EFFECT OF CONTINUOUS APPLICATION OF RICE HUSK ASH (RHA) ON INCEPTISOLS OF PALAKKAD EASTERN PLAINS

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled "**Effect of continuous application of rice husk ash (RHA) on Inceptisols of Palakkad Eastern plains**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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Certified that the thesis entitled **"Effect of continuous application of rice husk ash (RHA) on Inceptisols of Palakkad Eastern plains"** is a record of research work done independently by **Ms. Rincy Rose T. John** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the advisory committee of **Ms. Rincy Rose T. John (2014-11-146)**, a candidate for the degree of **Master of Science in Agriculture**, with major field in **Soil Science and Agricultural Chemistry**, agree that the thesis entitled **"Effect of continuous application of rice husk ash (RHA) on Inceptisols of Palakkad Eastern plains"** may be submitted by **Ms. Rincy Rose T. John**, in partial fulfillment of the requirement for the degree.

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"Commit your works to the LORD

And your plans will be established"

(Proverbs 16:3)

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Rincy Rose T. John

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ABBREVIATIONS

ANSA	1-amino, 2- naphthol, 4- sulfonic acid
Avail.	Available
C/N	Carbon- Nitrogen ratio
DTPA	Diethylene triamine penta acetic acid
EC	Electrical conductivity
ECEC	Effective cation exchange capacity
EM	Effective microorganism solution
Exch.	Exchangeable
MWD	Mean weight diameter
NA and A	Non- amended area/ palm and Amended area / palm
OM	Organic matter
PAS	Percentage aggregate stability
POC	Particulate organic carbon
POC_M	Particulate organic carbon associated with macro-aggregates
POC_m	Particulate organic carbon associated with micro-aggregates
POM	Particulate organic matter
RH	Rice husk
RHA	Rice husk ash
TC	Total carbon
WHC	Water holding capacity

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Introduction

1 INTRODUCTION

The global production of rice approximately amounts to six hundred million tons, annually. Reddy and Alvarez (2006) described India and China as contributing 123 and 177 million tons annually to the rice production of the world as major rice producing countries.

Rice husk ash (RHA) is a form of charcoal obtained from the controlled combustion of rice husk. A huge amount of rice husk is thus generated every year in all the rice growing countries. In South India, on an average 50 percent of the rice husk obtained is being used as a source of fuel in rice mills, hotels and brick making industries. The major junk is often dumped as waste in open field or burnt off.

Vadavannur region under Inceptisol soil order of Palakkad eastern plains stands out as a location which is under RHA application continuously for the past 30 to 35 years. Large amount of RHA accumulates every year as a by-product of *Gayathri* and *Vasantha* rice mills, founded way back in 1973-1974, is collected and utilized as an amendment by the farmers and have good opinion about crop performance consequent to its application. The palms grown in amended location are free of any pest and diseases.

The coconut palm (*Cocos nucifera* L), 'tree of heaven', and is a versatile plant and one of the most important palm to the small farmers in Kerala. It can be described as '*Kalpataru*' because almost every part of this palm is used for daily needs of the people (Mandal, 2010). It can be grown on most of the soil types of tropical condition. Nowadays the area under coconut and its productivity is showing a declining trend because of so many reasons like nutritional imbalance, non stability of market price, spread of disease and pests, non-attainment of full bearing potential of palms, vagaries of monsoon, prolonged dry spells, non- adoption of package of practices and planting in unsuitable areas.

Healthy soil decides to a great extent the crop performance besides timely management practices and plant protection measures. Soil health is an integration of physical, chemical and biological properties, of which very little information is available on the improvement in physical properties through amendments like rice husk ash.

With this background the present investigation titled 'Effect of continuous application of rice husk ash on Palakkad Eastern plains' was undertaken with the following objectives

- to study the effect of continuous application of RHA on physico - chemical properties of Inceptisols of Vadavannur area
- to examine performance of coconut palms in the RHA amended fields

The realization of objectives would unravel the possibility of explaining the scientific background to RHA application to the agricultural fields with an eco-friendly and effective approach for crop waste management and promote availability based utilization of rice husk ash in the field.

Review of Literature

2. REVIEW OF LITERATURE

The literature pertaining to the present investigation on the "Effect of continuous application of rice husk ash (RHA) on Inceptisols of Palakkad Eastern plains" is reviewed below under different headings.

2.1 Production of rice and rice husk

Approximately six hundred million tons of rice is produced globally in a year. China and India are the major rice producing countries with an annual production of 177 and 123 million tons, respectively (Reddy and Alvarez, 2006).

The rice grain or paddy consists of husk and brown rice. On an average paddy contains 72 per cent of rice, 5-8 per cent of bran and 20 - 22 per cent of husk (Yadav and Singh, 2011). Rice milling is the process of separation of husk and bran to get brown rice which generates the rice husk as a by- product of rice industry. China and India produce about 39 and 25 million tons of rice husk annually. Rice husk is the most unutilized agricultural wastes in many rice producing countries which has been quantified to nearly 120 million tons (Kumar *et al.*, 2013). It was estimated that 0.20 t of husk is produced from about one tone of paddy and from every tone of husk generates approximately about 0.18 t to 0.20 t of ash after burning, depending on the variety, climatic conditions, and geographical location (Ampadu *et al.*, 2010). The production of rice paddy, rice husk and rice husk ash in major rice producing countries are given in Table 1.

From the proportion of rice husk to paddy to the extent of 20 per cent and ash to husk to the extent of 18 per cent respectively, the total global ash production was presumed as high as 21.6 million tons per year (Oleh, 2006). The chemical composition of rice husk resembles many common organic fibers as it contains 40-50 per cent cellulose, 25 - 30 per cent lignin, 15-20 per cent ash and 8-15 per cent moisture (Hwang and Chandra, 1997).

Table 1. Production of rice paddy, rice husk and rice husk ash in major rice producing countries

Country	**Rice /paddy production (Mt)**	**Husk production (Mt)**	**Potential RHA production (18 per cent of husk) (Mt)**
China	177.59	35.52	6.39
India	123.0	24.6	4.43
Indonesia	48.65	9.73	1.75
Bangladesh	39.00	7.80	1.40
Vietnam	31.32	6.26	1.13

(Sources: Oleh, 2006)

Rice husk is rich in nutrients, like silicon, potassium apart from 70 per cent each of cellulose and lignin. The high content of cellulose and lignin poses resistance to decomposition by natural microbes, which in turn makes it unsuitable for soil application. Generally, major portion of the husk is either dumped as waste or burnt in open air which causes air pollution and health problems. While it's burning most evaporable components are slowly lost leaving silicates. Only paddy husk is reported to retain such a huge proportion of silica in it. A small amount of rice husk is also used as fuel for boilers, generation of electricity and as bulking agent in composting animal manure (Bronzeoak, 2003 and Asavapisit and Ruengrit, 2005).

2.2 Rice husk ash

Rice husk ash is a general term used for all types of ash produced from burning rice husk, an agricultural byproduct at a temperature less than 1000 °C (Kumar *et al.*, 2013 and Jili *et al.*, 2014). The rice husk is used as an energy source for biomass power plants and in rice mills. After burning, rice husk ash with approximately one-fifth (20-25%) of the original weight is obtained as a by-product. The RHA produced by cyclonic furnace in rice mills appears black or grey in colour depending on the ash content and often retains its husk shape.

According to the norms of ABNT (ABNT-NBR 10004, 2004), RHA is classified as a non-hazardous and non-inert residue (class II).

2.3 Uses of rice husk and rice husk ash

Rice husk can be used for production of ethanol, acetic acid, furfural, xylitol *etc* and in manufacturing of partition boards. It was also used as cleaning and polishing agent in metal and machine industries, as building material and as industrial raw material also used for land filling (Yadav and Singh, 2011).

However its use in agriculture in the raw form is very much limited for the reasons already stated, but after making into ash or composting with suitable additives like effective microorganism (EM) solution and molasses and it can be transformed into quality material suited for agricultural purpose, much similar to any other organic amendment (Aryalekshmi, 2016).

The potential of RHA is immense *viz*; in manufacturing of commercial products such as silica gels, silicon chip, synthesis of activated carbon, zeolites, ingredients for lithium ion batteries and energy storage/capacitor. It is also used in steel and cement industries (Kumar *et al.*, 2013). It has an important role in soil stabilization to meet the specified engineering requirements such as optimum moisture content and maximum dry density (Singh and Mittal, 2014).

2.4 Composition of rice husk ash

The composition of RHA has been researched upon by many scientists. Rice husk ash is a very light material with a micro-porous structure and has a bulk density of about 0.15 g cm^{-3} (Haefele *et al.*, 2009). Bhadoria *et al.* (2007) found that the pH of RHA was about 7.57 in 1: 5 RHA water suspensions and that bulk density ranged from 0.3 - 0.43 Mg m^{-3}. Nnabude and Mbagwu (2001) reported the composition of RHA as organic carbon (18.50 %), total N (0.77 %), available P (26.0 mg kg^{-1}), K (0.66 cmol (+) kg^{-1}), Ca (0.32

cmol (+) kg^{-1}), Mg (1.06 cmol (+) kg^{-1}) and Na (0.20 cmol (+) kg^{-1}). They also observed that the material possessed a C/N ratio of 21:1.

Utami *et al.* (2012) determined the chemical composition of RHA in their work on increasing P-availability and P-uptake using sugarcane filter cake and rice husk ash to improve Chinese cabbage (*Brassica* sp) growth in Andisol of East Java, reported that organic C (1.56 g100 g^{-1}), total P (0.56 g 100 g^{-1}), total N (0.42 g 100 g^{-1}), C/P ratio 2.78, C/N ratio 3.71, Ca (1.25 cmol (+) kg^{-1}), Mg (1.98 cmol (+) kg^{-1}), K (0.34 cmol (+) kg^{-1}) and Na (0.36 cmol (+) kg^{-1}).

According to Nottidge *et al.* (2009), the content of N, P, K, Ca, Mg and organic carbon was 2.10, 12.50, 9.00, 64.00, 12.20 and 1.23 g kg^{-1} respectively and the pH of RHA was obtained as 10.86.

According to Oleh (2006), RHA contained 5.91 per cent of carbon and was black in colour. It acted as a pozzolana (material with a high silica content of above 85 per cent) and can be used to make special concrete mixes.

Ampadu *et al.* (2010) from their investigation on use of rice husk ash-calcined clay blend as a pozzollana reported a low bulk density of RHA. However a high percentage of silica (80 %) and relatively small amounts of K_2O, Na_2O and Fe_2O_3 were obtained.

2.5 Effect of rice husk ash on soil properties

The soil amendments differ in their origin, composition, application rate and mode of action like improvements in soil structure, aeration and drainage, increasing water holding capacity, reducing soil compaction, tillage and hard pan condition, better workability range, encouraging root development and increasing yield.

As a soil amendment, use of RHA is limited in agricultural field, even though; they have the capacity to improve the soil physico-chemical properties. The RHA does not only supply nutrients but also act as a soil conditioner that can retain nutrients thus reducing the leaching loss of nutrients (Mariati, 2014).

2.5.1 Physical properties

According to Mbagwu (1989), organic waste amendment reduced soil bulk density, increased soil total porosity, which controls the water movement and gas exchange in soil. This situation also favoured the soil micro-organisms by providing the required water and oxygen.

Williams *et al.* (1972) reported that RHA application significantly reduced the bulk density of soil in their work on burning v/s incorporation of rice crop residues.

Bulk density of soils of greenhouse was reduced with application of rice husk compost (RHC). The values of field capacity (FC), permanent wilting point (PWP) and available water capacity (AWC) increased with the application of RHC when compared with control from a study on effects of rice husk compost application on soil quality parameters in greenhouse conditions by Demir and Gulser (2015).

The conversion of rice husk into RHA at high temperature or the carbonization process improved the water holding capacity of the resultant material (Oshio *et al.*, 1981 and Oguike *et al.*, 2006). The water holding capacity of rice husk showed an improvement from 251 to 353 per cent (Milla *et al.*, 2013). Similar results on the soil physical properties like bulk density and total porosity was also reported by Nnabude and Mbagwu (2001) from their work on physico-chemical properties and productivity of a Nigerian Typic - Haplustult amended with fresh and burnt rice-mill wastes.

2.5.1.1. Effect on aggregate stability of soil

Aggregate stability is an important property of soil quality. The size distribution of aggregates in soil determines root penetration, organic matter stabilization, susceptibility to compaction, soil erodibility, *etc* (De Gryze *et al.*, 2006). Mean weight diameter (MWD) is one of the important indices of soil aggregation. Stability index, structural coefficient and per cent aggregate stability are also used for expressing soil aggregation. Per cent aggregate stability is obtained by multiplying structural coefficient with 100 (Ushakumary, 1983).

The stability and formation of soil aggregates is dependent on the amount and types of clays and the quantity of organic matter. The improvement in soil structure due to addition of various types of organic material in the soil has been extensively studied (Griffiths and Jones, 1965; Monnier, 1965 and Tabatabai and Hanway, 1968). Malik *et al.* (1965) stressed the effect of organic matter towards improving the stability of soil aggregates.

Acton *et al.* (1963) and Mehta *et al.* (1960) reported that the polysaccharides (a component of organic matter) correlated positively with aggregate stability of soil. The high C/N ratio of the amendments and the slow rate of decomposition contributed to their lasting effects on aggregate stability. In general, organic waste had a prominent effect on inducing soil aggregation especially the stability of water stable micro- aggregates (Dettman and Emerson (1959) and Glauser *et al.* (1988)).

Jili *et al.* (2014) found that the addition of RHA in soil increased the formation of micro- aggregates which indicated the ability of RHA to increase soil aggregation. Aggregate stability enhanced the water movement in soil, root penetration, seedling emergence and water holding capacity and reduced the runoff and erosion.

According to Lu *et al.* (2014), rice husk biochar increased the macro-aggregates (diameter > 0.25 mm) and reduced the micro- aggregates (diameter < 0.25 mm). They reported that the rice husk biochar amended soils had higher MWD, water holding capacity, porosity and higher available water content whereas the tensile strength and coefficient of linear extensibility (COLE) had reduced due to its application as compared to control in clayey soil. They concluded that it could act as a glue between macro and micro aggregates.

2.5.1.2. Effect on infiltration rate

Infiltration is the process of entry of water due to sorption that happens in the soil air interface followed by vertical flow of water through soil profile. It is expressed as infiltration rate and helps in assessment of textural and structural conditions of soil surface, the ability of subsurface layers for transmitting the water and also for deciding the supply rate of irrigation water (ISSS, 2012). According to Bouwer (1986), the rating for infiltration in a soil is presented in Table 2.

Table 2. Rating chart of infiltration in soil

Infiltration rate (cm h^{-1})	Rating
> 254	Very rapid
127-254	Rapid
63-127	Moderately rapid
20- 63	Moderate
5-20	Moderately slow
1-5	Slow
< 1	Very slow

(Bouwer, 1986)

Lugo-Lopez (1952) reported that infiltration rates of various soils of Puerto-Rico could be improved by incorporating organic matter into the soil. Wood and Blackburn (1981) observed that aggregate stability had the greatest influence on infiltration rate, which in turn was closely related to organic matter content. Fahad *et al.*, (1982) reported low infiltration rate due to micro-porosity and reduced aggregate stability.

It was reported that significant differences in infiltration rates among RHA-mixed, RHA- mulched and the control in loamy sand soils. They concluded that RHA – mixing method was beneficial for loamy sands to increase infiltration rate (Essien and Saadou, 2012).

2.5.1.3. Effect on consistency of soil

Consistency is a term used to indicate the degree of firmness of cohesive soils. Atterberg developed a method to describe the consistency of fine-grained soils with varying moisture contents, known as Atterberg limits. Soil behaves more like a solid at very low moisture content. When the moisture content is very high, the soil and water may flow like a liquid. The liquid limit (LL) is defined as the moisture content, in percentage, at which the soil changes from a liquid to a plastic state. Plastic limit (PL) is the water content, in per cent, of a soil at the boundary between the plastic and semi-solid states. Plasticity index (PI) is the range of water content over which a soil behaves plastically. Numerically, it is the difference between the liquid limit and the plastic limit. The PI is used for expressing the consistency of soil (Pal, 2013).

According to Burmister (1949), plasticity index is classified in a qualitative manner, which is furnished in Table 3.

Table 3. Classification of plasticity index

Plasticity index	**Description**
0	Non plastic
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	High plasticity
> 40	Very high plasticity

(Burmister, 1949)

Smith *et al.* (1985) and Hemmat *et al.* (2010) reported the increase in PL and LL values due to increase in soil specific surface area and activity of soil. Plasticity index of a soil increased proportionately with increasing clay fraction. Okafor and Okonkwo (2009) reported that plasticity index decreased from 17.07 to 10.02 per cent when the application rate of RHA increased from zero to 12.5 per cent. This was due to the replacement of the finer soil particles by the RHA which resulted in a reduction of the clay content and plasticity index. They also found that the addition of RHA increased the volume stability of the soil. Among the treatments, application of RHA at the rate of 10 per cent was observed to be the optimum level for the lateritic soil.

Jili *et al.* (2014) from their studies on effects of rice husk ash on soil consistency and compactibility found out that the application of RHA increased the optimum water content (OWC), plastic limit (PL) and liquid limit (LL) values of soil. They also reported that RHA application increased the soils' resistance to mechanical forces.

An increase in plasticity and liquid limits and decrease in plasticity index was obtained in clayey soils amended with rice husk biochar, by Lu *et al.* (2014) from a study conducted in typical Vertisols of Northern China.

Compaction is one of the important physical characters of soil which can be used to express the mechanical strength of soil. Increased external pressure by different practices in soil increases the compaction due to increase in the density with applied stress. The moisture content and the extent of compaction affect the workability of soil. Addition of RHA into the soil not only imparted the physical filling effect but also improved the workability range thus reduced the compactability of loamy soils (Jili *et al.*, 2014).

The workability range was particularly related to moisture content at the plastic limit of soil (Godwin and Spoor, 1977). It was estimated that the optimum water content for tillage was in the range of 0.7- 0.9 PL on the four different Swedish soils studied by Keller *et al.* (2007).

2.5.1.4. Effect on particulate organic carbon in soil

Soil organic matter is one of the important indicators of soil health. It can regulate the water holding capacity and structural stability by affecting quantity of macro - aggregates and micro - aggregates. Particulate Organic Matter (POM) is considered as the partially decomposed soil organic matter with less than 2 mm and greater than 0.053 mm in size (Cambardella and Elliott, 1992); it is more sensitive to management practices compared to total soil organic matter. Particulate organic carbon (POC) is an effective measure of active soil organic matter, provides the information about the mineralization and dynamics of N and other microbiological processes in the soil. POC is mainly associated with macro - aggregates and micro – aggregates and the range of macro - aggregates and micro - aggregates in soil has been reported to be between 0.50 to 0.25 and

0.25 to 0.053 mm, respectively (Ontl *et al.*, 2015). Fortuna *et al.* (2003) found that addition of compost increased the POC contents in the soil.

Aggregate formation within the micro-pores stabilized the organic matter and protected the POM from rapid microbial decomposition which enhanced the mean residence time (MRT) of POM than unprotected inter- aggregate organic matter (Golchin *et al.*, 1994 and Puget *et al.*, 2000).

2.5.2 Effect on chemical properties

Several studies revealed that the incorporation of rice husk ash could significantly improve soil properties by increasing soil pH, enhancing organic carbon, increasing available nutrients and removing heavy metals from the system, ultimately increasing crop yields (Williams *et al.,* 1972).

Rice husk ash acted as an amendment for acidic soil. It was found that the RHA reacts much faster (with a reactivity of about 300 %) than conventional limestone, with a low effective calcium carbonate equivalent (around 3 %) and it was due to its possession of reasonable quantities of the basic cations like Ca, Mg, K, Na, and other essential elements including P and very little N (Paul *et al.*, 2005 and Islabao *et al.*, 2014).

Chien *et al.* (2011) reported the capacity of RHA to reduce the acidity and to improve the soil nutrient status when used as mixtures which was attributed to the high specific surface area of the RHA.

