatment. The hot water extractable B recorded in T2, T3 and T5 were on par and were significantly higher than that from all other treatments. Available Fe, Mn and Zn were not significantly influenced by the treatments.

5.6.9. Effect of treatments on fractions of carbon at harvest stage

The highest water soluble carbon was recorded in T2(table 47). The hot water extractable carbon recorded in T4, T5, T8, T9 and T10 were on par and were significantly higher than that in other treatments. Significant positive correlation was obtained between WSC and organic carbon in soil (0.537**). Hot water extractable carbon had significant positive correlations with organic carbon (0.729**), total N (0.501**), available N (0.637**), N content in grain (0.634**) and straw (0.588**). Water soluble carbon had very high direct effect on straw yield the path coefficient being 0.46 and high direct effect on grain yield (0.366).

5.6.10. Effect of treatments on fractions of nitrogen at harvest stage

The amino acid nitrogen fraction in treatments T5 and T6 were significantly higher than that in other treatments and were on par. The total hydrolysable nitrogen fraction was not significantly influenced by different levels of treatment application in the experiment plot. The ammoniacal nitrogen fractions in treatments T6, T8 and T10 were significantly higher than that in other treatments and were on par. With respect to nitrate fraction, treatments T4, T7 and T9 were on par and were significantly higher than that in other treatments (table 48 and 49).

5.6.11. Nutrient content in straw at harvest

Highest content of nitrogen in straw was recorded in T9 (1.53 %) and lowest in T1(1.08 %) (table 50). Though T9 recorded highest it was on par with T10. Nitrogen content in straw was significantly and positively correlated with organic carbon (0.545**), total N (0.682**), available N (0.443*), hot water extractable carbon (0.588**) and ammoniacal N fraction (0.406*)

The treatment application could not significantly influence the total P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B content of straw at harvest stage.

5.6.12. Analysis of nutrients in grain

The total nitrogen content recorded in the treatments T5, T9 and T10 were on par and were significantly higher than that in all other treatments (table 53). Nitrogen content in grain was significantly and positively correlated with organic carbon (0.508**), total N (0.744**), available N (0.457*), hot water extractable carbon (0.634**) and ammoniacal N fraction (0.425*)

The application of treatments could not produce any significant effect on the total phosphorus, potassium, calcium and magnesium contents in the grain. Highest S content was noticed in T3 and was significantly higher than that in other treatments. Micronutrient content in grain except B did not vary significantly with respect to application of different treatments. The total B content in T2, T3, T4, T8, T9 and T10 were on par and were significantly higher than that in all other treatments (table 54).

Summary

Summary

- Majority of soils from *Kuttanad* could be included in strongly acidic category (5.1-5.5) and *Kole* lands in moderately to slightly acidic (5.6-6.5) category. Both *Pokkali* and *Kaipad* tracts were near neutral (6.6-7.3) in soil reaction.

- The electrical conductivity was highest in *Pokkali*, followed by *Kaipad* area. Vechur *Kari* soils recorded higher EC values among soils of *Kuttanad* region. Low EC values were recorded in *Kole* lands.

- Among the various groups of soil collected, Vechur *Kari*, Lower *Kuttanad* and *Pokkali* recorded very high values for available P. The available P status was sufficient in Upper *Kuttanad* area. The available P was low to medium (<10- 24 kg ha^{-1}) in other areas.

- The available K status was high in *Kuttanad*, *Pokkali* and Thrissur *Kole*. It was medium in *Kaipad* and Ponnani *Kole* area.

- Out of 45 samples, 41 were deficient (< 300 mg kg^{-1}) in calcium.

- Soils from Purakkad *Kari* and upper *Kuttanad* were sufficient (>120 mg kg^{-1}) in magnesium. All other locations in *Kuttanad* as well as in *Kaipad, Pokkali and Kole* lands recorded lower values of magnesium (<50 mg kg^{-1}).

- Three samples from Ponnani *Kole* and one sample from Thrissur *Kole* (Adattu *Kole)* were deficient in available sulphur (<5 mg kg^{-1})

- Very high values of iron were recorded in all the locations

- Soils from Vechoor *Kari*, Purakkad *Kari*, Lower Kuttanad and *Pokkali* were deficient in manganese (<1 mg kg^{-1}).

