DYNAMICS OF IRON AND ALUMINIUM TOXICITY ON RICE (*Oryza sativa* L.) IN SALINE HYDROMORPHIC SOILS OF KAIPAD

by

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KERALA, INDIA

2017

DECLARATION

I, hereby declare that this thesis entitled **"DYNAMICS OF IRON AND ALUMINIUM TOXICITY ON RICE (*Oryza sativa* L.) IN SALINE HYDROMORPHIC SOILS OF KAIPAD"** 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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LIST OF ABBREVIATIONS AND SYMBOLS USED

%	Per cent
cm	Centimeter
GPS	Global Positioning System
$dS\ m^{-1}$	deci Siemens per meter
EC	Electrical conductivity
et al.	And co-workers
Fe	Iron
Fe^{2+}	Ferrous
Fe^{3+}	Ferric
Al^{3+}	Aluminium ion
Fig.	Figure
g	Gram
&	and
ha^{-1}	Per hectare
@	at the rate of
KAU	Kerala Agricultural University
kg	Kilogram
$kg\ ha^{-1}$	Kilogram per hectare
POP	Package of practices
S. No.	serial number
g/plant	gram per plant
$mg\ L^{-1}$	milligrams per litre

$\mu g\ g^{-1}$	Microgram per gram
M	Molar
mL	Milliliter
Fe (III) - EDTA	Iron ethylenediamine tetra acetic acid
CRD	Completely randomized design
N	Nitrogen
P	Phosphorus
K	Potassium
Ca	Calcium
Mg	Magnesium
S	Sulphur
Al	Aluminium
Mn	Manganese
Zn	Zinc
Cu	Copper
B	Boron
Si	Silicon
Na	Sodium
F	Fluorine
pH	Soil reaction
S_1	Submergence level 1 (5 cm)
S_2	Submergence level 2 (10 cm)

T	Treatment
SE	Standard error
NS	Non-significant
V_1	Variety 1 (Ezhome-1)
V_2	Variety 2 (Kuthiru)
viz.	Namely
t ha^{-1}	Tonnes per hectare
i.e.	That is
vs.	Versus
GI	Geographical Indications
CEC	Cation exchange capacity
DAI	Days after incubation
DAT	Days after transplanting
Avail.	Available
Exch.	Exchangeable
$\leq$	Less than or equal to

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Introduction

1. INTRODUCTION

Rice (*Oryza sativa* L.), popularly known as the "King of cereals" is the staple food crop of majority of the population of our country. India ranks second in global rice production accounting, 157.2 million tonnes per year (FAO Stat, 2017). It is a tropical crop capable of growing in wetlands and freshwater marshes. About 10 per cent of the world's cultivable landmass is accounted by wetlands. Due to the shrinking area under cultivation, the greatest potential for expansion of cultivable land under rice lies in these wetlands. As long as the population tends to increase in the developing nations, the demand for food production also grows. Efforts have to be put in for expansion of the area under rice cultivation and thereby stabilise food security. Wetlands are potential areas for future cereal production. Crop productivity enhancement in cultivated lands is also a strategy. Rice is the major crop suited for the wetland ecosystems. Proper emphasis has to be laid to improve and expand rice production in these unexplored new areas.

Kaipad, characterized by the unique saline hydromorphic tracts covers the north Malabar districts of Kozhikode, Kannur and Kasaragod of Kerala. These coastal wetlands are located approximately between the GPS coordinates 11.25°N to 12.5°N latitude and 75.0°E to 75.77°E longitude (Vanaja, 2013). The Kaipad tract covers an area of about 4100 hectares (Vanaja, 2013), a major part of which about 2500 hectares is located in the Kannur district of Kerala. These are brackish water tracts enriched with high inherent organic matter content and essential nutrients thereby having a high production potential. Salinity, toxicity of iron and aluminium are the major hurdles in enhanced productivity here. Pedologically, these soils are dominated by the presence of different iron and sulphur containing minerals like pyrite and jarosite.

An integrated farming system of rice cultivation and aquaculture is practised in Kaipad. Rice cultivation is practised during the first season in the low to medium saline phase of production cycle during June to October after the onset of monsoon showers. These areas are subjected to periodic floods in the monsoon and prevalence of high salinity during the summer season. The 'Kaipad' rice which is cultivated in the coastal wetlands of Kerala has been included in the Geographical Indications (GI) registry which is a part of the Intellectual Property regime. 'Kuthiru' and 'Orkayama' are the popular traditional land races widely grown in these tracts (Vanaja and Mammootty, 2010). Ezhome-1 is a high yielding variety which has 60 to 70 per cent more production potential than that of traditional land races.

The coastal wetlands of Kerala account about 13 per cent of the total geographical area of the state and plays important roles in ecological, economic and social well-being of the people. Large quantities of carbon are sequestered by Kaipad lands and thereby acts as a terrestrial carbon sink. All wetlands avoid accelerated emission of carbon as carbon dioxide and thus act as a promising option for alleviating climate change (CPGD-Kerala).

The growth and yield parameters of rice in wetlands are greatly affected by excess concentration of certain nutrients including iron and aluminium. Iron toxicity is a nutrient disorder which occurs in submerged soils and is associated with large concentrations of reduced iron in the soil solution. Iron induced yield reduction is frequently associated with a poor nutrient status of the soil (Benckiser *et al.*, 1983). The typical visual symptom is the "bronzing" of rice leaves and associated yield losses. The severity of iron toxicity depends on the content and type of the clay minerals, exchangeable soil iron and soil pH.