Abrishamkesh *et al.* (2015) revealed that rice husk biochar application resulted in increased soil organic carbon, cation exchange capacity and available potassium. A study conducted by Masulili *et al.* (2010) pointed out that RHA had high CEC, which resulted in higher CEC of soil.

An investigation was conducted by Paul *et al.* (2005) to determine the effects of rice husk ash (RHA) and phosphorus (P) on soil pH, cation exchange capacity, base saturation, growth and yield of okra (*Abelmoschus esculentus* L). Increase in exchangeable magnesium (Mg), potassium (K) and effective cation exchange capacity (ECEC) were observed in the soil due to RHA application leading to fertility improvement of the acid sands. They also found that RHA had no effect on P sufficient soils. The study also showed that the optimum level of RHA plus 50 kg urea ha^{-1} could sustain rapid growth and better yield of okra even faster than NPK, because RHA contained almost all other essential plant nutrients.

Many researchers have reported that silicates highly influence the P chemistry in soils as they compete with phosphate ions for sorption sites (Obihara and Russell, 1972; Alvarez *et al.*, 1980 and Shariatmadari and Mermut, 1999).

Utami *et al.* (2012) studied the effects of RHA on P availability, P uptake and plant growth (*Brassica* sp). They observed that the RHA was effective in reducing P retention, increasing P availability and its uptake. The RHA application significantly decreased P adsorption and increased the P desorption in rice and wheat systems compared with control in an alkaline soils of Punjab (Gupta *et al.*, 2014).

Anda *et al.* (2008) from an investigation on the application of the rice husk compost in an Oxisol could get significant increase in soil pH, Ca, Mg (K, sodium (Na), silicon (Si) in soil. Similar results were also reported by Chien *et al.* (2011) from their works on application of rice husk charcoal on remediation of acid soil.

Rice husk compost application improved soil quality and tomato yield in greenhouse. The soil properties like organic matter, available P, exchangeable Mg and K were increased where as Ca got decreased (Demir and Gulser, 2015).

Badar and Qureshi (2014) studied the effect of composted rice husk on growth and biochemical parameters of sunflower plants. They concluded that composted rice husk improved the soil fertility which enhanced the total carbohydrate and protein content in sunflower plants.

2.5.2.1 Effect on silicon nutrition

Silicon is a beneficial element for plants especially rice, a typical silicon-accumulator. Amorphous silica is the only form of silicon in plants (Ding *et al.*, 2008) which will precipitate in the epidermal tissues of plant cells in the form of silica gel, known as phytoliths. Accumulation of silicon helps the optimal growth, imparts resistance to pest and disease and sustains production of rice. Application of the plant residues to the rice field will help to replenish the silicon in the soil because rice stem and leaf contained 5-6 per cent silicon and 10 per cent of it was contained in rice husk (Elawad *et al.,* 1982). But the release of silicon from rice husk happened only on composting or ashing.

Silicon played an important role in hull formation in rice and enhanced the rice grain quality (Savant *et al.*, 1997). Singh *et al.* (2006) found that 180 kg silicon per hectare increased nitrogen and phosphorus content in rice grain and straw which resulted in increased dry matter production and yield. The silicon absorption capacity may vary with plant species. Sugarcane could absorb 300-700 kg of silicon per hectare, rice 150-300 kg of silicon per hectare whereas wheat plant absorbed silicon from the soil to an extent of 50-150 kg of per hectare (Bazilevich, 1993).

Rice husk ash mainly consists of amorphous silica (80%-85%). The silica in the ash undergoes structural transformations during the combustion and it was dependent upon the combustion time, temperature and turbulence during combustion (Gidde and Jivani, 2007). Rice hull ash and rice straw can be used as a source of silicon to increase the crop yield (Kalra *et al.*, 2003) and biological ability of plants to withstand adverse environmental conditions.

The deficiency of silicon in reducing biological ability of plants to withstand adverse environmental conditions has also been reported by Rafi *et al.* (1997).

The effectiveness of RHA and RH in removing heavy metals like cadmium from the soil systems has been recorded by Mahvi *et al.* (2005) from their work on application of rice husk and its ash in cadmium removal from aqueous solution.

2.6 Effect of rice husk ash on crop production

2.6.1 Field crops

Several studies have helped to conclude the effectiveness of RHA application in enhancing the nutrient status of soil which in turn improved the soil fertility and crop production. Sitio *et al.* (2007) reported an improvement in rice growth and yield in the peat soil of Sumatra supplied with RHA and EM 4. Ebaid and El-Refaee (2007) reported a significant increase in root depth, shoot length, plant height and crop growth rate of paddy at harvest stage following the application of RHA at different rates starting from 0 to 9.6 t ha^{-1} from their works on utilization of rice husk as an organic fertilizer to improve productivity and water use efficiency in rice fields. Rice husk ash also helped to increase water use efficiency from 0.56 to 0.88 kg m^{-3}.

According to Masulili *et al.* (2010) and Thind *et al.* (2012), application of RHA could positively increase the plant height, number of tillers and dry biomass. The improvement of soil properties with organic soil amendments like rice husk ash, rice husk biochar, rice husk and rice straw application resulted in an improvement of rice growth and yield (Karmakar *et al.*, 2009).

The Si content of the soil samples increased with the increase in the dose of silica produced from micronized rice husk ash, resulting in an increase in grain yield of rice (Magale *et al.*, 2011).

From an investigation on utilization of rice husk charcoal as soil amendment for improving acidic soil fertility and productivity, Mariati (2014) reported that the highest maize yield was associated with application of rice husk charcoal at the rate of 6-9 tha^{-1}.

Njoku *et al.* (2015) studied the effect of rice husk dust on soil chemical properties and maize grain yield in Abakaliki, South Eastern Nigeria. Soil pH, organic carbon, total N, C/N ratio, available P and maize grain yield increased due to the application of rice husk dust. They could also recommend the use of rice husk dust as soil amendment to increase soil productivity as well as to sustain crop yield.

2.6.2. Horticultural crops

Inden and Torres (2004) reported that the increase in yield and total soluble solids content in tomato (*Lycopersicon esculentum*) were observed when perlites plus carbonized rice hull (PCRH) was used as growth substrate.

An investigation on response of groundnut grown on acidic Ultisol of Nigeria to rice-husk ash applied at 0, 1, 2, 3 and 4 t ha^{-1} showed significant increase in soil P, K and Ca status with growth and kernel yield of the crop when RHA was used at the rate of 3 tha^{-1} (Nottidge *et al.*, 2009).

Priyadharshini and Seran (2009) conducted a study on paddy husk ash as a source of potassium for growth and yield of cowpea (*Vigna unguiculata* L.) and concluded that application of paddy husk ash as a source of potassium at the rate of 4.5 t ha^{-1} were favorable for yield advancements in cowpea in sandy soils.

Dhatt and Kaler (2009) observed that the combination of cow dung, press mud and rice husk charcoal (1:1:1(v/v)) gave best performance among 17 nursery growing media tried for the cauliflower growth and growth parameters under shade net conditions.

Utami *et al.* (2012) reported that RHA application could improve the growth of Chinese cabbage (*Brassica* Sp) in Andisol of East Java.

A study on RHA application in lettuce and cabbage conducted by Carter *et al.* (2013) showed an increase in final biomass, root biomass, plant height and number of leaves in all the cropping cycles as compared to control.

While evaluating the changes in properties of composting rice husk and their effects on soil and cocoa growth by Anda *et al* (2008), an increase in plant growth up to 37 per cent due to rice husk compost application was reported. Milla *et al.* (2013) opined that the application of rice husk biochar increased biomass production of water spinach in a field experiment.

Growing medium consisting of peat and rice hull in the ratio 70: 30 yielded higher shoot and dry weight of *Pinus halepensis* with respect to control (Marianthi, 2006).

2.7 Coconut

Literature on the effect of soil physical properties getting improved with RHA application is meagre in Kerala conditions. However an earnest attempt has been made to compile the available literature on this line. Since, the present investigation is undertaken to evaluate the impact of RHA on soil physical properties where the coconut palms were subjected to RHA application for nearly three decades.

Coconut (*Cocos nucifera* L), belonging to the family Arecaceae, is a perennial palm with an economic life span of 60-70 years. It is one of the important plantation cum oil crops grown in Kerala. Kerala and Tamil Nadu are the top coconut producing states in India. Homestead farms along with coconut palms are peculiar characteristic of farming in Kerala. From time immemorial, it is the farmers practice to apply organic manures and ash to coconut palms. Thampan (1972) indicated that any organic manure that could supply the required amount of nutrients to the palm, which is equal to inorganic fertilizer, is beneficial for bearing palms.

A study on Integrated Nutrient Management (INM) in East coast tall coconut conducted by Mohandas (2012) could help in concluding that 50 per cent N substitution can be achieved through organic manure (composted coir pith), which resulted in annual increase in nut yield. An investigation of coconut husk ash as a fertilizer for coconut palms on peat soils showed that the coconut husk ash can provide a substantial proportion of K fertilizer and also improve the nut production (Bonneau *et al.*, 2010).

Integrated nutrient management practice involving application of organic manures along with recommended dose of inorganic fertilizers was considered as the best practice for crop improvement and maintaining soil productivity in coconut plantations (Kamalakshi Amma *et al.* (2001) and Jnanadevan (2015)).

2.7.1 Relation between soil nutrients and nutrients in coconut leaves

The relation between soil nutrients and nutrients in leaf of coconut has been extensively studied by different researchers. The coconut palm is a good consumer of nutrients, particularly K, Cl, and N for its growth and productivity.

Studies showed that the palms responded well to the N content in soil. Wahid *et al.* (1974) got significant and positive correlation between soil and plant K in coconut. Sodium showed a negative correlation in concentration but it was not significant. Phosphorous uptake of palm was very less compared to K and N.

Jack (1965) reported that soil K decreased from the surface to the sub soil in the high yielding areas of coconut and soil K showed a positive correlation with plant K.

2.7.2 Relation between leaf nutrients and yield of coconut

According to Ziller and Prevot (1963), the critical levels of nutrients like N, P, K, Ca and Mg in the 14^{th} leaf (index leaf) were observed as 1.7, 0.1, 0.45, 0.5 and 0.4 per cent respectively. These values were modified by Fremond *et al.* (1966). According to him the critical levels of N, P, K, Ca and Mg were recorded as 1.8-2, 0.12, 0.8-0.1, 0.5 and 0.3 per cent respectively.

Fremond *et al.* (1966) found that N significantly increased the number of female flowers, number of nuts and copra yield.

Bachy (1963) pointed out the importance of K-Ca-Mg equilibrium in the plant and its effect on yield of the oil palm and coconut in their work on foliar diagnosis intended to study the relationship between cations.

An investigation on potassium content of soils and leaves of coconut in high and low yielding areas, conducted by Jack (1965) revealed that the soil and leaf K contents highly correlated with number of nuts produced.

According to Devi and Pandalai (1968), the content of foliar N, phosphoric acid, potash, Fe and Mn showed positive correlation with yield of coconut.

Ollangnier *et al.* (1970) reported five per cent yield increase due to increase in leaf N concentration from 2.3 to 2.7 per cent.

Wahid *et al.* (1974) in their work on mono and divalent cations with yield in coconut revealed that leaf K has an important role in increasing yield of crop.

According to Krishnakumar (1983), coconut yield was significantly correlated with N concentration in leaf. The coefficient of partial correlation between K content and yield of second and 10^{th} leaves were significant. The contents of Ca, Mg and Na were significantly correlated with yield only in 14^{th} leaf of palm.

Materials and Methods

3 MATERIALS AND METHODS

The project entitled "Effect of continuous application of rice husk ash (RHA) on Inceptisols of Palakkad Eastern plains" was conducted in the Department of Soil Science and Agricultural Chemistry, College of Horticulture, Kerala Agricultural University during 2014 -2016. The present study was undertaken to find out the physical and chemical changes of soils due to the continuous application of rice husk ash (RHA) and its relation to performance of coconut palms. For this purpose, soil samples and coconut leaf samples were collected from Eastern plains of Palakkad district of Kerala. The experimental area was at Vadavannur region, which belongs to Vadavannur series, fine loamy, mixed, iso-hyperthermic family of Udic Haplustepts. The materials used and the methods followed for the study is summarized below.

3.1. Collection and processing of rice husk ash samples

In Kerala, agro-industrial wastes like rice husk ash (RHA) are available in sufficient quantities and their disposal poses a great threat to the environment especially the land where it is dumped and naturally the surrounding area including water bodies. Rice Husk Ash (RHA) samples used in the present study were collected from *Gayathri* and *Vasantha* rice mills in Vadavannur, Palakkad where the husk generated during milling is mostly used as a fuel in the boilers for processing paddy leaving rice husk ash to an extent of 20 % of the husk burnt. RHA is produced under incomplete oxidation as a partially burnt char at a temperature of 250 to 400°C. The collected samples were preserved for nutrient analysis. The analytical procedures for RHA are given in Table 4.

3.2. Collection and processing of soil samples

A preliminary survey was conducted in the Palakkad Eastern plains to identify the areas where RHA amendment *in vogue*. The survey could identify four locations (Muthalamada (L1), Vadavannur (L2), Thathamangalam (L3) and Mullakkalkolambu (L4)), where RHA amending was practiced for 30 years. For contrasting evaluation an

Plate 1. Rice mill at Vadavannur

Plate 2. Rice husk combustion unit

Plate 3. Rice husk samples

Plate 4. Rice husk ash samples

Plate 5. Rice husk ash samples collected from Vadavannur regions

Table 4. Analytical procedures for RHA

Parameter	Methods		Reference
	Extraction	Estimation	
pH	RHA: water suspension in 1:10 ratio	Potentiometric method using pH meter	FCO, 1985
N	Micro-kjeldahl digestion	Distillation	Piper, 1942
K	Diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio)	Flame photometer (Model: CL 378)	Piper, 1942
P	Diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio)	Spectrophotometer (Model: Lambda 25)	Piper, 1942
Ca, Mg, Fe, Mn, Zn, Cu and Al	Diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio) (Piper, 1942)	ICP-OES(Model: Optima 8000)	
Heavy metals	Diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio) (Piper, 1942)	ICP-OES(Model: Optima 8000)	
Si	Microwave digestion system (HNO_3: H_2O_2 :HF in 7: 2: 1 ratio)	Spectrophotometer with reducing agent ANSA (Model: Lambda 25)	Ma *et al.*, 2002
CEC	Neutral *N* NH_4OAc	Distillation	Piper, 1942
Bulk density	Keen- Raczkowski brass cup method		Piper, 1942
Moisture content (%)	Moisture meter (Model: MB 23)		
C	Elemental analyzer (Model: multi EA 4000)		

additional four locations in the near vicinity of the location already identified, there was no application of RHA, were selected.

Soil samples were collected during the period August – December, 2015 from two categories of fields at the rate of 10 samples and replicated thrice from each location from a depth of 15 cm. The collected samples were air dried, processed and sieved through 2 mm sieve and preserved in polythene covers for different nutrient analysis. Physical and chemical properties of the soil were determined as per the standard procedures as mentioned in Table 5 (a) and Table 5 (b).

3.2.1. Aggregate stability

Aggregate stability of soil was determined using Yoder's apparatus based on wet sieving. The soil sample (50 g) was placed on the top of the set of sieves, which were arranged on decreasing order of diameter ($8 > 4 > 2 > 1 > 0.5 > 0.21 > 0.15$ mm). Then the sample was wet sieved for 30 minutes. The fraction retained on each sieve was dried to constant weight at 105°C and weighed. From the data, following indices were calculated (ISSS, 2012).

a) Aggregate size distribution

b) Mean weight diameter (MWD)

$$\text{MWD (mm)} = \Sigma\, d_i \times W_i$$

Where, 'd_i' is the mean diameter of each size range and 'W_i' is the fractional weight of aggregates retained on that size range to the total weight of sample taken for analysis.

c) Stability index is the difference between per cent clay and silt as determined by the mechanical analysis and that obtained by suspension of soil in water.

d) Structural coefficient

$$\text{Structural coefficient} = (D-S)/S$$

Where, 'D' is the percentage of particle < 0.25 mm as determined by mechanical analysis and 'S' is the percentage of particle < 0.25 mm as determined by wet sieving.

e) Percentage aggregate stability

$$\text{Percentage aggregate stability} = \text{structural coefficient} \times 100$$

Table 5 (a). Methods of physical properties of soil

Parameter	Method	Reference
Aggregate stability	Yoder's apparatus	Yoder (1936) as cited by Pal, 2013
Bulk density	Keen- Raczkowski brass cup method	Piper, 1942
Consistency	Liquid limit device	Casagrande (1932) as cited by Pal, 2013
Soil texture	International pipette method	Robinson,1922
Total porosity	Keen- Raczkowski brass cup method	Piper, 1942
Water holding capacity	Keen- Raczkowski brass cup method	Piper, 1942

Table 5 (b). Methods of physico-chemical and chemical properties of soil

Parameter	Methods		Reference
	Extraction	Estimation	
pH	1:2.5 soil: water suspension	Potentiometric method using pH meter	Jackson, 1958
Electrical conductivity	1:2.5 soil: water suspension	Conductivity meter	Jackson, 1958
Total N	Kjeldahl's digestion	Distillation	Jackson, 1958
Total P	Diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio)	Spectrophotometer (Model: Lambda 25)	Hesse, 1971

Table 5 (b). Contd...

Parameter	Methods		Reference
	Extraction	Estimation	
Total K	Diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio)	Flame photometer (Model: CL 378)	Hesse, 1971
Exchangeable K and Na	0.01 *M* $BaCl_2$	Flame photometer (Model: CL 378)	Hendershot and Duquette, 1986
Exchangeable Ca, Mg and Al	0.01 *M* $BaCl_2$	ICP- OES (Model: Optima 8000)	Hendershot and Duquette, 1986
Available K	Neutral *N* NH_4OAc	Flame photometer (Model: CL 308)	Jackson, 1958
Available P	0.5 *M* $NaHCO_3$ (Olsen's extractant)	Spectrophotometer (Model: Lambda 25)	Watanabe and Olsen, 1965
Exchangeable Fe, Mn, Zn and Cu	DTPA	ICP- OES (Model: Optima 8000)	Leggett and Argyle, 1983
Available Si	0.5 *M* CH_3COOH	Spectrophotometer with ANSA reducing agent (Model: Lambda 25)	Korndorfer *et al.*, 2001
Total C	Elemental analyzer (Model: multi EA 4000)		Sato *et al.*, 2014
Organic carbon	Wet oxidation method		Walkley and Black, 1934
Effective cation exchange capacity	Summation method Exchangeable cations - K, Na ,Ca , Mg and Al		Hendershot and Duquette, 1986

3.2.2 Measurement of infiltration rate of water in soil

Infiltration rates were measured *in situ* at each location using double ring infiltrometer. Double ring infiltrometer consists of inner and outer cylinders having 30 cm and 60 cm diameters respectively. After removing the plants and crop residues from the surface of soil, it was slightly levelled to reduce soil disturbance to the minimum and to install the cylinders. The cylinders were concentrically installed in soil at about 10-15 cm depth using a hammer. Then water was filled up to the mark initially in inner cylinder, followed by the outer one. The recession of water in the inner cylinder was recorded at a time interval of five minutes until the amount of water entering into the soil per unit time became a constant. The average infiltration rates were calculated using the data following the methodology suggested by Dakshinamurti and Gupta (1968) and Michael (1999).

3.2.3 Physical fractionation of particulate organic carbon in soils

Particulate organic carbon (POC) was determined by physical fractionation method as given by Handayani *et al.* (2010). Physical fractionation by sieving is established on the separation of aggregates on the basis of particle size. The range of macro - aggregates and micro - aggregates in soil has been reported to be between 0.50 to 0.25 and 0.25 to 0.053 mm, respectively (Ontl *et al.*, 2015). In order to separate the macro - aggregates and micro - aggregates, wet sieving was done using test sieves of varying diameters *viz;* 0.50, 0.25 and 0.053 mm. After sieving, the portion of soil that remained on each sieves were collected separately and dried at 60^{o} C in a hot air oven. Then 10 g of each aggregate fraction was taken and dispersed with 40 ml of 5% sodium hexametaphosphate and shaken for an hour in a rotary shaker. The soil water suspension thus obtained was transferred over the 0.053 mm sieve with several washings using distilled water. The soil remaining on the sieve was taken and dried at 60^{o} C in a hot air oven for 24 h and its carbon content was estimated using an Elemental analyzer (Model No. multi EA 4000, Sato *et al.*, 2014). The flow chart on particulate organic carbon fractionation is given in Fig. 1.