- Out of 45 samples, 31 samples were deficient in copper.

- None of the samples were deficient in available zinc content.

- Out of 45 samples, only 9 samples were deficient in available boron.
- Among the soils collected from *Kuttanad*, *Kari* soils from Vechur and Purakkad recorded the highest organic carbon status. The organic carbon status of Upper *Kuttanad* and *Kayal* lands were lower than *Kari* soils.
- Among the acid saline rice soils of *Pokkali* and *Kaipad*, *Pokkali* soils recorded higher values of organic carbon than *Kaipad*. The status of organic carbon was high in Ponnani *Kole* than in Thrissur *Kole*.
- The organic carbon was significantly and positively correlated with total nitrogen (0.970**) and available nitrogen (0.509**) status in these soils.
- Total nitrogen is the single most independent factor explaining 94 per cent variability of organic carbon in these soils
- The trend of total carbon status in *Kuttanad* and all other locations followed the same trend as that of organic carbon since the content of inorganic carbon was negligible and hence there was no difference between the total and organic carbon.
- Organic carbon is the dominant independent variable that could explain 99.8 per cent variability of total carbon in these soils.
- Total carbon, organic carbon, total nitrogen and hot water extractable carbon content significantly and positively influenced available nitrogen in soils.
- The C:N (OC:Tot N) ratio was between 12-15:1 in 9 locations. Majority of samples from Thrissur and Ponnani Kole were included in this category. It was between 15-20:1 in 29 locations. Majority of samples from *Kuttanad*, *Pokkali* and *Kaipad* fall under this category. The C:N ratio was above 20:1 in 7 locations. Three samples from Purakkad *Kari* and two samples from Upper *Kuttanad* and one each from Vechur Kari and Pokkali were included here.

- Carbon recovered from clay fraction is the dominant independent variable that could explain 64.6 per cent variability of organic carbon in these locations
- The water soluble carbon being derived from completely decomposed organic matter is not associated with nitrogen in soils.
- The HWEC being the most labile pool of carbon had significant influence on mineralisation process thereby contributing to total and available nitrogen.
- The permanganate oxidizable carbon being a stabilized pool might not undergo further decomposition to release nitrogen and hence its contribution to available pool is negligible.
- Total hydrolysable nitrogen had significant positive correlation with total carbon (0.527**), organic carbon (0.528**), total nitrogen (0.547**), available nitrogen (0.349*), hot water extractable carbon (0.413**) and amino acid nitrogen (0.360*).
- The direct effect of total hydrolysable nitrogen (THN) on total nitrogen was very high and positive (+0.570) among soils. Total hydrolysable nitrogen had a positive and high direct effect on available nitrogen (+0.378) also indicating its influence on mineralization
- The amino acid nitrogen was significantly and positively correlated with total hydrolysable nitrogen (0.360*) and ammoniacal nitrogen (0.33*) but had shown very little contribution to mineralizable N as indicated by the direct and indirect partial coefficients.
- Ammoniacal nitrogen being a dynamic and time dependent variable though contributing significantly to available N content, its effect on total nitrogen is negligible

- No significant correlations were obtained between nitrate nitrogen content, organic carbon, total nitrogen, available nitrogen and fractions of carbon and nitrogen. This is due its high solubility and losses by leaching.
- The treatments with increased levels of nitrogen based on C:N ratio could produce significant effect on plant height, number of productive tillers, number of grains per panicle, grain yield and straw yield.
- The maximum grain yield of 8.22 Mg ha^{-1} was recorded in the treatment which received the application of nitrogen based on C:N ratio recommendation (wet analysis) (T5) is almost 2 tonnes increase over control
- The organic carbon significantly influenced the total nitrogen and available nitrogen status in the experimental plot. The total nitrogen content both in soil and plant was significantly influenced by higher doses of nitrogen fertilizers prescribed as per C:N ratio (treatments T5-T10).
- Among organic carbon fractions, hot water extractable carbon contributed to the mineralizable pool than water soluble carbon. The water soluble carbon being derived from completely decomposed organic matter is not associated with nitrogen in soils. The HWEC being the most labile pool of carbon had significant influence on mineralisation process thereby contributing to total and available nitrogen.
- Among the organic pools of nitrogen, the total hydrolysable nitrogen contributed significantly to mineralizable N. Among the inorganic fractions of nitrogen, ammoniacal nitrogen is contributing more to the available pool of nitrogen than nitrate nitrogen fraction probably because of its high solubility and losses by leaching. The significant correlation of ammoniacal nitrogen to available nitrogen in soil and plant supports this fact.

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References

References

Andrews, S. S., Karlen, D. L. and Cambardella, C. A. 2004. The soil management assessment framework. Soil Sci. Soc. Am. J. 68:1945-1962.

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

Berger, K. C. and Troug, E. 1939. Boron estimation in soils and plants. Indian Eng. Chem. Anal. Ed. 11:540-542.

Bhindhu, P.S. 2017.Chemistry and transformation of calcium and magnesium in tropical acid soils of Kerala. Ph.D. (Ag) thesis, Kerala Agricultural University, Thrissur,283p.

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

Brar, S. S. and Giddens, J. 1968. Inhibition of nitrification in Bladen grassland soil. Proc. Soil Sci. Soc. Am. 32:821-823.

Bray, R.H. and Kurtz, L.T. 1945. Determining total, organic and available forms of phosphate in soils.Soil Sci. 59: 39-45.

Bremner, J. M. 1967. Nitrogenous compounds. Soil Biochemistry. Marcel Dekkar, Inc., New York. p. 19-66.

Broadbent, F. E. 1968. Nitrogen immobilization in relation to nitrogen containing fractions of soil organic matter. Proc. Symposium on Isotopes and Radiation in Soil Organic Matter studies. I. A. E. A., Vienna. p 131-140.

Bouman B. A. M. and Tuong T. P. 2001. Field water management to save water and increase its productivity in irrigated lowland rice.Agric Water Manag. 49: 11-30.

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.

Cambell, N. E. R. and Lees, H. 1967. The nitrogen cycle. Soil Biochemistry Vol.I. A. D. Mclaren and G. H. Peterson (eds.) Marcel Dekker, Inc., New York. p. 194-215.

Cheng Y. Q, Yang L.Z., Cao, Z. H., Ci E.,and Yin, S. 2009. Chronosequential changes of selectedpedogenic properties in paddy soils as compared with non-paddy soils. Geoderma 151:31-41.

Chesire, M.V. and Mundie, C.M. 1981. The distribution of labelled sugars in soil particle size fractions as a means of distinguishing plant and microbial carbohydrate residues. J. Soil Sc.32:605-618.

Cox, F.R. 1987. Micronutrient soil tests. Correlation and calibration. In: Brown, J.R. (Ed.). *Soil Testing: Sampling, Correlation, Calibration and Interpretations*. SSSA, Madison, pp. 97-117.

Culman, S.W., Snapp, S.S., Freeman, M.A., Schipanski, M.E., Beniston, J. and Lal, R. 2012b. Permanganate oxidizable carbon reflects a processed soil fraction that is sensitive to management. *Soil Sci. Soc. Am. J.* 76:494–504.

Das, D. K. 1996. Introductory Soil Science. Kalyani publishers,Calcutta. 433p.

Fageria, N. K., Santos, A. B., Filho M. P., and Guimarães, C. M. 2008. Iron toxicity in lowland rice. J.Plant Nutri. 31:1676–1697.

Ghani A., Dexter M and Perrott K. W. 2003. Hot-water extractable carbon in soils; a sensitive measurement for determining impacts of fertilisation, grazing and cultivation. *Soil Biol.Biochem*. 35 (9): 1231–1243.

George, A. 2011. Availability indices of boron in major soil groups of Kerala. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, 89p.

GOK [Government of Kerala]. 2017. Economic Review 2017 [on-line]. Available: http://spb.kerala.gov.in/images/pdf/er2017/pdf [20 December 2018].

Gotoh, S., Arargi, S., Koga, H. and Ono, S. 1986. Hydrolyzable organic forms of nitrogen in some rice soil profiles as affected by organic matter application. Soil Sci. Plant Nutr.32(4):535-550.

Gupta, U. C. 1962. The nature and distribution of amino acids in soil organic matter. Proc. Soil Sci. Soc. Am. 26:280-290.