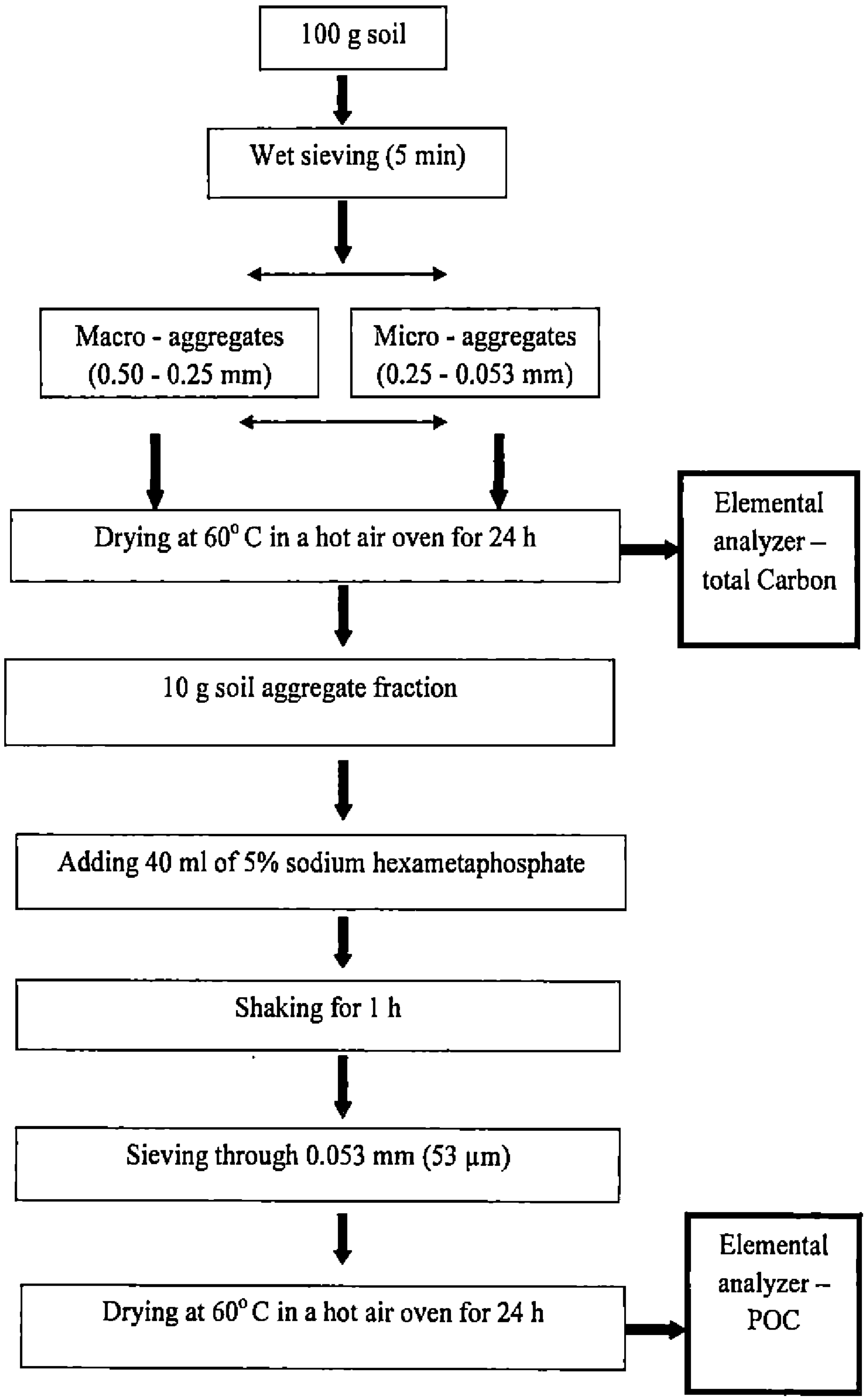

Figure.1. Flow chart of physical fractionation of POC in soil

3.3 Collection and processing of leaf samples

The phenotypically uniform palms were selected from RHA amended and non-amended locations. But the management practices adopted varied depending on locations. The palms from the amended area were under an integrated nutrient management practice (inorganic nutrient + RHA) whereas, the non-amended palm were under inorganic nutrient application alone. The manurial schedule followed by the farmers was not uniform. Though the quantity of individual nutrients supplied was as per recommendations. The general practice followed by the farmers of Vadavannur region is listed below (Table 6).

Table 6. Integrated nutrient management practices followed by the farmers for coconut in Vadavannur region

Category	**Fertilizers / manures**	**Quantity**
Amended locations	Coconut mixture	2-3 kg/palm/year
	Fertilizer (18:18:18)	2.5 kg/palm/year
	FYM	15-20 kg/ palm
	Rice husk ash	4 - 6 baskets on volume basis to supply nearly 40 kg/ palm
Non-amended locations	Fertilizer (Urea, rock phosphate/ Factamphos, Muriate of potash)	2-2.5 kg/palm/year
	Coconut mixture	2-3 kg/palm/year
	Fertilizer (18:18:18)	2-2.5 kg/palm/year
	FYM	15-20 kg/ palm

Leaf samples were collected from the 14th frond (index leaf) of selected coconut palms from RHA amended and RHA non- amended categories at the rate of 10 samples from each location. Five leaflets from either side of the middle portion of the frond were taken out. From each of the collected leaflets, 30 cm each on top and bottom was discarded

Plate 6. Recording of biometric observations of index leaf

Plate 7. Measurement of infiltration rate

Plate 8. RHA amended coconut gardens at Vadavannur region

so as to get the middle portion of the leaf lamina leaving the mid rib, as reported by Mathewkutty (1994). The leaf lamina was first washed with tap water and wiped with cotton dipped in distilled water, cut into small pieces, transferred to brown paper covers and dried in a hot air oven at 80 ± 2 ^{0} C. The dried samples were powdered and stored for nutrient analysis using standard procedures (Table 7).

3.3.1 Biometric observations of index leaf

The biometric characters of index leaf such as, length of index leaf, average length and width of leaflets per index leaf and total number of leaflets were recorded. Besides the total number of bunches per palm and the number of nuts per bunch were also collected at the time of leaf sample collection. In addition average annual yield of the selected palms were gathered from the farmers and also calculated using the formula given below.

Average annual yield = (total no. of nuts / total no. of bunches) x 10*

* On the assumption that there will be ten number of harvests annually.

3.4. Statistical analysis

All the statistical analysis were done using 'SPSS (16.0)' package.

Table 7. Methods of leaf analysis

Parameter	Methods		Reference
	Extraction	Estimation	
N	Microkjeldahl digestion	Distillation	Piper, 1942
P	Diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio)	Spectrophotometer (Vanado-molybdate yellow colour method)	Piper, 1942
K and Na	Diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio)	Flame photometer (Model: CL 378)	Piper, 1942
Ca and Mg	Diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio) (Piper, 1942)	ICP-OES (Model: Optima 8000)	
Fe, Mn, Zn and Cu	Diacid digestion (HNO_3: $HClO_4$ in 9:4 ratio) (Piper, 1942)	ICP-OES (Model: Optima 8000)	
Si	Microwave digestion system (HNO_3: H_2O_2 :HF in 7: 2: 1 ratio)	Spectrophotometer with ANSA reducing agent	Ma *et al.*, 2002

Results

4. RESULTS

The results of the study on "Effect of continuous application of rice husk ash (RHA) on Inceptisols of Palakkad Eastern plains" are presented in this chapter under six different sub- heads.

4.1. Composition of RHA

4.2. Physical properties of soil

4.3. Chemical properties of soil

4.4. Physical fractionation of particulate organic carbon

4.5. Characters of the coconut palm

4.6 Impact of RHA application on soil properties and coconut palm– an overview

4.1. Composition of RHA

The characteristic properties of RHA samples, collected from Vadavannur (*Vasantha* and *Gayathri* rice mills) region of Palakkad, for the present study are furnished in Table 8.

The most important character of an amendment is its pH. In this study the pH of RHA varied from 7.5 to 8.3 in 1: 10 RHA water suspension. It was observed to have an EC of 0.2-1.4 dS m^{-1} and contained 10-15 per cent moisture.

The elemental composition was total carbon (2.0-7.0%), N (0.18- 0.27%), P (0.39 -0.57%), K (0.35-0.58%), Ca (0.08-0.1%), Mg (0.09-0.2%) and Si (18.75-35%) respectively. The material possessed a C/N ratio of 21:1. The micronutrient status was Fe (500-1600 mg kg^{-1}), Mn (180-320 mg kg^{-1}), Cu (3-5 mg kg^{-1}) and Zn (10.0-12.0 mg kg^{-1}).

The Al content was about 80-150 mg kg^{-1}. It had a CEC ranging from 7.5 to 9.5 cmol (+) Kg^{-1}. The bulk density was from 0.24 to 0.94 Mg m^{-3}. The maximum water holding capacity of RHA was very high ranging from 170 to 250 per cent on volume basis.

Table 8. Composition and characteristics of RHA samples used in the study

Parameters	Range
pH (1:10 ratio)	7.5 - 8.3
EC (1:10 ratio) (dS m^{-1})	0.2 - 1.4
CEC (cmol (+) kg $^{-1}$)	7.5 - 9.5
N (%)	0.18 - 0.27
P (%)	0.39 - 0.57
K (%)	0.35 - 0.58
C (%)	2.0-7.0
Ca (%)	0.08 - 0.10
Mg (%)	0.09 - 0.20
Si (%)	18.75 – 35.00
Fe (mg kg^{-1})	500-1600
Mn (mg kg^{-1})	180 – 320
Zn (mg kg^{-1})	10.0-12.0
Cu (mg kg^{-1})	3.0 – 5.0
Al (mg kg^{-1})	80 – 150
Maximum water holding capacity (%) (v/v)	170-250
Bulk density (Mg m^{-3})	0.24 - 0.94
Moisture content (%)	10.0 -15.0
C/N ratio	21:1

All the heavy metals *viz;* Hg, Cd, Pb, Cr, Ni, Co and As remained below the detectable limit.

4.2. Physical properties of soil

The physical properties of the soil, soil texture and soil consistency were analyzed at the beginning of the experiment to have a basic information of the soils to be experimented.

4.2.1 Soil texture

The textural classes were observed as sandy loam, loamy sand and sandy clay loam in the four locations (Table 9). The clay content was more in sandy clay loam soils (12-28 %) whereas the sand fraction was highest for loamy sands of Mullakkalkolambu non-amended region. The content of clay was low (5-7%) in the loamy sands as well as in sandy loam. Among the locations, no difference was observed in texture consequent to RHA addition.

4.2.2 Soil consistency

From the Table 10, it is evident that except the non-amended Mullakkalkolambu, all others showed 'medium plasticity'. Non-amended Mullakkalkolambu showed a low plasticity. Plastic limit was found to be highest in Vadavannur amended (12.02%) and lowest for non-amended Thathamangalam (3.60 %) soil. The range of liquid limit was from 11.85 to 25.75 per cent. On comparing the PI, it was noted that the values ranged from 5.15 (non- amended Mullakkalkolambu) to 17.5 per cent (non- amended Thathamangalam).

4.2.3 Aggregate stability

The physical properties of the soil such as MWD, infiltration rate, bulk density, porosity and water holding capacity were analyzed to know the effectiveness of RHA on the physical properties of soil. A two sample case 't' test was used to measure the effectiveness of amendment.

Table 9. Mechanical composition of soil in the experimental area

Locations	Categories	Sand	Silt	Clay	Textural class
		%			
Muthalamada (L1)	NA	67.50	25.00	6.25	sandy loam
	A	66.25	20.87	7.06	sandy loam
Vadavannur (L2)	NA	60.00	28.06	12.16	sandy clay loam
	A	61.25	18.06	21.13	sandy clay loam
Thathamangalam(L3)	NA	63.70	20.75	24.81	sandy clay loam
	A	65.87	11.43	21.06	sandy clay loam
Mullakkalkolambu (L4)	NA	68.12	26.12	5.33	loamy sand
	A	66.51	15.06	18.12	sandy clay loam

Table 10. Atterberg limits and plasticity index of different locations

Locations	Categories	Plastic limit	Liquid limit	Plasticity index	Description
		%			
Muthalamada	NA	6.87	19.05	12.18	Medium plasticity
	A	7.32	21.84	14.52	Medium plasticity
Vadavannur	NA	8.70	21.17	12.47	Medium plasticity
	A	12.02	22.06	10.04	Medium plasticity
Thathamangalam	NA	3.60	21.11	17.50	Medium plasticity
	A	9.55	25.60	16.05	Medium plasticity
Mullakkalkolambu	NA	6.70	11.85	5.15	Low plasticity
	A	9.29	25.75	16.46	Medium plasticity

The distribution of water stable aggregate in soil was studied using sieves of < 0.15 mm to 8- 4 mm diameter (Table 11). The water stable aggregates were seen unevenly distributed in all soils irrespective of RHA addition. Aggregate percentage in the category < 0.15 mm ranged from 7.98 to 18.79 per cent where as it was from 4.21 to 9.41 per cent under sieves with diameter of 0.21 -0.15 mm. On reaching the diameter range of 0.5 - 0.21 mm, there was an increase in the aggregate percentage with values ranging from 23.11 to 38.14 per cent. The aggregate percentage showed a minimum value of 12.18 per cent in the non-amended fields of Thathamangalam to 23.71 per cent in the non-amended fields of Mullakkalkolambu. In the 2-1 mm diameter range, the aggregate per cent varied from 14.71 per cent (Thathamangalam non-amended) to 24.47 per cent (Thathamangalam amended). On the whole, the percentage of aggregates with diameter from 0.21- 0.15 mm and 4- 8 mm diameter were observed to be minimum while the maximum was in the diameter range of 2- 0.2 mm.

The highest mean weight diameter (MWD) was recorded at the Thathamangalam amended (1.41 mm) soils and lowest at the Vadavannur non-amended soil (0.76 mm) (Table 12). Significant difference in MWD was observed with respect to different locations. It was found to vary from 0.76 to 1.13 mm in non-amended locations and 1.0 to 1.41 mm in amended regions. Stability index percentage ranged from 30.25 (Muthalamada non-amended) to 58.41(Thathamangalam amended). No significant difference was recorded in the stability index.

Structural coefficient varied from 0.18 (non-amended Vadavannur) to 0.75 (amended Muthalamada). An increasing trend in percentage aggregate stability could be visualized from the non-amended to amended fields, the lowest value of 17.65 being registered in RHA non- amended fields of Vadavannur and the highest (74.87) in the RHA amended fields of Muthalamada. Only MWD showed significant difference among RHA amended and non-amended fields.

Table 11. Distribution of water stable aggregates in soil

Locations	Categories	Percentage of aggregates (%)						
		8 - 4 mm	4 -2 mm	2 - 1 mm	1 - 0.5 mm	0.5 - 0.21 mm	0.21- 0.15 mm	< 0.15 mm
Muthalamada	NA	2.17	8.70	19.57	22.83	29.35	5.43	11.96
	A	3.13	10.44	16.49	18.79	27.14	5.22	18.79
Vadavannur	NA	1.18	4.71	17.65	18.82	35.29	9.41	12.94
	A	6.32	11.58	14.74	20.00	29.47	4.21	11.58
Thathamangalam	NA	7.35	25.21	14.71	12.18	23.11	7.35	7.98
	A	2.13	12.77	24.47	20.21	26.60	4.26	9.57
Mullakkalkolambu	NA	3.09	2.06	15.46	23.71	38.14	6.19	11.34
	A	4.20	16.81	15.97	21.01	23.11	6.30	13.66

Table 12. Different indices of soil aggregation of RHA amended and non-amended soils

Locations	MWD (mm)		Stability index (%)		Structural coefficient		Percentage aggregate stability	
	NA	A	NA	A	NA	A	NA	A
Muthalamada	0.97	1.00	30.25	39.63	0.35	0.75	34.78	74.87
Vadavannur	0.76	1.24	52.13	45.88	0.18	0.21	17.65	21.05
Thathamangalam	1.13	1.41	36.50	58.41	0.26	0.50	25.53	50.06
Mullakkalkolambu	0.80	1.23	33.06	46.19	0.23	0.26	23.23	25.86
Mean	0.88	1.16	43.46	42.94	0.25	0.43	25.29	42.96
t value	3.09*		0.19 (NS)		1.35 (NS)		1.37 (NS)	

4.2.4 Infiltration rate

The data on infiltration rate of soil is furnished in Table 13. The amended locations recorded more infiltration rate as compared to non-amended locations except the loamy sand of Mullakkalkolambu. The highest value recorded in non-amended Mullakkalkolambu (19.12 cm h^{-1}) location was not accounted for the independent 't' test, hence the remaining population in the both categories showed significant difference in the case of infiltration rate. The infiltration rate in RHA amended regions was 4.87 cm h^{-1} as against 2.4 cm h^{-1} in non-amended regions. With respect to the infiltration rate, the t value was significant among amended and non-amended populations.

On working out the correlation between infiltration and aggregate stability a high positive correlation was observed with percentage aggregate stability (0.728**) and a high negative correlation with plasticity index (-0.728**). As in amended soils, infiltration in non-amended soil also exhibited negative correlation with plasticity index (-0.842**). As regards non-amended soils, MWD positively correlated with plasticity index (0.751) whereas it was positively correlated with percentage aggregate stability (0.575**) in amended areas (Appendix 1).

4.2.5 Bulk density, porosity and water holding capacity

A perusal of the data showed a decrease in bulk density of amended soils as against the non- amended ones, though the reduction was not significant statistically (Table 14(a)). The bulk density of soil ranged from 1.0 to 1.34 Mg m^{-3} in non-amended regions and 0.98 to 1.32 Mg m^{-3} in amended regions.

The average porosity of soil was 41.86 per cent in non-amended and 46.86 per cent in amended locations. In the case of maximum water holding capacity, the average values of 37.24 per cent and 40.34 per cent respectively were recorded at non-amended and amended regions. In amended regions a significant improvement in porosity and WHC was evident. Another observation was the high variation noticed among samples collected from particular locations as evidenced from the high values of standard deviation. So, a two

Table 13. Infiltration rate of water in RHA amended and non- amended soil

Locations	Infiltration rate ($cm\ h^{-1}$)	
	NA	A
Muthalamada (L1)	6.65	7.71
Vadavannur (L2)	2.20	4.35
Thathamangalam (L3)	2.61	5.42
Mean	2.40	4.87
t value	4.41*	
Mullakkalkolambu (L4)	19.12	2.65

Table 14 (a). Bulk density, Porosity and WHC of soil

Locations	Bulk density ($Mg\ m^{-3}$)		Porosity (%)		Max. water holding capacity (%)	
	NA	A	NA	A	NA	A
Muthalamada	1.342	1.320	44.364	48.986	41.664	45.336
Vadavannur	1.124	0.994	40.816	45.922	34.672	38.644
Thathamangalam	1.002	0.984	40.446	44.578	38.942	39.834
Mullakkalkolambu	1.086	1.060	41.834	44.818	33.696	37.538
Mean	1.138	1.089	41.865	46.076	37.244	40.338
Std. deviation	0.093	0.053	2.07	2.45	3.02	2.36
t value	1.378 (NS)		4.915**		2.93**	

Table 14 (b). Location wise variation of Porosity and WHC of soil

Locations	Porosity (%)		Max. water holding capacity (%)	
	NA	A	NA	A
Muthalamada	44.364	48.986	41.664	45.336
Vadavannur	40.816	45.922	34.672	38.644
Thathamangalam	40.446	44.578	38.942	39.834
Mullakkalkolambu	41.834	44.818	33.696	37.538
Mean	41.865	46.076	37.244	40.338
CD (0.05) Amendment	1.51		1.52	
CD (0.05) Interaction	NS		NS	

factor (locations and amendment) analysis was resorted to wherever it was necessary to compare the locations based on the effectiveness of amendment.