Gupta, U.C. 1972. Effects of boron and limestone on cereal yields and on B and N concentrations of plant tissue.Commun. Soil Sci. Plant Anal. 6: 439-450.

Haider, K., Fredrick, L. R. and Flaig, W. 1965. Reactions between amino acid compounds and phenols during oxidation. Pl. Soil. 22:49-64.

Haque, M. A. and Haque, M. M. 2016. Growth, yield and nitrogen use efficiency of new rice variety under variable nitrogen rates. Am. J. Plant Sci. 7(3):612-622.

Hazra, G. C., Mandal, B. and Mandal, L. N. 1987. Distributions of Zn fractions and their transformations in submerged rice soils.Plant and Soil., 104(2): 175-181.

Isirimah, N. O. and Keeney, D. R. 1973. Nitrogen transformation in aerobic and waterlogged histosols. Soil Sci. 115:123-129.

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

Jagadamma, S. and Lal, R. 2010. Distribution of organic carbon in physical fractions of soils as affected by agricultural management. Biol. Fertil. Soils. 46:543-554.

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 Biol. and Biochem. 8:209-213.

John, I.E. 2014. Wet soil analysis for nutrient prescription in paddy soils. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur,191p.

Jorgenson, F. E. 1967. Fractionation of nitrogen in three forest soils. Proc. Soil Sci. Soc. Am. 31:707-708.

Kamoshita A. 2007. Historical changes in urban rice production systems in Tokyo, 467 Japan. Plant Prod Sci. 10:245-269.

Kelley, K. R. and Stevenson, F. J. 1995. Forms and nature of organic N in soil. Fertil. Res. 42:1-11.

Kelley, K. R. and Stevenson, F. J. 1996.Humic substances in terrestrial ecosystems. Elsiever. 407-427 pp.

Keeney, D. R. and Nelson, D. W. 1982. Nitrogen in organic forms. In. Page, A. L. (eds), Methods of soil analysis, American Society of Agronomy, Madison, pp. 643-698.

Krishnamoorthy, K. K. and Durairaj, R. 1968. Amino-acid distribution pattern in soil. Madras agric. J. 55:134-139.

Malival, G. L. and Khangarot, A. S. 1966. Occurrence of amino acids and reducing sugar in acid hydrolysates of fulvic acid isolated from Rajasthan soils. J. Indian Soc. Soil Sci. 124:334-342.

Manorama Thampatti, K.C. 1997. Morphological, physical and chemical characterization of the soils of North Kuttanad. Ph.D. thesis, Kerala Agricultural University, Vellanikkara, Trichur, 130p.

Massoumi, J. and Cornfileld, A. H. 1963. A rapid method for determinationnof sulphate in water extracts of soils. *Analyst.*88:321-322.

Mini, E. R. 1992. Fractionation of organic and inorganic nitrogen in important soil types of Kerala. M. Sc. Thesis, Kerala Agricultural University, Vellanikkara, Trichur, 78p.

Mishra, S. R., Pattnaik, P., Sethunathan, N. and Adhya, T. 2003. Anion-mediated salinity affecting methane production in a flooded alluvial soil. Geomicrobiology. 20(6):579-586.

Ponnamperuma F. N. 1972. The chemistry of submerged soils. AdvAgron. 24:29-96.

Panse, V.G. and Sukatme, P.V. 1978. *Statistical Methods for Agricultural Workers*. ICAR, New Delhi, 347p.

Patrick, W. H. and Mahapatra, I. C. 1968. Transformation and availability to rice of nitrogen and phosphorus in waterlogged soils. AdvAgron. 20:323–356.

Piper, C.S. 1966. *Soil and Plant Analysis*. Hans publishers, Mumbai, 365p.

Qualls, R. G., Haines, B. L. and Swank, W. T. 1991. Fluxes of dissolved organic nutrients and humic substances in a deciduous forest. Ecol. 72:254-266.

Quinn, M. and Solomon, S. K. 1966. Hydrolysis of soil nitrogen by strong acids. Nature. 211: 664-665.

Ramamoorthy, B. and Velayutham, M. 1976. Nitrogen, phosphorus and potassium in soil chemistry, forms and availability. In: J. S. Kanwar (Ed.) Soil Fertility, Theory and Practice, ICAR, New Delhi. P.156-201.

Russel, E. W. 1966. The role of organic matter in soil productivity. The use of isotopes and soil organic matter studies. FAO/IAEA Report, Vienna. p. 3-19.

Santhosh, C. 2013. Chemistry and transformation of boron in soils of Kerala. Ph.D. thesis, Kerala Agricultural University, 256p.

Schulz, E. 1990. Die heißwasserextrahierbare C-Fraktion als Kenngröße zur Einschätzung des Versorgungszustandes der Böden mit organischer Substanz (OS) (The hot water extractable Cfraction as indicator for the status of soil organic matter). Tag Ber Akad Landwirtsch Wiss Berlin 295: 269-275.

Sims, J.R. and Johnson, G.V. 1991. Micronutrient soil tests. In: Mortvedt, J.J., Cox, F.R.human, L.M. and Welch, R.M. Micronutrient in Agriculture (2nd ed.), SSSA, Madison, USA, pp 427-476.

Singh, S. and Bhandari, G. S. 1963. A study on the amino compounds in acid hydrolysates and aqueous leachates of some soils of Rajasthan. J. Indian Soc. Soil Sc. 11:1-7.

Singh, O. P. and Datta, B. 1988. Organic carbon and nitrogen status of some soils of Mizoram occurring at different altitudes. J. Indian Soc. Soil Sci. 36:125-132.

Sowden, F. J., Chen, Y. and Schnitzer, M. 1977. The nitrogen distribution in soils formed under widely differing climatic conditions. Geochimica et Cosmochimica Acta. 41:1524-1526.

Stevenson, F.J. 1957. Distribution of forms of nitrogen in some soil profiles. Proc. Soil Sci. Soc. Am. 21:283-287.

Subbiah, B. V. and Asija, G. L. A. 1956. A rapid procedure for the estimation of available nitrogen in soils. Curr. Sci. 25: 259-260.

Tabatabai, M. A. 1982. Sulfur. In:Page, A. L., Miller, R. H., and Keeney, D. R. (eds.). *Methods of soil analysis. Part 2- Chemical and microbiological properties. (2nd Ed.).* American Society of Agronomy, Madison, Wisconsin, USA, pp. 501-538.

Tao, S. and Lin, B. 2000. Water soluble organic carbon and its measurement in soil and sediment. Water Res. 34(5): 1751-1755.

Tiessen, H and Stewart, J. W. B.1983. Particle size fractions and their use in studies of soil organic matter:II. Cultivation effects on organic matter composition in size fractions. Soil Sci. Soc. Am. J. 47:509-514.

Tisdall, J.M. and Oades, J.M. 1982. Organic matter and water stable aggregates in soils. J. Soil Sci.33:141-163.

Usha, P. B. and Jose, A. I. 1983. Carbon-nitrogen relationship in laterite soils of Kerala. Agric. Res. J. Kerala. 21: 15-22.

Walkley, A.J. and Black, I.A. 1934. Estimation of soil organic carbon by chromic acid Titration method. Soil Sci. 31: 29-38.

Watanabe, F.S. and Olsen, S.R. 1965. Test of an ascorbic acid method for determining Phosphorus in water and sodium bicarbonate extracts from soil. Soil Sci. Soc. Am. Proc. 29:39-45.

Weigel A1, Eustice T1, Van Antwerpen R1, Naidoo G1 and Schulz E2.2011. Soil organic carbon (SOC) changes indicated by hot water extractable carbon (HWEC). *Proc. S. Afr. Sug. Technol. Assess.* 84: 210 – 222.

Weil, R. R.., Islam, K.R., Stine, M.A., Gruver, J.B. and Samson-Liebig S. E.2003. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. Am. J. Alternative Agric. 18:3–17.

Witt C, Cassman K. G., Olk, D. C., Biker, U., Liboon, S. P., Samson, M. I., and Ottow, J. C. G. 2000. Crop rotation and residue management effects on carbon sequestration, nitrogen cycling and productivity of irrigated rice systems. Plant Soil. 225: 263-278.

Zacharias, M. 1989. Assessment of nitrification rate of Kerala soils and economic factors influencing it. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 110p.

Zhao, A., Zhang, M., He, Z., Zhang, H., Endale, D. M. and Schomberg, H. H. 2012. Water-extractable soil organic carbon and nitrogen affected by tillage and manure application. *Soil Sci.* 176:307-312.