The porosity and WHC were significantly higher in amended locations as compared to non-amended locations though it was not significant among the different locations (Table 14(b)).

In non- amended soils, bulk density was correlated with plasticity index with a correlation coefficient of 0.408 at 7.4 per cent level. The porosity had significant positive correlation with PAS (percentage aggregate stability, 0.527*). Maximum WHC also correlated significantly with PAS (0.744**) and plasticity index (0.503*). In the case of amended soils, porosity showed positive correlation with infiltration rate (0.493*) and negative correlation with plasticity index (-0.492*). Water holding capacity had maximum positive correlation with infiltration (0.75**), PAS (0.758**) and plasticity index (0.433 at 5.6 % level) and negative correlation with MWD (-0.541*).

4.3 Chemical properties of soil

The chemical properties of soil were also initially analyzed using 't' test, so as to infer on the effect of amendment as was done for physical properties.

4.3.1 Electro-chemical properties

The pH and EC of the amended and non-amended regions are presented in Table 15. Muthalamada and Vadavannur regions recorded a pH of 6.8 and 7.3 in non- amended and amended regions respectively and it was significant also. In contrast, Thathamangalam and Mullakkalkolambu fields registered a significant reduction in soil pH following RHA addition.

Electrical conductivity followed similar trend as that of pH. The highest value of 0.15 dS m^{-1} was recorded at the amended Vadavannur region and lowest was at amended Thathamangalam (0.061 dS m^{-1}) fields. Locational difference existed in the case of EC with Muthalamada and Vadavannur locations showing a significant increase in EC in amended locations whereas Thathamangalam and Mullakkalkolambu did not register such

Table 15. pH and electrical conductivity of the amended and non-amended soils

Locations	pH		EC (dS m^{-1})	
	NA	A	NA	A
Muthalamada	7.12	7.96	0.095	0.135
Vadavannur	6.58	6.80	0.068	0.155
Mean	6.8	7.35	0.082	0.145
Std. deviation	0.505	0.728	0.029	0.071
t value	1.66*		3.68*	
Thathamangalam	6.24	5.61	0.077	0.070
Mullakkalkolambu	6.55	5.90	0.078	0.061
Mean	6.35	5.75	0.077	0.065
Std. deviation	0.288	0.304	0.016	0.042
t value	5.57**		2.3 (NS)	

*Significant at 0.05 level

** Significant at 0.01 level

Table 16. Status of major nutrients, total carbon and organic matter in the soil

Locations	Total N		Total P		Total K		Total C		Organic matter	
	(%)									
	NA	A	NA	A	NA	A	NA	A	NA	A
Muthalamada	0.070	0.082	0.06	0.09	0.10	0.09	1.23	2.24	1.22	1.38
Vadavannur	0.072	0.084	0.04	0.11	0.05	0.17	1.15	2.74	0.80	1.62
Thathamangalam	0.052	0.108	0.05	0.11	0.07	0.13	1.30	2.73	1.02	1.74
Mullakkalkolambu	0.062	0.086	0.05	0.12	0.09	0.11	1.44	2.75	1.11	1.72
Mean	0.064	0.090	0.05	0.12	0.08	0.13	1.28	2.62	1.04	1.62
Std. deviation	0.162	0.241	0.017	0.147	0.019	0.047	0.249	0.418	0.322	0.293
t value	2.71**		2.17**		4.46**		10.92**		5.04**	

significance. Another finding was the positive correlation (0.587**) that existed between soil pH and EC in amended soil.

4.3.2 Total nutrients

Total N, P, K and C recorded significantly higher values in amended areas as compared to non-amended area on carrying out 't' test (Table 16). The highest (0.108 %) and lowest (0.052 %) value for N were registered in the amended and non-amended fields of Thathamangalam.

Phosphorus was significantly high in all RHA amended regions. It was only 0.04 per cent in the non-amended fields of Vadavannur. Total K values ranged from 0.05 to 0.10 per cent in non-amended locations and from 0.09 to 0.17 per cent in amended locations and were significantly high. Carbon content in RHA amended soils ranged from 2.24 to 2.75 per cent with an average of 2.62 per cent as against 1.28 per cent registered in non amended locations. The amended soils were richer in terms of carbon contained. The lower values for standard deviation obtained for total N, P, K and C implies the less amount of variation that existed between amended and non-amended sites.

In non-amended soil, a significant and positive correlation was noticed only between total N and available Si (0.605**) whereas in amended soils, total N exhibited positive correlation with exchangeable K (0.393 at 8.7%), exchangeable Fe (0.658**) and exchangeable Cu (0.614**) and a negative correlation with exchangeable Ca (-0.452*) and ECEC (-0.442 at 5.1%) (Appendix 3).

4.3.3 Organic matter

The amended and non-amended locations varied significantly with respect to organic matter content (Table 16). It ranged from 1.38 to 1.74 per cent in amended region and from 0.80 to 1.22 per cent in non-amended regions. The RHA amended and non-amended locations were comparable in relation to organic matter as supported by the low values of standard deviation. However a positive correlation existed between organic matter with carbon in both amended (0.637**) and non- amended (0.555*) soils.

4.3.4 Available nutrients

The availability of primary nutrients P and K were significantly higher in amended locations as compared to non-amended locations (Table 17 (a)). But the standard deviation was very high, due to which a two factor analysis was done to know the effectiveness of amendment over locations. From the analysis of variance, it was clear that an interaction prevailed between the amendment and location in deciding the available status of P and K. The Vadavannur soils recorded highest (76.24 mg kg^{-1}) content of available P followed by Mullakkalkolambu and Thathamangalam, which were on par. In amended regions, the available K content was highest at Thathamangalam (188.67 mg kg^{-1}) and lowest at Muthalamada (89.77 mg kg^{-1}).

Similarly, the silicon availability also showed significant difference between amended (165.86 mg kg^{-1}) and non-amended areas (108.66 mg kg^{-1}). The available silicon content in the amended regions followed the order *viz;* Muthalamada (175.48 mg kg^{-1}) > Vadavannur (173.85 mg kg^{-1}) > Mullakkalkolambu (170.19 mg kg^{-1})> Thathamangalam (143.95 mg kg^{-1}) (Table 17 (b)). Another finding was the significant negative correlation between available Si and exchangeable Mn (-0.573**) when amended with RHA.

4.3.5 Exchangeable cations and effective cation exchange capacity (ECEC)

The results obtained on exchangeable cations *viz*; K, Na, Ca and Mg are presented in Table 18. The content of exchangeable bases was significantly higher in amended areas as compared to non-amended areas. The exchangeable Ca content was highest in amended locations and the average content was 7.44 cmol (+) kg^{-1} as against 5.69 cmol (+) kg^{-1}in non-amended regions. Exchangeable Mg content was 4.94 cmol (+) kg^{-1} in amended sites as compared to 3.94 cmol (+) kg^{-1} registered in non-amended sites. RHA amended locations recorded high amount (0.29 cmol (+) kg^{-1}) of exchangeable K whereas the average value for exchangeable K in non-amended regions was only 0.21 cmol (+) kg^{-1}. Exchangeable Na also showed similar trend as that of Ca and K among amended and non-amended locations.

Table 17 (a). Status of available nutrients in the soil

Locations	Avail. P		Avail. K		Avail. Si	
	mg kg^{-1}					
	NA	A	NA	A	NA	A
Muthalamada	56.20	71.34	51.88	89.77	124.69	175.48
Vadavannur	33.63	76.24	36.20	131.84	125.20	173.85
Thathamangalam	40.33	58.92	45.3	188.67	90.57	143.95
Mullakkalkolambu	45.73	65.03	88.63	149.07	94.20	170.19
Mean	43.97	67.88	55.50	139.83	108.66	165.86
Std.deviation	9.41	8.18	11.82	26.71	7.69	11.42
t value	3.58**		10.22**		16.17**	

Table 17(b). Location wise variation of available nutrients in soil

Locations	Avail. P		Avail. K		Avail. Si	
	mg kg^{-1}					
	NA	A	NA	A	NA	A
Muthalamada	56.20	71.34	51.88	89.77	124.69	175.48
Vadavannur	33.63	76.24	36.20	131.84	125.20	173.85
Thathamangalam	40.33	58.92	45.30	188.67	90.57	143.95
Mullakkalkolambu	45.73	65.03	88.63	149.07	94.20	170.19
Mean	43.97	67.88	55.50	139.83	108.66	165.86
CD (0.05) Amendment	1.67		8.41		6.42	
CD (0.05) Interaction	17.60		11.89		12.84	

Effective cation exchange capacity is the total amount of exchangeable cations *viz*; K, Na, Ca and Mg in soils having pH value greater than seven and these cation plus aluminium contribute to ECEC in acidic soils. The high content of cations in amended locations ultimately increased the values of ECEC (12.6 cmol (+) kg^{-1}). In non-amended locations the mean value of ECEC was only 9.82 cmol (+) kg^{-1}.

4.3.6 Micronutrients

The location wise status of Fe and Mn was similar as that of pH. Those locations, that were comparable in the case of Fe and Mn contents, were separately subjected to 't' test (Table 19) to reduce the error to the minimum.

In the case of Fe a comparison of the mean value obtained in amended (53.04 mg kg^{-1}) and non-amended (26.91 mg kg^{-1}) regions of Vadavannur and Muthalamada showed only a slight difference in. Whereas in the two other locations (Thathamangalam and Mullakkalkolambu), the mean value showed a marked difference in the contents of Fe between non-amended (55.4 mg kg^{-1}) and amended (108.52 mg kg^{-1}) soils. With respect to Mn status significant decrease was noticed in amended (34.48 mg kg^{-1}) regions as against non-amended (21.41 mg kg^{-1}) ones in Muthalamada and Vadavannur. However in Thathamangalam and Mullakkalkolambu locations the status of exchangeable Mn remarkably increased consequent to RHA addition registering a mean of 286.7 mg kg^{-1}in amended regions in contrast to 44.14 mg kg^{-1} recorded in the non-amended regions.

The values on soil Zn content did not reveal any significant difference among locations and among categories (Table 20). But in case of Cu content, a significant reduction was noticed in amended regions (1.96 mg kg^{-1}) unlike the non-amended (2.12 mg kg^{-1}).

4.4. Physical fractionation of particulate organic carbon

The semi-decomposed organic materials with a size range of 0.25 to 0.053 mm is considered as POC. It can be estimated by physical fractionation of soil on the basis of size.

Table 18. Status of exchangeable cations (K, Na, Ca and Mg) and effective cation exchange capacity of soil

Locations	Exch. Ca		Exch. Mg		Exch. K		Exch. Na		ECEC	
	cmol (+) kg^{-1}									
	NA	A	NA	A	NA	A	NA	A	NA	A
Muthalamada	6.77	8.19	5.288	5.520	0.21	0.27	0.036	0.068	12.22	13.91
Vadavannur	4.95	7.70	3.724	4.274	0.21	0.31	0.070	0.060	8.86	12.18
Thathamangalam	6.16	6.97	4.138	4.936	0.17	0.30	0.066	0.064	10.49	12.13
Mullakkalkolambu	4.90	6.90	2.636	5.064	0.24	0.30	0.064	0.072	7.73	12.19
Mean	5.69	7.44	3.940	4.940	0.21	0.29	0.059	0.066	9.82	12.60
Std. deviation	1.29	1.20	0.780	0.970	0.17	0.19	0.010	0.120	1.93	1.69
t value	4.96**		2.17*		3.64**		5.14*		4.41**	

Table 19. Status of iron and manganese in soil

Locations	Exch. Fe		Exch. Mn	
	mg kg^{-1}			
	NA	A	NA	A
Muthalamada	22.25	32.03	24.73	13.21
Vadavannur	31.57	74.05	44.23	28.83
Mean	26.91	53.04	34.48	21.01
Std. deviation	1.38	2.92	1.37	2.41
t value	3.8*		3.89**	
Thathamangalam	72.21	110.25	47.12	205.35
Mullakkalkolambu	38.64	106.80	41.18	368.10
Mean	55.40	108.52	44.14	286.70
Std. deviation	2.3	1.71	1.5	2.12
t value	8.16**		5.13**	

Table 20. Status of zinc and copper in soil

Locations	Exch. Zn		Exch. Cu	
	mg kg^{-1}			
	NA	A	NA	A
Muthalamada	5.33	3.16	1.44	2.75
Vadavannur	1.97	2.68	2.12	1.35
Thathamangalam	1.57	2.26	2.72	2.39
Mullakkalkolambu	2.23	2.65	2.20	1.36
Mean	2.77	2.68	2.12	1.96
Std. deviation	3.35	0.59	0.81	0.68
t value	1.86 (NS)		1.13*	

Table 21. Status of POC associated with macro and micro aggregates in soil

Locations	POC_M (> 0.25 mm)		POC_m (0.25 - 0.053 mm)	
	%			
	NA	A	NA	A
Muthalamada	0.22	0.44	0.33	0.64
Vadavannur	0.32	0.58	0.29	0.92
Thathamangalam	0.33	0.79	0.35	1.34
Mullakkalkolambu	0.38	0.58	0.41	1.22
Mean	0.35	0.65	0.35	1.16
Std. deviation	0.08	0.19	0.11	0.46
t value	5.71**		6.69**	

The fractions of POC associated with macro (> 0.25 mm) and micro (0.25 - 0.053 mm) aggregates are presented in Table 21.

The POC associated with macro-aggregates were higher in RHA amended locations. It ranged from 0.44 to 0.79 per cent in the amended regions and from 0.22 to 0.38 per cent in non-amended regions. The POC associated with micro-aggregates also recorded a higher percentage in amended areas (0.64 to 1.34%) whereas the variation was only 0.29 to 0.41 per cent in non-amended locations. On comparing POC associated with macro and micro aggregates, POC_m was found to be more than POC_M in amended as well as in non-amended areas.

4.5. Characters of the coconut palm

The characters of coconut palm studied include the biometric observations of index leaf (14th opened frond), yield attributes of palm, average yield of palm and nutrient status of index leaves. The results are presented as follows.

4.5.1 Biometric characters of index leaf

As in the case of physical and chemical properties of soil, a collation was made on the biometric characters of the palm with and without RHA. The total number of leaflets per index leaf was found to be more (229) in RHA amended palms as compared to non-amended palms (212) (Table 22) and it was also significant as evidence from the t value. The high values for standard deviation indicated pronounced difference among the amended and non-amended sites. The significant effect of location on deciding the total number of leaflets was further confirmed in the Muthalamada and Mullakkalkolambu regions from the two factor analysis (Table 23 (b)).

The average length of index leaf was found to be significantly high in the palms of amended regions with a mean length of 4.83 m as compared to 4.41 m in palms of non-amended locations. The locational effect was not significant. RHA amended palms and non-amended palms were not significantly different in the case of average length and width of leaflets (Table 22).

Table 22. Biometric observations of index leaf of coconut palms in amended and non-amended locations

Locations	Total no. of leaflets		Avg. length of index leaf		Avg. length of leaflet		Avg. width of leaflet	
	-		M		cm		Cm	
	NA	A	NA	A	NA	A	NA	A
Muthalamada	205.4	233.1	4.41	5.06	88.80	111.00	3.27	3.49
Vadavannur	223.2	229.1	4.24	4.64	106.80	100.53	3.39	3.60
Thathamangalam	220.0	229.3	4.43	4.83	101.40	110.93	3.65	3.79
Mullakkalkolambu	203.3	228.6	4.58	4.79	111.40	118.00	3.57	4.35
Mean	212.7	229.7	4.41	4.83	101.75	109.75	3.47	3.86
Std. deviation	14.94	13.19	0.37	0.38	6.91	5.43	0.37	0.47
t value	5.40**		4.97**		3.51 (NS)		4.18 (NS)	

Table 23(a). Yield attributes and average yield of coconut palms in amended and non-amended locations

Locations	No. of nuts per palm		No. of bunches per palm		Avg. yield of palm	
	-		-		(Nuts/ palm/ year)	
	NA	A	NA	A	NA	A
Muthalamada	49.2	70.4	5.7	7.8	85.70	90.20
Vadavannur	37.6	55.2	6.0	7.4	60.90	74.50
Thathamangalam	40.2	61.5	7.2	7.1	55.50	86.60
Mullakkalkolambu	61.8	65.1	7.5	6.8	83.10	95.70
Mean	47.2	63.1	6.6	7.2	71.30	86.75
Std. deviation	16.7	15.9	1.13	0.87	22.04	20.46
t value	7.3**		2.98*		9.13**	

Table 23(b). Location wise variation of yield attributes and average yield of coconut palms in amended and non-amended locations

Locations	Total no. of leaflets		No. of nuts per palm		No. of bunches per palm		Avg. yield of palm	
	-		-		-		(Nuts/ palm/ year)	
	NA	A	NA	A	NA	A	NA	A
Muthalamada	205.40	233.10	49.2	70.4	5.7	7.8	85.7	90.2
Vadavannur	223.20	229.10	37.6	55.2	6.0	7.4	60.9	74.5
Thathamangalam	220.00	229.30	40.2	61.5	7.2	7.1	55.5	86.6
Mullakkalkolambu	203.30	228.60	61.8	65.1	7.5	6.8	83.1	95.7
Mean	212.75	229.75	47.2	63.1	6.6	7.2	71.3	86.8
CD (0.05) Amendment	5.84		5.54		0.37		10.75	
CD (0.05) Interaction	11.68		11.07		NS		7.5	

Table 24 (a). Primary nutrient content in index leaf of coconut palm

Locations	N		P		K	
	%					
	NA	A	NA	A	NA	A
Muthalamada	1.75	1.79	0.17	0.19	0.51	0.85
Vadavannur	1.67	2.13	0.16	0.20	0.48	0.84
Thathamangalam	2.01	2.43	0.20	0.22	0.77	0.80
Mullakkalkolambu	1.93	2.31	0.20	0.23	0.59	0.89
Mean	1.84	2.17	0.18	0.21	0.59	0.84
Std. deviation	0.16	0.36	0.03	0.03	0.13	0.07
t value	3.15**		2.95**		10.83**	

4.5.2 Yield attributes and average yield of palm

The significant effect in yield of palm was revealed from the 't' value. Number of nuts per palm per year was 63 in amended area while it was only 47 in non-amended area (Table 23 (a)). It was significantly more in amended palm. The more number of nuts were recorded in the palms of Muthalamada region. Both in the amended and non-amended sites much variation was seen among the samples as evidenced from the higher values of standard deviation. Locational effect was prominent on yield both under amended and non-amended locations except Muthalamada.

The number of bunches per palm was significantly more in amended region as compared to non-amended regions. The average yield was calculated with an equation considering the number of nuts and bunches per palm. Based on this the average yield in the amended region was worked out as 86 nuts/palm/year and as 71 nuts/palm/year in non-amended regions. Location exerted a marked effect on yield with the highest (96 nuts/palm/year) being from Mullakkalkolambu region.

4.5.3 Nutrient status of index leaf

The primary nutrient status of index leaf was significantly more in the amended palms (Table 24 (a)). The N content was 2.17 per cent in amended palms as against 1.84 per cent in non-amended palms and it was significant statistically. The content of P (0.21 %) and K (0.84%) also followed similar trend. On evaluating the influence of location on primary nutrient status it was seen that only the content of K was affected by location, it being highest in the palms of Muthalamada and Mullakkalkolambu. The calcium content was significantly more in amended palms with an average value of 0.623 per cent while it was only 0.604 per cent in non-amended palms. Such a difference was not noticed in the case of Mg and Na content between the amended and non-amended locations. However the content of Si was significantly more in amended regions with an average value of 2.56 per cent as compared to non-amended palms (1.93 %). The amended and non-amended palms did not show any significant difference with respect to micronutrient content.