CARBON: NITROGEN DYNAMICS IN ACID SULPHATE AND ACID SALINE RICE SOILS OF KERALA

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ABSTRACT OF THE THESIS

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Abstract

The present study was undertaken to unravel the chemistry of Carbon: Nitrogen dynamics in submerged acid sulphate and acid saline soils, to identify the labile fractions of these elements contributing to soil fertility and to modify the organic carbon based fertility ratings for nitrogen recommendation in *Kole* lands.

Forty-five representative soil samples from 4 different rice growing acid saline and acid sulphate soils of Kerala were collected and characterized for pH, EC, OC, total carbon, total nitrogen, available nutrients (N, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn and B) and microbial biomass carbon. The soil samples were analysed as such after sampling on wet basis and the results were expressed on moisture free basis to have uniformity.

The organic carbon status of the soils varied from 0.81 to 7.58 per cent. Soils from *Kaipad* recorded the lowest and soils from Vechoor *Kari* of *Kuttanad* recorded the highest value of organic carbon. The total nitrogen ranged from 0.05 per cent in upper *Kuttanad* to 0.42 per cent in Vechur *Kari*. The highest available nitrogen content of 281.38 kg ha^{-1} was recorded in sample from Vechoor *Kari* and the lowest of 19.84 kg ha^{-1} in Purakkad *Kari*. The C:N ratio varied from 13:1 to 24:1. Widest C:N ratio was recorded in soils of Upper *Kuttanad* and the lowest in soils from Thrissur *Kole*. The organic carbon was significantly and positively correlated with total nitrogen and available nitrogen status. Total nitrogen was the single most independent factor explaining 94 per cent variability of organic carbon.

Soil samples were subjected to fractionation studies (both physical and chemical) to quantify the carbon and nitrogen that is associated with different inorganic and organic constituents in soil. In physical fractionation, soil carbon and nitrogen preferentially recovered from the sand, silt and clay size fractions were estimated. Of this, carbon recovered from clay size fraction was the dominant independent variable that explained 64.6 per cent variability of organic carbon.

The different chemical carbon fractions studied were water soluble carbon (WSC), hot water extractable carbon (HWEC) and permanganate oxidizable carbon

(POC). The water soluble carbon being derived from completely decomposed organic matter was not associated with nitrogen in soils. The HWEC being the most labile pool of carbon had significant influence on mineralisation process thereby contributing to total and available nitrogen content. The permanganate oxidizable carbon being a stabilized pool might not undergo further decomposition to release nitrogen and hence, its contribution to available pool was negligible.

Among the organic pools of nitrogen, the total hydrolysable nitrogen contributed significantly to mineralizable N. Among the inorganic fractions of nitrogen, ammoniacal nitrogen was contributing more to the available pool of nitrogen than nitrate nitrogen fraction probably because of high solubility and losses of latter by leaching.

A field experiment was conducted to investigate the response of rice to different levels of nitrogen in Adattu *Kole* with an initial C:N ratio of 20:1. The treatments with increased levels of nitrogen based on C:N ratio (treatments T_5-T_{10}) produced significant effect on plant height, number of productive tillers, number of grains per panicle, straw yield and grain yield. The total nitrogen content both in soil and plant were significantly influenced by higher doses of nitrogen fertilizers prescribed as per the C:N ratio.

Among the carbon fractions, hot water extractable carbon contributed more to the mineralizable pool than water soluble carbon. The direct effect of total hydrolysable nitrogen on total and available nitrogen was very high. Ammoniacal nitrogen being a dynamic and time dependent variable, though contributing significantly to available N content, its effect on total nitrogen was negligible. This was in conformity with the results of experiment in characterization of soil samples collected from 45 locations.

The maximum grain yield of 8.22 Mg ha^{-1} was recorded in the treatment where nitrogen was applied based on C:N ratio (wet analysis). An increase of 1.15 Mg ha^{-1} of grain yield was recorded over the treatment where soil test based fertilizer recommendation was applied. The highest straw yield of 17.47 Mg ha^{-1}

was recorded in treatment where nitrogen applied was double that of C:N ratio based recommendation. The highest net return was obtained in treatment where nitrogen was applied as per the C:N ratio in soil.