Table 24(b). Location wise variation of primary nutrient content in index leaf of coconut palm

Locations	N		P		K	
	%					
	NA	A	NA	A	NA	A
Muthalamada	1.75	1.79	0.17	0.19	0.51	0.85
Vadavannur	1.67	2.13	0.16	0.20	0.48	0.84
Thathamangalam	2.01	2.43	0.20	0.22	0.77	0.80
Mullakkalkolambu	1.93	2.31	0.20	0.23	0.59	0.89
Mean	1.84	2.17	0.18	0.21	0.59	0.84
CD (0.05) Amendment	0.113		0.01		0.035	
CD (0.05) Interaction	NS		NS		0.069	

Table 25. Secondary nutrient content in index leaf of coconut palm

Locations	Ca		Mg	
	%			
	NA	A	NA	A
Muthalamada	0.647	0.585	0.368	0.410
Vadavannur	0.511	0.704	0.379	0.410
Thathamangalam	0.638	0.614	0.394	0.417
Mullakkalkolambu	0.621	0.590	0.414	0.447
Mean	0.604	0.623	0.389	0.421
Std. deviation	0.090	0.070	0.050	0.060
t value	2.94**		1.33 (NS)	

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Table 26. Silicon and sodium content in index leaf of coconut palm

Locations	Si		Na	
	%			
	NA	A	NA	A
Muthalamada	2.29	2.97	0.68	0.73
Vadavannur	1.54	2.51	0.73	0.69
Thathamangalam	2.61	2.97	0.73	0.67
Mullakkalkolambu	1.28	1.78	0.73	0.78
Mean	1.93	2.56	0.72	0.72
Std. deviation	0.72	0.72	0.07	0.06
t value	6.35**		0.35 (NS)	

Table 27. Micronutrient content in index leaf of coconut palm

Locations	Fe		Mn		Zn		Cu	
	mg kg^{-1}							
	NA	A	NA	A	NA	A	NA	A
Muthalamada	140.56	188.08	48.92	58.32	25.31	19.11	3.76	2.72
Vadavannur	168.80	192.47	37.16	68.60	20.19	20.55	2.92	2.44
Thathamangalam	219.36	173.56	77.00	104.92	24.04	33.91	4.20	3.08
Mullakkalkolambu	169.48	161.88	83.60	97.24	25.37	28.63	3.92	5.80
Mean	174.55	178.99	61.67	82.27	23.72	25.55	3.70	3.51
Std. deviation	71.96	18.91	29.58	26.43	4.25	8.24	0.81	1.35
t value	1.27 (NS)		1.54 (NS)		1.16 (NS)		0.60 (NS)	

4.6 Impact of RHA application on soil properties and coconut palm– an overview

The objectives of the present study were achieved through analyzing the physical and chemical properties of soil and crop performance. Among the soil properties those with statistically significant effect on a particular parameter were selected for getting a true picture of the effect brought about by RHA addition.

4.6.1 Physical properties

Significant increase was evident with respect to WHC, porosity, MWD and infiltration rate as regards the physical properties.

4.6.2 Chemical properties

Among the chemical parameters studied, significant positive effect was obtained with respect to total nutrients, total C, OM, available P, K and Si, exchangeable cations, ECEC and POC.

4.6.3 Biometric parameters of index leaves

The biometric parameters studied included length of index leaf, average length of leaflets, average width of leaflets and total number of leaflets. Of these, RHA addition made a significant effect on characters like total number of leaflets and their average length.

Yield attributes and average yield were prominent in the amended region due to the long term application of RHA.

4.6.4 Nutrient content of index leaf

The 14^{th} frond of coconut, considered as index leaf in the present study was subjected to chemical analysis for assaying the content of N, P, K, Ca, Mg, Si and micronutrients. In all the four locations selected for assessing the impact of RHA, a significant difference on leaf nutrient content was noticed only in the case of N, P, K, Ca and Si.

Discussion

5. DISCUSSION

The results obtained from the project entitled “Effect of continuous application of rice husk ash (RHA) on Inceptisols of Palakkad Eastern plains” are discussed in this chapter with suitable illustrations in the light of related literature.

Representative soil samples collected from four locations of two categories (RHA amended and non- amended) *viz;* Vadavannur, Muthalamada, Thathamangalam and Mullakkalkolambu, were analyzed to study the physico- chemical properties.

5.1 Composition of RHA

The most important character of an amendment is its pH. In this study, pH of the amendment, RHA, in RHA water (1:10) suspension varied from 7.5 to 8.3 (Table 8 and Fig. 2). The destruction of cellulose and hemicellulose present in rice husk takes place at 300-350°C to produce organic acids and phenolic substances. After 350°C, alkali salts separates from those organic matrixes which in turn increase the pH of the burnt product (Abe, 1988). Thus, it is evident that the RHA would have an alkaline pH and its application will increase the pH of the soil and also reduce the soil acidity. This may be the probable reason for the alkaline nature of RHA obtained in this investigation. Similar results were also reported by Bhadoria *et al.* (2007); Njoku and Mbah (2012); Theeba *et al.* (2012) and Islabao *et al.* (2014) from their work on RHA.

An EC of 0.2-1.4 d S m^{-1}, moisture content of 10-15 per cent and a CEC ranging from 7.5 to 9.5 cmol (p^{+}) Kg^{-1} were the other chemical properties possessed by RHA. The RHA used as an amendment in the experimental region had a relatively good CEC which in turn can contribute to more nutrient adsorption. The high value of CEC may be due to the increased surface area and sorption capacity of RHA (Theeba *et al.*, 2012). Similar CEC value for RHA has also been reported by many researchers (Masulili *et al.* (2010); Njoku and Mbah (2012); Theeba *et al.* (2012) and Aziz *et al.* (2015)).

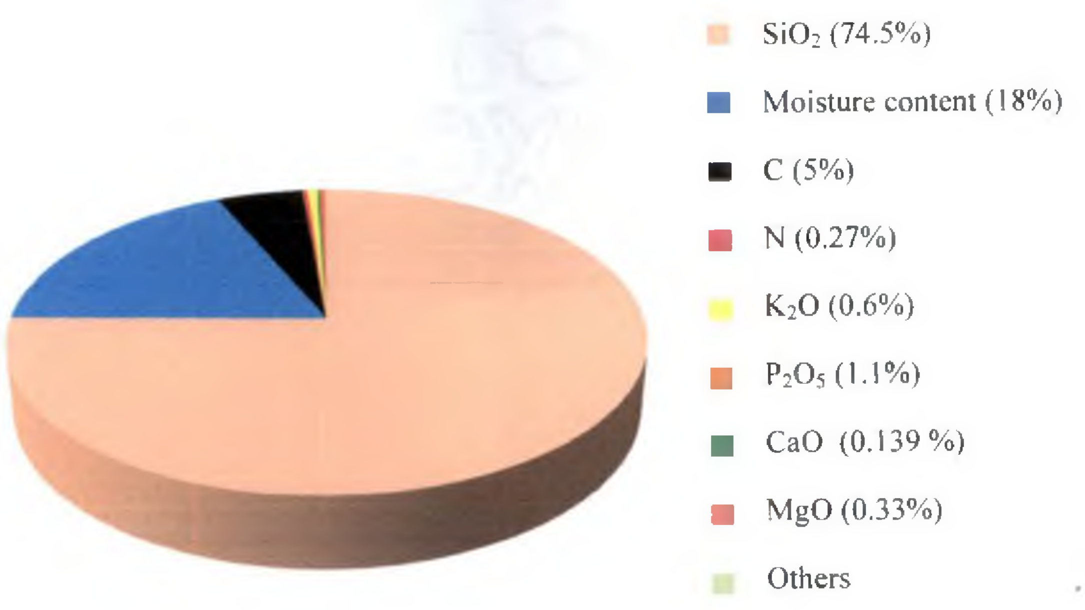

Fig. 2. Composition of RHA (%)

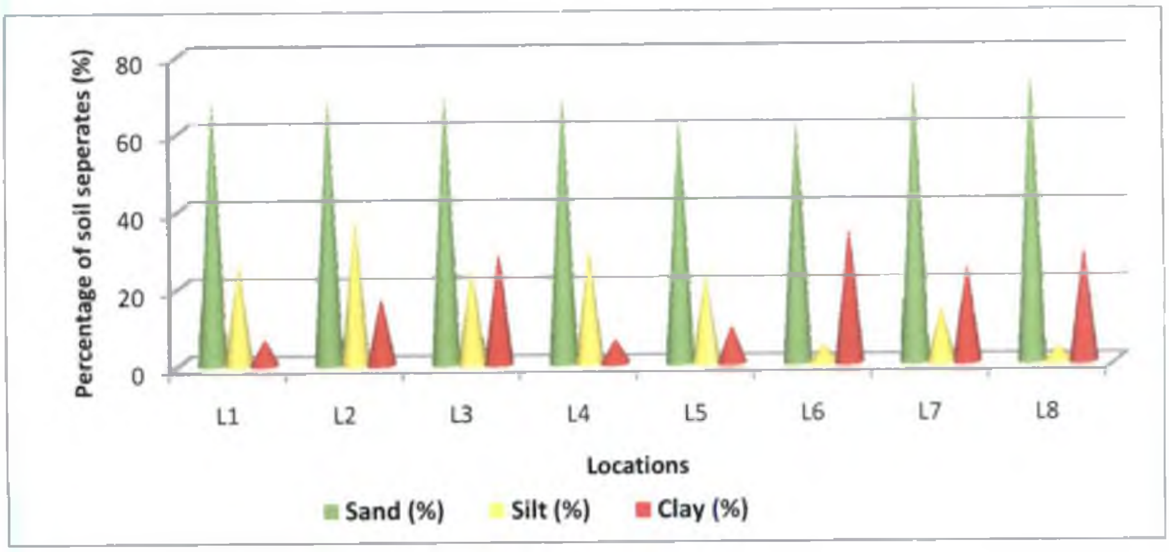

Fig.3. Mechanical composition of soil

L1 : Muthalamada non- amended
L2 : Vadavannur non-amended
L3 : Thathamangalam non-amended
L4 : Mullakkalkolambu non- amended
L5 : Muthalamada amended
L6 : Vadavannur amended
L7 : Thathamangalam amended
L8 : Mullakkalkolambu amended

The elemental composition of RHA in this inquiry was recorded as total carbon (2.0-7.0%), N (0.18- 0.27%), P (0.39 -0.57%), K (0.35-0.58%), Ca (0.08-0.1%), Mg (0.09-0.2%) and Si (18.75-35%) respectively. The carbon conversion was incomplete at temperature greater than 900°C whereas, it was complete under lower temperatures. The unconverted C found in the ash was in strong and stable carbon-silica bonds (Anuradha *et al.*, 1992) which do not become oxidized even under temperature more than 1000°C. This could be the reason for the high content of C in RHA. These results are in conformity with reports of Nnabude and Mbagwu (2001); Nottidge *et al.* (2009); Masulili *et al.* (2010) and Utami *et al.* (2012).

The elemental composition of RHA disclosed carbon and silicon as the major constituents. The content of other elements was very less. Rice is one of the silicon accumulating plant and no other plant part except rice husk is capable of retaining such a huge proportion of silica. The high content of silica in rice husk ash is the reason for high amount of silicon in RHA (Bui *et al.* (2005); Hawa and Tonnayopas (2013) and Abukari (2014)). In addition to this, carbon-silica bonds in burnt products also can increase the silicon content of RHA. The material possessed a C/N ratio of 21:1 thus enabling rapid decomposition and nutrient release. The micronutrient status was Fe (500-1600 mg kg^{-1}), Mn (180-320 mg kg^{-1}), Cu (3-5 mg kg^{-1}) and Zn (10.0-12.0 mg kg^{-1}), which is in agreement with the finding of Islabao *et al.* (2016).

The bulk density of RHA used in this experiment, ranged from 0.24 to 0.94 g cm^{-3} which endorses the findings of Masulili *et al.*(2010) (1.15 Mg m^{-3}) and Haefele *et al.*, (2009) (0.15 g cm^{-3}). The fineness and light weight nature of RHA after burning of rice husk may be the reason for its lower bulk density.

The values for heavy metals *viz;* Hg, Cd, Pb, Cr, Ni, Co and As tested remained below the detectable limit and this makes it a safer material for field use as per FCO specification for organic manures (FCO, 1985).

5.2. Physical properties of soil

The physical properties studied include soil texture, infiltration rate, aggregate stability, consistency, bulk density, porosity and water holding capacity. Results obtained under different physical parameters are interpreted with supporting evidences.

It is the soil texture, an important basic character of the soil, which partly determines water absorption, water storage, ease of tillage operations and rate of aeration in soil (Das, 2012). The texture of the different locations experimented belonged to three classes *viz;* sandy clay loam, sandy loam and loamy sand (Fig. 3). The textural difference observed in different locations in this investigation may be due to the heterogeneous nature of soil system, tropical climate coupled with high rainfall and temperature (Antony, 1982). This is quite expected as textural classes of soil are not subjected to easy modification in the field. The textural class influences the total pore space and distribution of macro and micro pores in soil and which in turn the soils' hydrological properties (Saha and Saha, 2012). Addition of RHA did not have any influence on modifying soil texture.

Infiltration rate is always recorded as a function of time. According to the infiltration rating outlined by Bouwer (1986) and adopted in this study, the amended soils showed 'slow' rate of infiltration in sandy clay loam and 'moderately slow' rate in sandy loam soils (Table 13 and Fig. 4). Non-amended soils of Mullakkalkolambu followed rapid infiltration rate because of its loamy sand texture. The higher porosity and low bulk density helped water to enter soil easily. In amended locations, infiltration rate showed a significant positive correlation with porosity (0.493*) and WHC (0.75**). Infiltration rate depends on texture, organic matter and moisture content in soil (Nnabude and Mbagwu, 1999). The increase in infiltration rate as a result of organic waste addition is dependent on factors like organic matter status (Foth, 1978), improved granulation (Anjaiah *et al.*, 1987) and pore space (Prove *et al*, 1990). High water holding capacity of RHA would have helped for improvement of infiltration rate in sandy soils. Rice husk ash amended locations also revealed significant correlation between infiltration rate and percentage aggregate stability (0.728**). The improvement in infiltration rate when aggregate stability is improved agrees with the findings of Benoit *et al.* (1962).

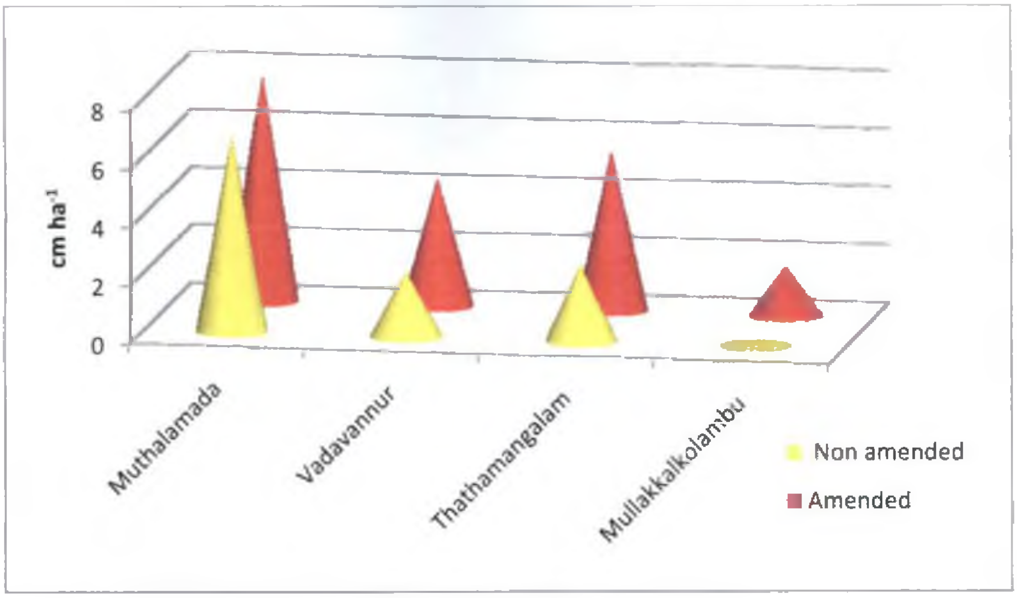

Fig. 4. Infiltration rate of amended and non-amended soil

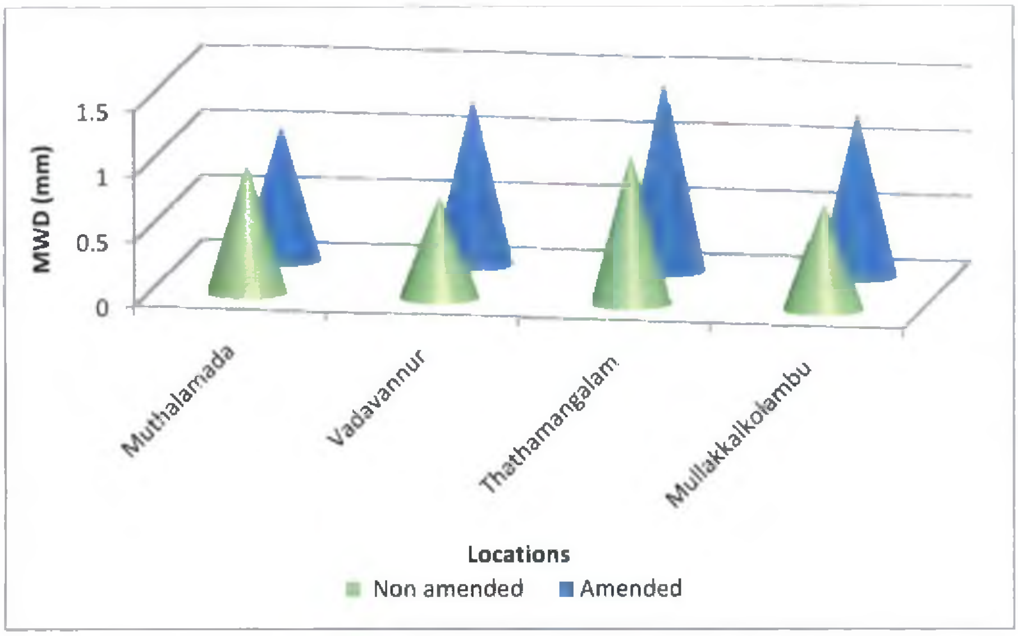

Fig. 5. Mean weight diameter of amended and non-amended soils

Soil aggregate formation and stability plays an important role in crop production. Degradation of soil can be reduced to a greater extent with good aggregation. From the Table 11, it is clear that the percentage of aggregates has increased based on sieve size in the diameter range of > 2 mm and < 0.15 mm with addition of RHA. This may be due to the formation of macro-aggregates by the coalition of micro-aggregates in soil. Application of organic wastes like RHA in large quantities can make beneficial impacts on stability of micro-aggregates (Glauser *et al.*, 1988). Greater amounts of stable aggregates suggest better soil quality. When the proportion of large to small aggregates increases, soil quality generally increases.

Mean weight diameter and structural coefficients are considered as indices of soil aggregates. On the basis of data obtained from Table 12 and Fig. 5, the highest range of MWD recorded from the amended locations (Vadavannur) under sandy clay loam textural class ranged from 1.0- 1.64 mm. The higher aggregation stability is due to the high amount of clay content in the sandy clay loam (20-35 %) than loamy sand (5-10%). Moreover the high amount of organic matter that acts as cementing agent for aggregation. Clay is the most important granulometric fraction for soil aggregation (Brady and Weil, 2008). Aggregate stability is mainly brought about by the interaction between organic matter and soil clay resulting in the formation of stable aggregates.

Favorable influence of organic matter on soil aggregation has been remarked by several scientists (Biswas *et al.*, 1971 and Patnaik *et al.*, 1989). The polysaccharide, one of the components of organic matter, is also positively correlated with aggregate stability (Acton *et al.*, 1963 and Mehta *et al.*, 1960).

Liquid limit has a significant role in increasing plasticity index. Hemmet *et al.* (2010) and Smith *et al.* (1985) suggested that an increase in specific surface area and activity of the amendment leads to an increase in liquid limit and plasticity index values of soil. However clay content is the most responsible factor for soil plasticity. According to the description of plasticity index given by Burmister (1949), the experimental soil comes under 'medium plasticity' in terms of plasticity index. The 'low plasticity' of loamy sands is due to the low content of clay particles in the soil.

It could be seen that the amended locations accounted low bulk density and high percentage of WHC and porosity (Fig. 6). On comparing with a mineral soil, RHA has much lower (0.24 g cm^{-3}, Table 8) bulk density. Its addition to the soil can reduce the overall bulk density of soil which will increase the porosity. Porespace is essential for air and water entry into soil, and for air, water, nutrient, and biota movement within soil. The property of RHA to improve the soil pore space and aeration is evident from the reduced bulk density. In RHA amended regions WHC exhibited a positive correlation with porosity (0.436 at 5.5 % level of significance). The higher water holding capacity of RHA also would help in more absorption and retention of water. This also confirms the improvement of bulk density, porosity and water holding capacity of soil in RHA amended area.

Organic matter addition increases WHC which is mainly due to increase in porosity (Brady, 1990). In the present investigation, a higher value for WHC was noticed in the amended region which is in agreement with the findings of Sharma and Uehara (1968) they ascribed it to the increase in number of micro pores by applying the organic matter in the soil system, which reinforces the higher porosity values of the soil. Organic matter plays an important role in soil, because of its higher CEC and water holding capacity as well as its chelation ability and influence on soil stability. It improves soil structure, aeration and aggregation (Sparks, 1995).

In short it can be stated that stable aggregates help to increase pore space, including small pores within and the large pores between aggregates. The large pores associated with large and stable aggregates in turn favor high infiltration rates and appropriate aeration required for plant growth.

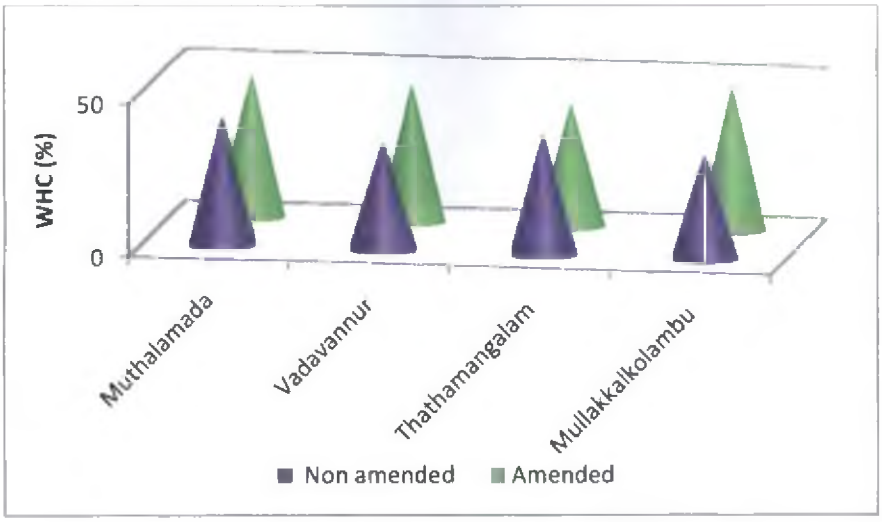

Fig. 6. Water holding capacity of amended and non-amended soils

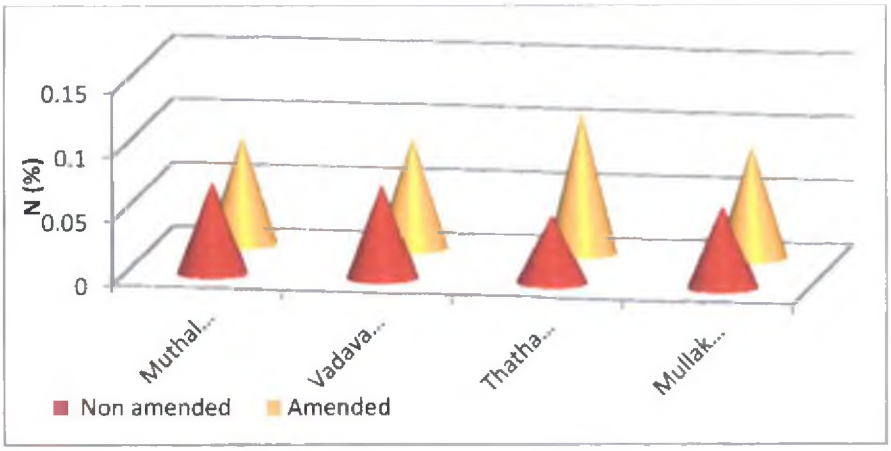

Fig. 7. Nitrogen content in soils of amended and non- amended locations

5.3 Chemical properties of soil

5.3.1 Electrochemical properties

The observed pH in the soil water (1:2.5) suspension ranged from 5.61 to 7.96. The change in soil pH due to the application of RHA was not significant (Table 15) even though, the material RHA tested neutral to alkaline in reaction (7.5-8.3). From various literature (Masulili *et al.*, 2010; Njoku and Mbah, 2012; Theeba *et al.*, 2012; Njoku *et al.*, 2015; Ogbe *et al.*, 2015 and Islabao *et al.*, 2016), it could be inferred that RHA can be used for reducing soil acidity much similar to any other liming material because of its alkaline reaction. Soil pH affects the availability of all nutrients in one way or another. Therefore, maintaining pH close to the ideal level 6.0 to 7.5 for most plants is important. The experimental regions were neutral to alkaline in pH and hence effect of RHA on soil reaction was not notable. However two locations (Muthalamada and Vadavannur) showed increase in its value, this increase is not considered harmful to soil quality because they remained close to neutrality. Lower soil pH in amended areas of Thathamangalam and Mullakkalkolambu regions may be related to the after effect of fertilizer application in that area.

Electrical conductivity indicates indirectly the total concentration of soluble salts and is a direct measure of salinity. Electrical conductivity showed an increasing trend with the application of RHA and maintained a positive correlation with soil pH (0.587**) in amended locations. This may be the reason for low EC values of the experimental area where pH remained in the acidic range. Higher EC values of RHA amended soil could be due to the presence of relatively higher amount of water soluble ions *viz.* K^+ and Na^+ and the high electrical conductivity value of the RHA (0.2-1.4 dS m^{-1}). The result is in accordance with the view of Gonzalez *et al.* (2010) who stated that the EC increases in acidic as well as alkaline soils when organic materials of different nature were applied.

5.3.2 Primary nutrients

The percentage of total N, P, K and C showed an increase in their content in RHA amended locations. The total N and K content ranged from 0.82 to 0.11 per cent and 0.09 to 0.17 per cent in amended locations respectively (Figures 7-9). In non-amended areas, the values ranged from 0.052 to 0.070 per cent for N and 0.05 to 0.10 per cent for K. This can assigned to the continuous application of nutrient rich, especially carbon rich, RHA material to the soil for a long period of time.

Similar results have also been reported from several studies (Duggan and Wiles (1976); Nnabude and Mbagwu (2001) and Ogbe *et al.* (2015)) on this subject. Increasing the dose of rice husk charcoal or waste can increase the soil C and N on all experiments conducted to evaluate the effect of long term application. From a study on using unburnt and a mixture of unburnt and burnt rice husk on maize yield by Njoku and Mbah (2012), it was found that total N increased significantly after three years of continuous application. Remarkable amount of N is available for plant because of organic matter, favorable pH and proper moisture in soil would have contributed positively to the yield increase.

The results on organic carbon (Fig. 10) showed significant increase in the amended region. However, the content was in medium range according to the fertility rating. The inability of organic manure (RHA) to enhance organic carbon content of soil considerably in spite of its application at high dose can be ascribed to the continuous cropping and tropical condition, which mediates the high rate of decomposition (Hunt *et al.*, 2010). The influence of OM application on bettering soil organic carbon content has also been reported by Khaleel *et al.* (1981). The loamy sand textured soils showed low content of organic carbon due to the association of free and labile fraction of organic matter which is easily lost from the light textured sandy soils. Organic matter plays an important role in improving WHC and soil stability, because of its high chelating ability associated with high CEC (Sparks, 1995). Hence it is considered as a good resource of available nutrient elements.

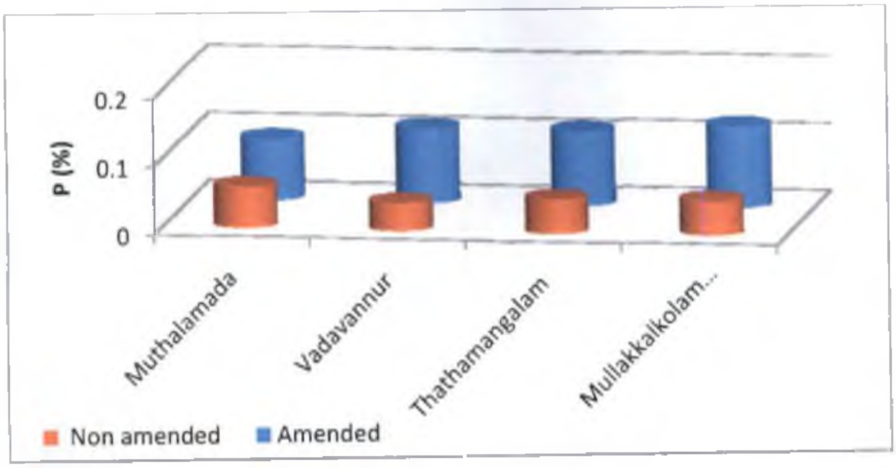

Fig. 8. Phosphorous content in soils of amended and non- amended locations

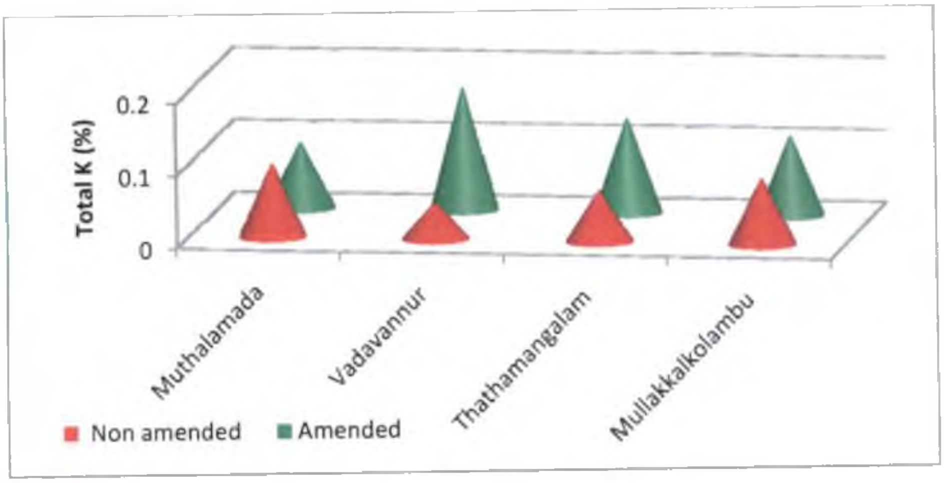

Fig. 9. Potassium content in soils amended and non- amended location

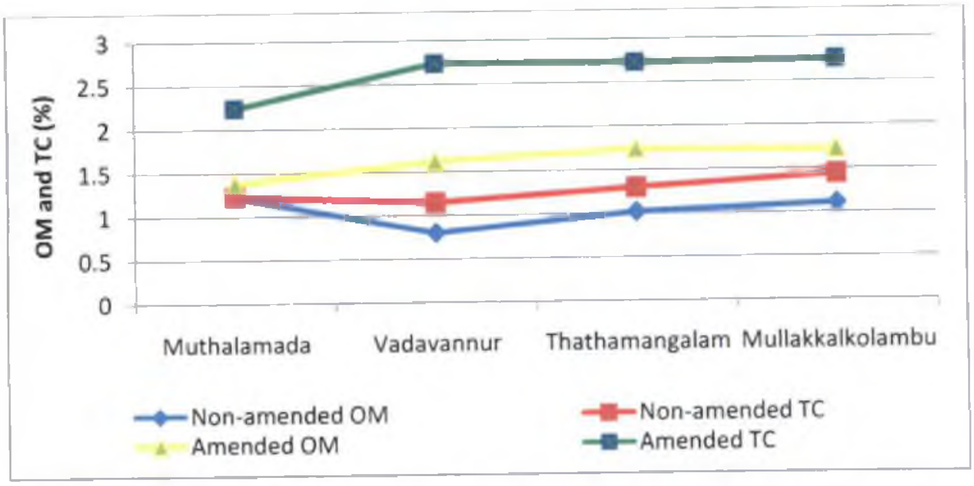

Fig. 10. Organic matter and total carbon status of amended and non-amended soils

A significant variation was obtained in the amended zones with respect to total K (Fig.9). RHA addition increased total K to the tune of 22 (Mullakkalkolambu) to 100 per cent (Vadavannur) in the four locations under consideration. The K contained in the amendment would have supplemented in increasing total K status (Mariati, 2014).

5.3.3 Available nutrients

The significant increase in available K, P and Si contents in RHA amended soils was a noticeable feature. Ozubor and Anoliefo (1999) stated that soils with low pH leads to the formation of complexes such as Al phosphates (Al_2PO_4) and Fe phosphates (Fe_2PO_4), in fixed forms thus reducing the easy availability of P to the plants. Results of present study also affirm that the nutrient availability is dependent on soil pH. As the soil pH increases, the negative charges also increases which results in the reduction of P adsorption, leading to increased availability of P. In addition to this, RHA being rich in silicon, the silicates from RHA may block the positive sites that otherwise would adsorb P thus enabling its desorption and plant use (Utami *et al.*, 2012). This phenomenon may be the expected reason behind the increased status of available P and available Si in soil on RHA addition (Fig. 12). High P in sandy soil might be due to continuous application of P fertilizers and less P fixation.

The availability of K (Fig. 11) also showed a significant increase, which could be due to the increase in pH brought about by better release and availability of all basic cations including K. The effect of pH on increasing soil K to the maximum level has also been reported by Brady and Weil (2008). Because of high amount of K in organic amendments that increases CEC, the K amount rises in soil. Masulili *et al.* (2010) also could register the high content of available K whenever fields were amended with rice husk biochar. This would be due to the high content of K in burnt (controlled) products such as RHA. The prolonged use of mineral fertilizers, manure, compost and other ameliorants increases the potassium content in the soil (Ogbe *et al.*, 2015). The increase of soil organic matter resulted in decreased K fixation and subsequent increase in K availability.

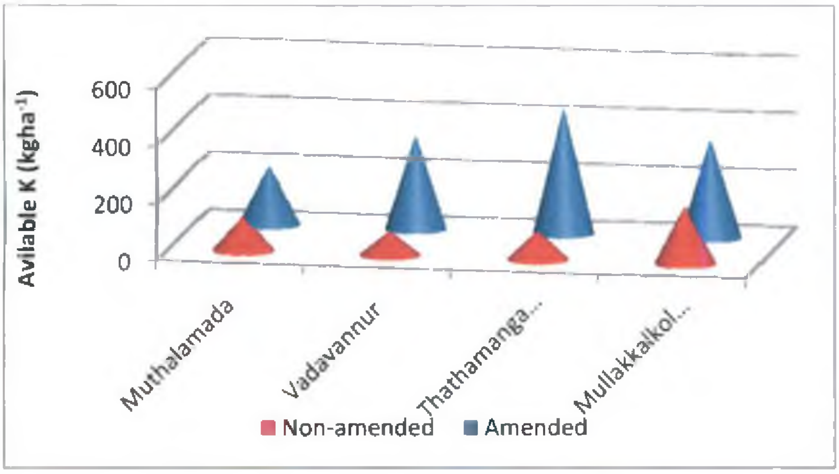

Fig. 11. Available potassium status of amended and non-amended soils

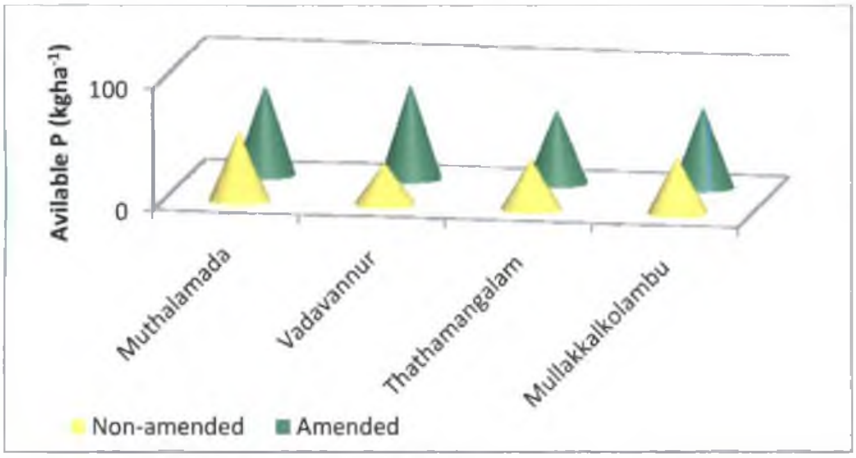

Fig. 12. Available phosphorous status of amended and non-amended soils

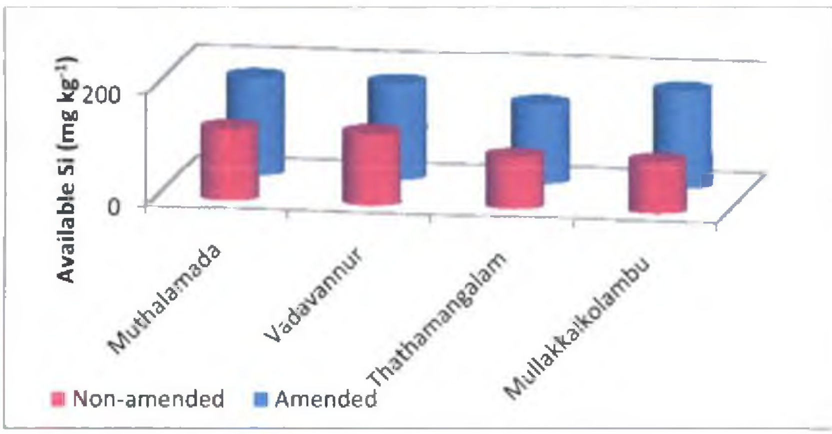

Fig. 13. Available silicon status of amended and non-amended soils

Available Si content of soil in amended area showed significant increase (Fig. 13) and it ranged from 141.5 to174.37 mg Kg^{-1} (Table 17). The high content of Si in RHA is expected to be the reason for significant increase in Si level of amended soils (Aryalekshmi, 2016). The results are in agreement with that of Nayar *et al.* (1982), who reported that the available Si in soils of Kerala ranged from 8 to 435 mg Kg^{-1}. Kim *et al.* (2010) stated that the continuous application of rice straw compost and silica fertilizers in a field for more than 56 years brought about a significant and positive impact on available Si and organic matter content. According to Phoned *et al.* (2014), available Si content increased with pH, cations, CEC and clay content.

5.3.4 Exchangeable nutrients

The influence of RHA on the soil exchangeable nutrients and ECEC are detailed in Table 18. Application of RHA increased the exchangeable bases (Ca, K and Na) and ECEC (Fig. 14). The increase in exchangeable K altered from 28 to 48 per cent among the RHA amended regions. The content of exchangeable Ca ranged from 6.9 to 8.19 cmol (+) kg^{-1} and from 4.9 to 6.77 cmol (+) kg^{-1} in amended and non-amended locations respectively. Increase in soil pH was accompanied by an increase in available Ca and the high positive correlation coefficient between exchangeable Ca and soil pH (0.439**) further confirms it.

One of the most important chemical properties of soil is its CEC that decides the interchange of a cation in soil solution phase with another adsorbed on the surface of soil clay/organic matter in equivalent proportions. This exchange of cations between solution phase and adsorbed phase is a reversible process. The net negative charge of the exchange complex is neutralized by exchangeable bases (Na, K, Ca and Mg) plus exchangeable acidity (Al^{3+} and H^{+}). In soil, the cation selectivity in two opposing directions is affected by OM. Cation exchange capacity is highly dependent upon soil texture and organic matter content. It is the closely spaced carboxyl and phenolic groups present in organic matter that cause an increase in specific surface area of soil and the resultant selectivity towards multivalent cations. Whenever the organic matter in soil increases the corresponding increase in internal: external surface area/ exchange site happen (ISSS, 2012). The increase in CEC of soil with organic matter application due to the negative charges produced from the carboxyl groups of organic matters has also been reported by Masulili *et al.* (2010).

The ECEC, the sum of bases and exchangeable acidity is thought to represent the soil's cation exchange capacity at field conditions. Effective cation exchange capacity values reflect conditions at the prevailing soil pH and can be manipulated by adding lime to the soil. As the pH increases, hydrogen dissociates, leaving an available negative exchange site. Thus the hydrogen is replaced by metallic cations, which in turn become exchangeable. Addition of RHA helps in pH increase which would in turn increase the exchange capacity of soil.

The results of the present experiment is in line with the observations of Njoku and Mbah (2012), who promulgated the increased concentration of exchangeable bases (K, Ca and Mg) on addition of burnt rice husk on soil physico-chemical properties and maize yield in the Ultisols of Nigeria. The chemistry stated for this positive effect was related to the organic matter content which tended to buffer the soils, leading to the release of exchangeable nutrients, especially cations and a higher ECEC value brought about by the organic matter mineralization. Both clay particle and organic matter have negatively charged sites that attract and hold positively charged cations. The view of Sharma *et al.* (1988) also supports this result. Such an increased CEC of soil was obtained in their experiment conducted with rice crop under prolonged application of FYM.

Influence of RHA on micronutrient status has been given in Table 19 and 20. The significance of micronutrients in crop growth and production is much alike the major nutrients, the difference only in the quantity required. An irregularity in micronutrient status in both categories of soils was a noticeable feature of the present investigation. Nutrient solubility and availability is regulated by soil pH and micronutrients are not an exception (ISSS, 2012). A highly acidic soil reaction increases the concentration of all micronutrients in soil solution. The high content of Fe and Mn in amended areas may be due to the high amount of sesquioxides present in the soil which on hydrolysis produces hydrogen ions leading to a reduction in soil pH. Presence of oxides and hydroxides of iron

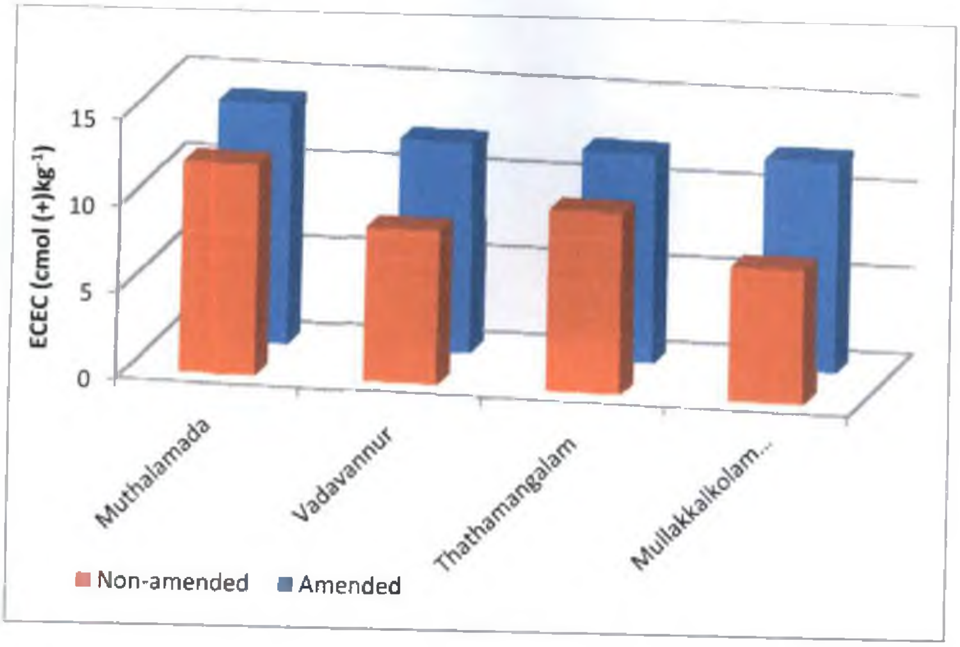

Fig.14. Effective cation exchange capacity of amended and non-amended soils

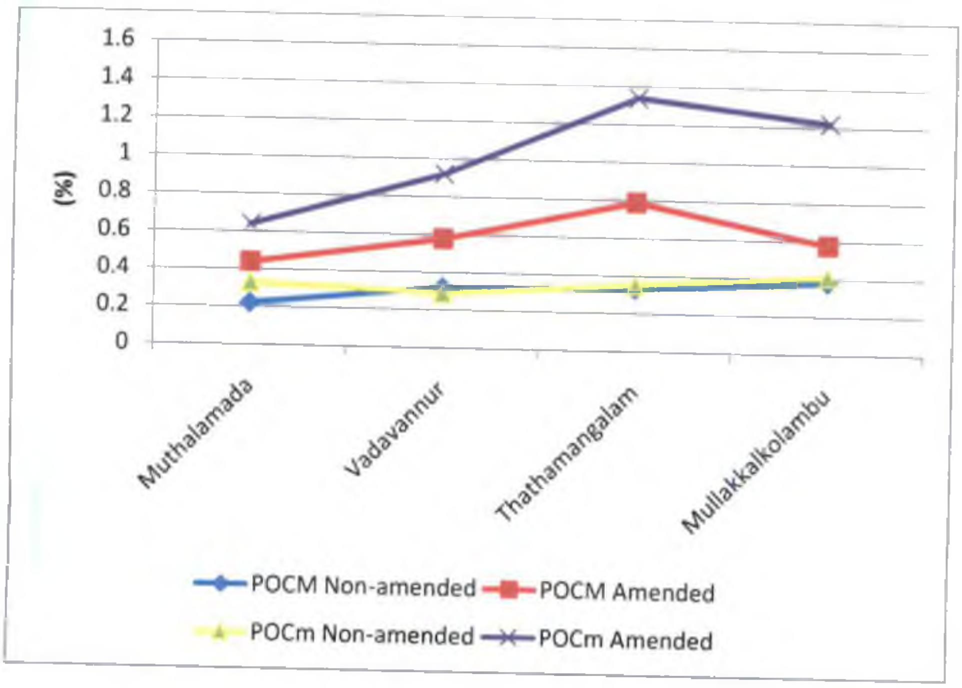

Fig. 15. Macro and micro aggregate associated POC status of amended and non-amended soils

and leaching of basic cations from the surface layers of the soils due to heavy rainfall may be the reason for high available iron content obtained in Thathamangalam and Mullakkalkolambu regions.

The soil pH is the most important factor controlling Zn availability, which decreases with the increase of the pH. Zinc can form insoluble compounds - precipitates during the mineralization of organic ameliorants and insoluble compounds in the form of $ZnCO_3$ in calcareous soils (Walker *et al.*, 2003). This may be the reason for the reduced content of Zn obtained in the RHA amended and non-amended soils.

Organic supplements lead to lower content of DTPA extractable Cu. The reduction of Cu content is due to the transformation of organic matter in a stable form that could link more Cu. The complex formation of Cu with organic matter may be the expected reason for lesser values on available Cu in RHA amended regions. In addition, the amendment itself would have released micronutrients on getting decomposed. Whenever the pH is more than seven they get precipitated as their hydroxides which are insoluble.

Humic acids from organic amendments tend to form complexes that are different for each metal and this complex formation is dependent on soil conditions such as pH, cation exchange capacity and clay mineral fraction.

5.4 Particulate organic carbon

The POC_M and POC $_m$ showed an increase in their value on adding RHA continuously for several years. The percentage of POC_M was low compared to the POC_m in all the locations (Table 21 and Figure 15). This result is strongly supported by Gupta *et al.* (1994), from their works on carbon and nitrogen mineralization as influenced by long-term soil and crop residue management systems in Australia where the particulate organic matter carbon was in the range of 2.8-5.1 g kg^{-1}.

Particulate organic matter improves the soil aggregation and forms organic core surrounded by mineral particles and aggregates. The micro- aggregates are highly stable than macro-aggregates. Soil structure models revealed that the macro-aggregates are composed of an assemblage of micro-aggregates (Tisdall and Oades, 1982).

The POC associated with micro and macro aggregates is more available to the microbes as a driving force, being in a semi-decomposed form. In this context, it is imperative to have information, expressed in percentage, on the ratio of POC_M and POC_m to total carbon (TC). The ratio of POC_M/TC ranged from 17.88 to 27.82 and from 19.64 to 28.93 in non-amended and amended regions respectively in the present study. In the case of POC_m/TC ratio, it varied from 25.2 to 28.7 (non-amended) and from 28.5 to 49.1 (amended). These results are in conformity with that of Bongiovanni and Lobartini (2006) who stated that the micro-aggregates were dominant over the macro-aggregates in peanut cultivated soils of Argentina and in governing the microbial activity especially that of nitrogen fixers. Another reason for the increased POC_m may be the destruction of macro-aggregates by cultivation which resulted in the rapid decomposition of organic matter thereby exposing the POC, the inner organic core, to rapid attack by micro organisms. The mechanical forces like ploughing and tillage can destruct the organic core, which results in exposure of organic substances (Six *et al.*, 2000) and their rapid oxidation and decomposition (Elliott, 1986).

5.5. Plant analysis

The phenotypically uniform palms were selected from RHA amended and non-amended locations for plant analysis. The management practices adopted were quite different based on locations. The palms from the amended area were under an integrated nutrient management practices (inorganic nutrient + RHA) whereas, the non-amended palm were under inorganic nutrient application alone. The source of inorganic nutrients was also different. The index leaves (14^{th} leaf) were collected from palms grown in both the regions for nutrient analysis.

Coconut is highly an exhaustive palm. The nutritional balance is essential to obtain higher and sustainable yield. In terms of leaf content of mineral nutrients, the results indicated that the amount of N, P, K, Ca and Si showed significant increase in RHA amended palms. Locational effect was significant only in the case of K.

The N content varied from 1.67 to 2.01 per cent and 1.76 to 2.43 per cent in non-amended and amended regions respectively (Fig. 16). Leaf N is strongly affected by soil N. The higher leaf content of N is may be due to the higher absorption of N from the soil. Data on the present study showed an increase in N content to the tune of 20 per cent in amended palm together with a positive effect on yield. This result is in accordance with that of Ollangnier *et al*, (1970) who reported a five per cent yield increase due to increase in leaf N concentration from 2.3 – 2.7 per cent. The NPK content in coconut was higher with integration of composted coir pith and inorganic manures or neem cake -bone meal- ash combination (Basavaraju and Hanumanthappa, 2010).

The leaf P also showed significant increase and the values were higher than critical levels prescribed by Fremond *et al.* (1966) in amended and non-amended palms. Increasing N-P-K rates on coconut were tested, with no yield response to the P increase (Sobral and Leal, 2005) showed the low requirement of P for coconuts. Eden *et al.* (1963) also reported the low requirement of P for coconut.

The highest (0.85-0.89 %) value of K was recorded from the palms amended with RHA (Figure 17) which shows exhaustive consumption of this nutrient. Potassium is one of the most important nutrients required by coconut palm. A positive correlation of K with yield (0.391*) was obtained which fully agrees with the findings of Gopi (1981) who opined that the number leaf retained by the palm was mainly a function of potassium applied and it was also significantly correlated with the yield. The direct influence of K on yield has also been reported by Indirakutty and Pandalai (1968). The presence of K increases the resistance of palm to certain pests and diseases, regulates water economy thus enabling the palm to withstand drought and improves all the nut characteristics by 14 per cent including quality and quantity of copra (Mandal, 2010).

In case of secondary nutrient Mg, no significant variation among the RHA amended and non-amended palms was noticed and this may be due to the high content of K

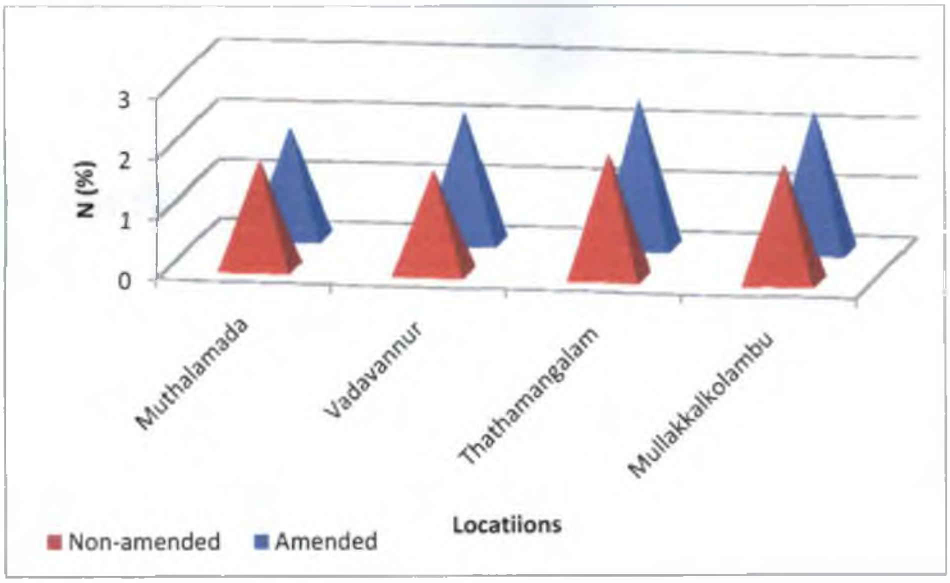

Fig.16. Nitrogen content in index leaf of coconut palms

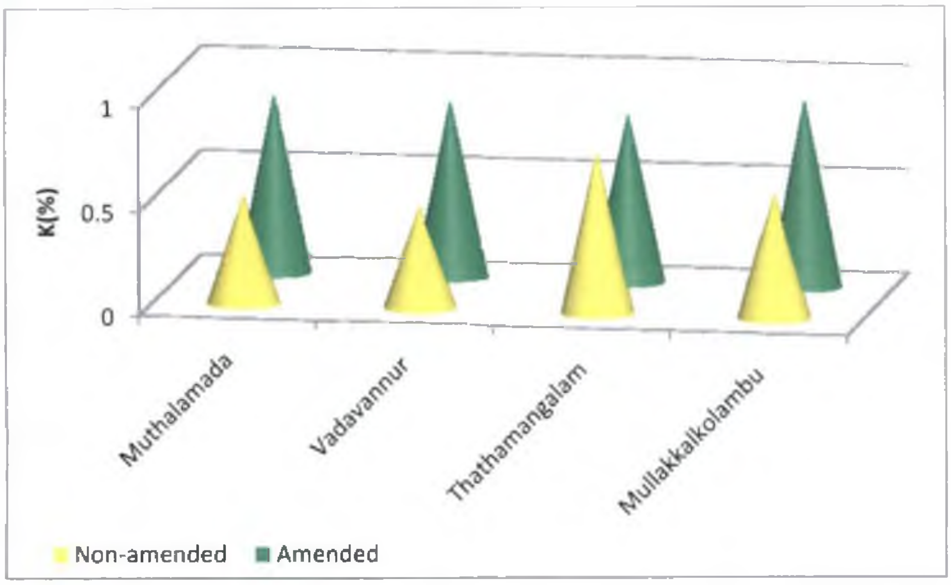

Fig.17. Potassium content in index leaf of coconut palms

in leaves, which hinders with absorption of Mg by palms (Mandal, 2010). Such an antagonism between K and Mg has been well established by many (Joseph, 1993 and Priya 2003)

The content of micronutrients in non-amended and amended palms was in sufficient range in all the locations. A dilution effect in leaf concentration of Fe, Zn, Mn, and Cu due to the greater vegetative growth of the plants under higher N and K concentration has been reported by Maheswarappa *et al.* (2014). Micronutrient content in index leaves of amended and non-amended palms was not significantly different but they were above the critical levels in both categories. The decomposition of organic manure improves the chemical fertility of soil thereby increasing the available status of plant nutrients in soil and in plants as well.

The silicon, a beneficial element for crops like rice and sugarcane, showed a high content in palms grown in amended regions in all the locations covered. The value ranged from 1.78 to 2.97 per cent in the amended region and from 1.28-2.61 per cent in non-amended tracts (Fig. 18). This may be due to the high content of Si that reached the respective soils from the amendment RHA containing 35 per cent silicon on an average. The beneficial effect of silicon to coconut has not been reported as for rice where it is found to impart resistance against major diseases and pests. Silicon exerts alleviate effects on various abiotic stress including salt stress, metal toxicity, drought stress, radiation damage, nutrient imbalance, high temperature so on. These effects are mainly attributed to the high accumulation of silica on the tissue surface (Ma and Yamaji, 2006). The correlation between yield and silicon content was negative which further reinstates its negative role in this perennial crop.

5.6. Biometric parameters of index leaf of coconut

Data on yield attributes and the biometric observations of index leaves (Table 23) showed that all parameters *viz*; total number of leaflets, average length of index leaves, nuts per palm and average yield of palms significantly increased wherever RHA was used as an organic amendment.

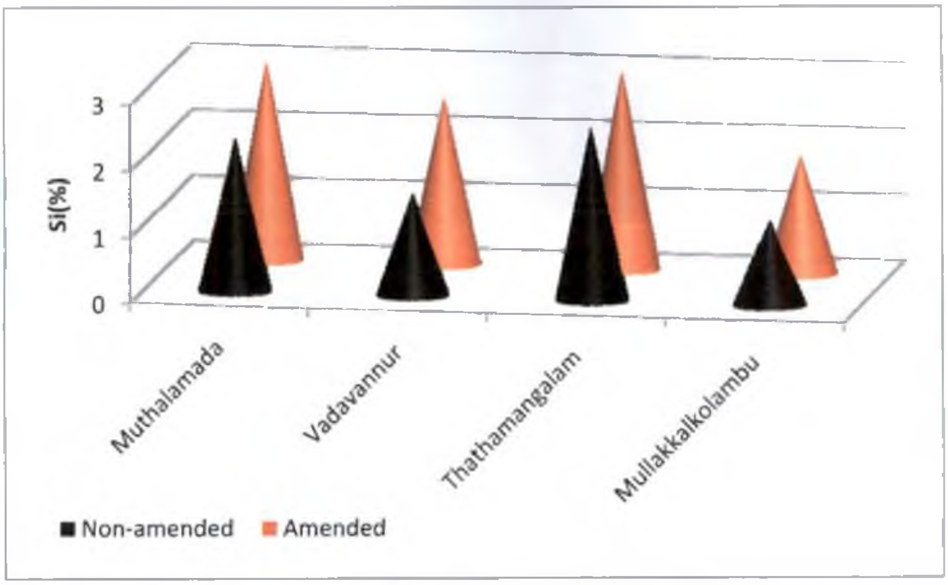

Fig. 18. Silicon content in index leaf of coconut palms

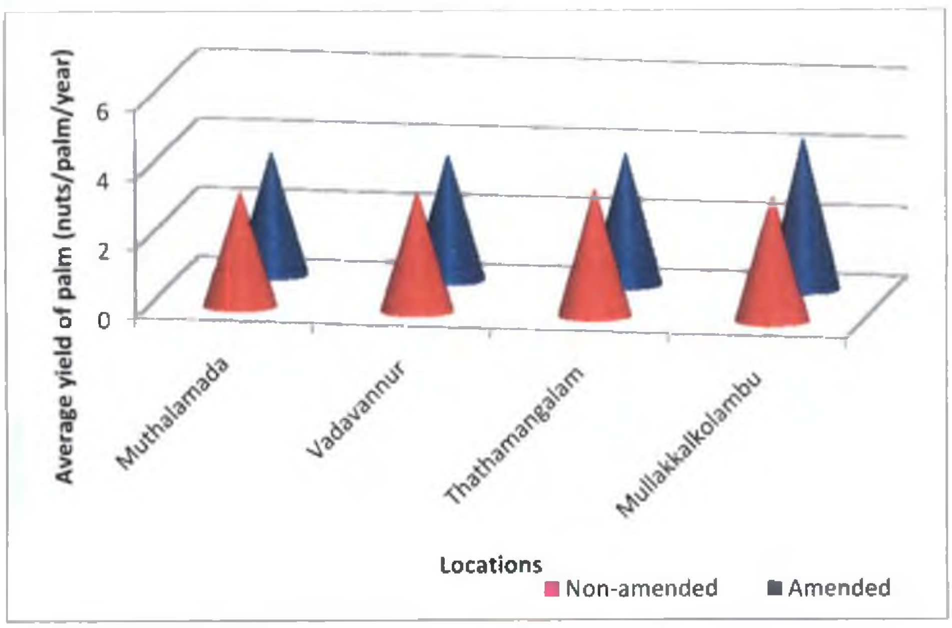

Fig. 19. Average yield of content palms in amended and non-amended fields

Mandal (2010) emphasised that the status of the primary nutrient (N and K) in a particular ratio is very important in determing the number of bunches and number of female flowers per bunch.

In this study all the yield attributes were positively influenced by applying RHA. The average yield of the palm grown in amended area ranged from 74.5 to 95.7 nuts/palm/year whereas in the non- amended zones it was from 55.5 to 85.7 nuts/palm/year. On comparing the different locations, much difference was noticed in both the categories. Increase in growth and yield of coconut palm in the RHA amended fields was a general remark of the farmers who have been using RHA for a long period of time. The healthy status of the palm in the amended region was prominent on general observation.

Increase in yield under amended fields in all the four locations might be due to better availability of essential nutrients and its uptake by palms (Fig. 19). Srinivasa -Reddy and Upadhyay (2002), Talashilkar *et al.* (2008) and Nath *et al.* (2012) stated an increase in yield of coconut consequent to integration of organic and inorganic fertilizers in different soil types. Similar results were also reported with the use of FYM (Marimuthu *et al*, 2001) and coir pith compost (Venkitaswamy, 2003) integrated with fertilizers for higher nut yield in coconut. Basavaraju and Hanumanthappa (2010) reported that application of neem cake -bone meal- ash combination produced higher coconut yield which was on par with the chemical fertilizers. Theeba *et al.*, (2012) related the higher yield obtained by addition of RHA to the improved nutrient use efficiency brought about by reducing nutrient losses through leaching.

An overview of the present study is conducted to gather information on the impulse of RHA as an amendment on physical and electro-chemical properties of soil and crop performance (Figures 20 & 21). In general, significant difference could be noticed only with respect to few parameters as regards soil properties and crop performance as well. Though the experimental area was under continuous usage of RHA for nearly three decades, the current investigation was only for a short span from 2015 August to 2016

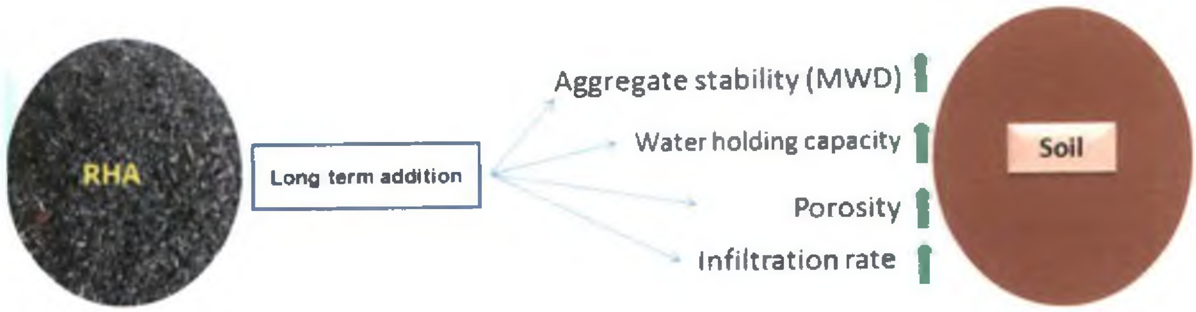

Fig. 20. Long term impact of RHA on physical properties of soil

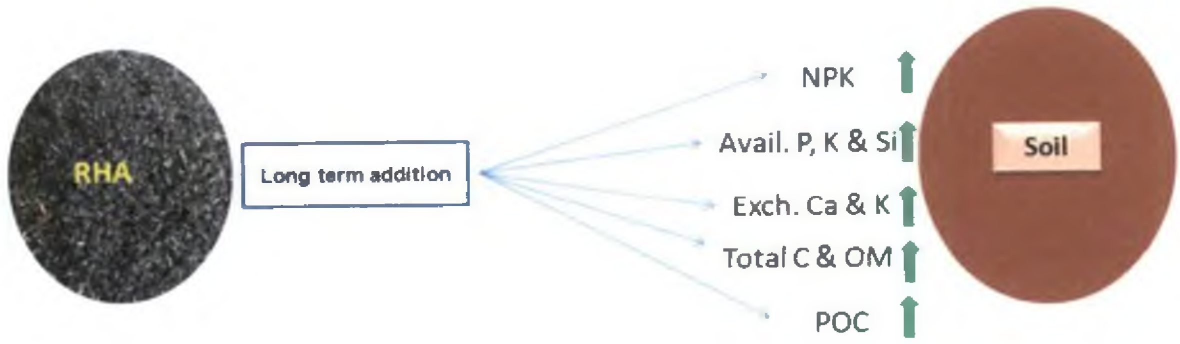

Fig. 21. Long term impact of RHA on chemical properties of soil

March. The farmers of Vadavannur region resorted to RHA application only with an objective to address the issue of environmental nuisance and menace, without attributing any scientific rationale on its value as a soil amendment. The results of the present study indicate the benefit of application of RHA in improving the physical and chemical properties of soil. The alkaline pH of RHA establishes its suitability as an alternative liming material for acid soils to improve the soil fertility and productivity. It is suggested that further studies conducted under designed experimental stipulations for validation of RHA would decipher more precise information on its suitability as a balanced material for soil amendment.

Summary

6. SUMMARY

The investigation entitled "Effect of continuous application of rice husk ash (RHA) on Inceptisols of Palakkad Eastern plains" was conducted in the Department of Soil Science and Agricultural Chemistry, College of Horticulture, Kerala Agricultural University during 2014 -2016. The present study was undertaken to find out the physico - chemical changes of soil due to the continuous application of Rice Husk Ash (RHA) and its relation with performance of coconut palms. Representative soil samples collected from four locations (Vadavannur, Muthalamada, Thathamangalam and Mullakkalkolambu) of two categories (RHA amended and non- amended) were analyzed to study the physico-chemical properties of soils from the Eastern plains of Palakkad district of Kerala.

The index leaves (14^{th} frond) of coconut palms were collected from the experimental area from RHA amended and non-amended locations. Biometric characters of index leaves were also noted. Rice Husk Ash (RHA) samples were collected from *Gayathri* and *Vasantha* rice mills in Vadavannur, Palakkad where the husk generated during milling is mostly used as a fuel in the boilers for processing paddy leaving rice husk ash. These samples (soil, plant and RHA) were analyzed for estimation of different nutrients. The salient results of the present study are given below;

Rice husk ash

- The material used in this study is the product obtained on incomplete oxidation of rice husk at a temperature of more than 300^{O} C, producing a char, containing high content of carbon.
- The RHA analyzed in this study possessed a neutral to alkaline pH with an EC of 1.4 dS m^{-1}.
- The elemental composition of the amendment consisted of silicon (35%), C (7 %), N (0.27%), P (0.5%), K (0.5%), trace amount of micronutrients (Fe- 500-1600 mg

kg^{-1}; Mn 180-320 mg kg^{-1}; Zn 10-12 mg kg^{-1} and Cu 3-5 mg kg^{-1}) and 80-120 mg $kg^{-1}$of aluminium. It was free of heavy metals like Cr, As, Pb, Hg and Cd.

- It possessed a CEC of 7.5-9.5 cmol (+) kg^{-1} and contain 10-15 per cent moisture
- The bulk density of RHA was 0.65 Mg m^{-3}.
- The C/N ratio of the RHA was 21:1.

Soil

- The long term application of RHA improved soil physical properties like aggregate stability, infiltration rate, WHC and porosity.
- Addition of RHA enhanced infiltration in sandy loam soils of Muthalamada to the extent of 15.9 per cent while it was up to 97.7 per cent in the sandy clay loam soils of Vadavannur area.
- Significant correlation existed between infiltration rate and WHC (0.75**) and also between percentage aggregate stability and WHC (0.758**).
- There was significant increase in total NPK, available P, K, and Si on addition of RHA in all the four locations experimented.
- The exchangeable cations (K, Ca and Mg) and ECEC showed an improvement in the amended regions.
- The micronutrients *viz*; Fe, Mn, Zn and Cu were in the sufficient range in the amended as well as non-amended regions.
- The locations amended with RHA showed significant increase in total carbon and particulate organic carbon, especially which associated with micro-aggregates.

Coconut palm

- There was much difference in the biometric parameters evaluated. Significantly higher yield was recorded in all four locations amended with RHA.
- A significant increase was observed in the content of N, K, Ca and Si in the index leaves of palms from amended area.
- The leaf N was positively correlated with available K in soil (0.769**).

- Leaf P content showed a significantly higher correlation with total soil P (0.622**), available soil K (0.504*) and plant content of N (0.483*).
- Silicon content of leaf was significantly correlated with total soil K (0.61**), available soil Mg (0.859**) and leaf Ca (0.612**).
- Among the nutrients studied, a significant positive correlation with yield was obtained only in case of K content of index leaf (0.391*).
- The high surface area and increased carbon content of RHA alleviated retention of nutrients by reducing leaching loss, which in fact is one of the major mechanisms for reducing nutrient use efficiency.
- An integration of organic RHA with chemical fertilizers would certainly enable soil fertility improvement and sustained productivity of crops.

Future line of work

- Validation of RHA in coconut palms under specific soil conditions.
- Characterizing the biological properties of soil under RHA application for studying its impact on soil biota.
- Evaluating the role of RHA in sequestering carbon.
- Investigating the efficacy of RHA as an ameliorant in acid soils.

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* Originals not seen.

Appendices

Appendix 1. Correlation analysis of soil physical parameters in non-amended area

	Bulk density	Porosity	WHC	Infiltration rate	MWD	PAS	PI
Bulk density	-						
Porosity	-	-					
WHC	-	-	-				
Infiltration rate	-	-	-	-			
MWD	-	-	0.424 (0.062)	-	-		
PAS	-	0.527*	0.744**	-	-	-	
PI	0.408 (.074)	-	0.503*	-0.842**	0.751**	-	-

Appendix 2. Correlation analysis of soil physical parameters in amended area

	Bulk density	Porosity	WHC	Infiltration rate	MWD	PAS	PI
Bulk density	-						
Porosity	-	-					
WHC	-	0.436 (0.055)	-				
Infiltration rate	-	0.493*	0.750**	-			
MWD	-	-	-0.541*	-	-		
PAS	-	0.432 (0.057)	0.758**	0.728**	0.575**	-	
PI	-	-0.492*	0.433 (0.056)	-0.798**	-	-	-

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed)
Sig (2 tailed) given in brackets

Appendix 3. Correlation analysis of soil chemical parameters in non- amended area

	pH	EC	OM	N	P	K	C	Av. k	Av. Na	Av. Ca	Av. Mg	Av. Si	Ex. K	Ex. Na	Ex. Ca	Ex. Mg	ECEC	Ex. Fe	Ex. Mn	Ex. Zn	Ex. Cu
pH																					
EC																					
OM																					
N																					
P																					
K					0.427 (.06)																
C			0.555*																		
Av.K																					
Av.Na	0.392 (.088)																				
Av.Ca	0.764**				0.498*	0.433 (.057)															
Av.Mg	0.596**								0.424 (.062)	0.78**											
Av.Si	0.572**			0.605**					0.471*	0.43 (.058)	0.75**										
Ex.K																					
Ex.Na	-0.76**	-.386 (.093)			-0.424 (.062)					-0.86**	-0.61**										
Ex.Ca			0.577**							0.48*				0.46*							
Ex.Mg	0.559*							-0.449*		0.72**	0.78**	0.44 (.051)		-0.64**	0.73**						
ECEC	0.442 (.051)		0.485*							0.62**	0.58**			-0.57**	0.95**	0.91**					
Ex.Fe	-0.639**						0.382 (.096)							0.43 (.059)							
Ex.Mn																		0.66**			
Ex.Zn	0.788**			0.41 (.075)	0.44 (.05)	0.474*				0.94**	0.67**	0.43 (.06)		-0.89**	0.46*	0.64**	0.58**				
Ex.Cu	0.468*		0.495*		0.414 (.07)					0.64**	0.43 (.061)			-0.58**	0.64**	0.72**	0.72**			0.66**	

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed) Sig (2 tailed) given in brackets

Appendix 4. Correlation analysis of soil chemical parameters in amended area

	pH	EC	OM	N	P	K	C	Av. k	Av. Na	Av. Ca	Av. Mg	Av. Si	Ex. K	Ex. Na	Ex. Ca	Ex. Mg	ECEC	Ex. Fe	Ex. Mn	Ex. Zn	Ex. Cu
pH																					
EC	0.587**																				
OM																					
N	-0.509*																				
P	-0.393 (.086)																				
K																					
C	-0.376 (.10)		0.637**			0.414 (.07)															
Av.K	0.674**				0.432 (.057)																
Av.Na	0.499**		-0.488*				-0.477*														
Av.Ca	0.61**	0.595**				0.377 (.10)			0.405 (.077)												
Av.Mg		0.508*				0.702**				0.424 (.062)											
Av.Si								-0.521*													
Ex.K	-0.539*			0.393 (.087)	0.628**																
Ex.Na		-0.419 (.06)									-0.5*										
Ex.Ca	0.439**	0.406 (.076)		-0.452*																	
Ex.Mg								-0.457*							0.545*						
ECEC	0.393 (.087)			-0.442 (.05)				0.444*							0.921**	0.828**					
Ex.Fe	-0.85**	-0.57**		0.658**				0.442 (.051)		-0.50*			0.57**		-0.396 (.084)						
Ex.Mn	-0.77**	-0.63**		0.424 (.062)				0.63**		-0.497*		-0.57**			-0.44 (.055)			0.679**			
Ex.Zn					-0.64**								-0.499*		0.603**		0.507*				
Ex.Cu	-0.73**			0.614**				0.457*					0.436 (.055)					0.767**	0.55*	-0.41(.08)	

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed) Sig (2 tailed) given in brackets

Appendix 5. Correlation analysis between average yield of palm and nutrient content in index leaf of coconut grown in non-amended area

	Avg. yield	N	P	K	Na	Si	Ca	Mg	Fe	Mn	Zn	Cu
Avg. yield	-											
N	-	-										
P	-	0.543*	-									
K	-	0.475*	0.804**	-								
Na	-		0.462*	0.462*	-							
Si	-	0.760**	0.646**	0.589**	-	-						
Ca	-	-	-	-	-	0.395 (.085)	-					
Mg	-	-	-	-	-	-	0.415 (.069)	-				
Fe	-	0.575**	0.636**	0.729**		0.556*	-	-	-			
Mn	-	-	-	-	0.445*	-	-	0.458*	-	-		
Zn	0.508*	-	-	-	-0.380 (.098)	-	0.640**	-	-	-0.484*	-	
Cu	-	-	0.553*	0.508*	-	0.419 (.066)	-	-	-	-	-	-

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed)
Sig (2 tailed) given in brackets

Appendix 6. Correlation analysis between average yield of palm and nutrient content in index leaf of coconut grown in amended area

	Avg. yield	N	P	K	Na	Si	Ca	Mg	Fe	Mn	Zn	Cu
Avg. yield	-											
N	-	-										
P	-	0.483*	-									
K	0.391 (.088)	-	0.380 (.098)	-								
Na	0.482*	-	0.469*	0.720**	-							
Si	-0.771**	-	-	-	-	-						
Ca	-0.678**	-	-	-	-	0.612**	-					
Mg	-	0.409 (.073)	-	-	-	-	-	-				
Fe	-0.528* (.017)	-	-	-	-	-	-	-	-			
Mn	-	0.661**	0.470*	-	-	-	-	-	-0.575**	-		
Zn	-	0.495*	-	-	-	-	-	-	-	0.419 (.066)	-	
Cu	0.476*	0.408 (.074)	0.424 (.062)	-	0.524*	-	-	0.480*	-	-	-	-

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed)
Sig (2 tailed) given in brackets

EFFECT OF CONTINUOUS APPLICATION OF RICE HUSK ASH (RHA) ON INCEPTISOLS OF PALAKKAD EASTERN PLAINS

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ABSTRACT OF THE THESIS

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ABSTRACT

The study entitled "Effect of continuous application of rice husk ash (RHA) on Inceptisols of Palakkad Eastern plains" was conducted during 2014 - 16 in the Department of Soil Science and Agricultural Chemistry, College of Horticulture, Vellanikkara with the objective of finding out the physical and chemical changes of soil resultant to continuous application of RHA and its relationship with performance of coconut palms.

Vadavannur region under Inceptisol soil order of Palakkad Eastern plains stands out as a location where RHA (the product obtained on partial oxidation of rice husk, from rice mill, at a temperature around 250 to 400°C) is continuously being applied in the field for three decades along with inorganic nutrients to the coconut palms at the rate of four to five baskets/palm on volume basis. In this study, RHA samples were collected from the rice mills and analyzed for its composition in terms of carbon, macro and micro nutrients and the beneficial element silicon.

Further, representative surface soil samples were collected during August - December 2015 from four RHA amended and non- amended locations of the Palakkad Eastern plains (Vadavannur, Muthalamada, Thathamangalam and Mullakkalkolambu) and its physico- chemical properties were determined. The index leaves (14^{th} leaf) of coconut palms were also collected from RHA amended and non-amended locations and biometric characters (length of index leaf, total number of leaflets per index leaf, average length and width of leaflets, number of bunches per palm and average yield) were recorded. Samples of soil and plant were analyzed for different nutrients *viz.* C, N, P, K, Ca, Mg, Fe, Mn, Cu, Zn, Na and Si.

Analysis of RHA revealed that its pH was alkaline (7.5-8.3). Cation exchange capacity of the material ranged from 7.5 to 9.5 cmol(+) kg^{-1}. Chemical constituents included Si (35%), C (7%), N (0.18- 0.27%), P (0.39-0.57%), K (0.35-0.58%), Ca (0.08-0.1%), Mg (0.09-0.2%) and micronutrients in trace amounts.

On comparison of the physical properties of soil in amended and non-amended locations, the aggregate stability, infiltration rate, water holding capacity and porosity were found to be positively influenced by RHA application. The content of total N, total and available P and K and available Si of soils showed significant increase in amended regions. Exchangeable cations and effective cation exchange capacity were also more in the RHA amended regions. The content of total carbon and particulate organic carbon especially that associated with micro-aggregates was high in the amended area as compared to the non-amended area.

A significant difference in the biometric observations of index leaves (length of index leaves and total number of leaflets per index leaf) of palms in amended location as against non-amended locations was another noticeable feature. The palms under integrated nutrient management along with RHA yielded more. The average yield per palm was observed as 86 nuts/year. The content of major nutrients, Ca and Si in the index leaves was also recorded high in the RHA amended palms.

The farmers of Vadavannur region resorted to RHA application only with an objective to address the issue of environmental nuisance and menace, without attributing any scientific rationale on its value as a soil amendment. The results of the present study indicate the benefit of application of RHA in improving the physical and chemical properties of soil. The alkaline pH of RHA establishes its suitability as an alternative liming material for acid soils to improve the soil fertility and productivity. It is suggested that further studies conducted under designed experimental stipulations for validation of RHA would decipher more precise information on its suitability as a balanced material for soil amendment.