High amounts of soluble Fe^{2+} (100-1000 mg L^{-1}) is found in acid soils (Ponnamperuma, 1972). During reduction of Fe (III) oxides, the availability of aluminium also increases to toxic levels (Fischer, 1983). Rice yields were reduced by 12 to 100 per cent, depending on the intensity of iron toxicity stress, soil fertility and the iron tolerance limit of the genotype (Sahrawat, 2005). The appearance of iron plaque on the roots of aquatic plants is a common feature in such soil. Antagonistic effects on the uptake of many essential nutrients such as

P, K, Mn and Zn has been reported due to the presence of higher concentration of ferrous ions. This has resulted in an increased presence of deficiency symptoms of these nutrients and consequent reduction in yield in lowland rice(Fageria *et al.*, 2008).

Aluminium is one of the major constraints that limit nutrient uptake, growth and rice yields (Fageria and Carvalho, 1982). It limits the root growth in acid soils, exhibits a variety of nutrient deficiency symptoms, with a consequent decrease in yield. Prolonged exposure of the roots to varying concentrations of aluminium leads to nutrient deficiencies like phosphorus, potassium, calcium and magnesium (Haug and Vitorello, 1996). At soil pH below 5.0, aluminium speciates into its various soluble forms, among which Al^{3+} is the most predominant form that is highly toxic to plants (Horst *et al.*, 1983) and thus makes the plant susceptible to lodging and nutrient deficiencies.

Some wetland soils are characterised by specific problems such as salinity, high sodium content, low pH or poor physical properties following drainage (Guthrie, 1984). The rice growing areas in the Malabar regions are not completely protected against periodic salt water intrusion during the rainy season. If rainfall is low, saline water will enter the field during high tides and destroy the crop. Salinity level of ≤ 8 dS m^{-1} is considered critical for rice (Maas, 1986). Excess salinity within the plant root zone has a deleterious effect on plant growth by causing reduction in transpiration and growth rates. Silicon is reported to play a significant role in reducing iron toxicity, aluminium toxicity and also various abiotic stresses including salinity and drought (Liang *et al.*, 2007). It also imparts resistance to various plant diseases through its defensive reaction mechanisms.

Even though salinity is a constraint limiting the production, it can be overcome by the use of proper amendments, management practices and salt tolerant varieties.

With this background, the present investigation is proposed with the following objectives:

1. To investigate the status of iron and aluminium in saline hydromorphic soils of Kaipad
2. To evaluate the performance of popular traditional rice varieties to varying levels of iron and aluminium concentration at different salinity levels and
3. To examine amelioration strategies for iron and aluminium toxicity.

Review of literature

2. REVIEW OF LITERATURE

The present study entitled "Dynamics of iron and aluminium toxicity on rice (*Oryza sativa* L.) in saline hydromorphic soils of Kaipad" was undertaken to investigate the status of iron and aluminium in saline hydromorphic soils of Kaipad, evaluate the performance of popular rice varieties to varying levels of iron and aluminium concentration at different salinity levels, and examine amelioration strategies for iron and aluminium toxicity. A short review of the above aspects is presented in this chapter.

2.1 Rice statistics in India and the world

Rice is a staple cereal food crop of about half of the world's population. It is grown throughout the tropics and sub tropics. More than 42 per cent of the total calories consumed by the human population are supplied through rice. Asian population depends more on rice for their dietary requirements than other countries (Chand, 1998). Even though India has the largest acreage of about 45 million hectare under rice, it stands second in production next to China. The world rice production accounted for about 472 mT in 2015-16. According to the second advance estimate of 2016-17, rice production in India accounted for about 110 mT (Directorate of Economics and Statistics, 2017).

2.2 Rice production in wetlands

Wetlands are potential regions for successful production of rice. About one fifth of the area in Kerala is accounted by these wetlands. Due to their high adaptability to these regions, rice is the major crop grown here. About 37 per cent of the rice production in Kerala is accounted by these wetlands (Joseph, 2016). The major rice cultivating lowlands of Kerala include Kaipad, Kuttanad, Pokkali and Kole lands. Kaipad tracts is characterised by the presence of saline hydromorphic soils and covers the North Malabar districts of Kozhikode, Kannur and Kasaragod. The growth and yield parameters of rice in these wetlands are greatly affected by various abiotic stresses such as salinity, excess concentration of certain nutrients including iron and aluminium (Boyer, 1982; Dobermann and Fairhurst, 2000).

2.3 Rice cultivation in Kaipad lands

Kaipad, characterized by the unique saline hydromorphic tracts covers the North Malabar districts of Kozhikode, Kannur and Kasaragod of Kerala. Rice cultivation is practiced during the first season in the low to the medium saline phase of production cycle during June to October after the onset of monsoon showers. These areas are subjected to periodic floods in the monsoon and prevalence of high salinity during the summer seasons. The entry of salt water from the sea during the summer months leads to the salinization of these soils. Further, this salinity gets washed off by the south west monsoon leading to decline in the salinity levels. Rice cultivation is carried out by the preparation of mounds during the month of April/ May. Then, after the first showers of monsoon, the sprouted seeds are sown on top of these mounds. After 45 days, the mounds are disassembled without causing any damage to the rice roots and spread uniformly. The rice crop is harvested in November-December after which shrimp culture is taken up in these lands.

2.4 Iron toxicity and its effects

Iron toxicity commonly occurs in acid sulphate soils that are rich in reducible iron with low to moderately high organic matter (Ponnamperuma, 1972). Ponnamperuma *et al.* (1955) also reported that iron toxicity is a nutritional disorder caused due to the immobilised ferrous (Fe^{2+}) ions in soil solution. The iron toxicity affected roots appear scanty, coarse, blunted and dark brown in colour. On flooding, the iron reducing bacteria oxidises the organic matter and reduces Fe^{3+} thereby the concentration of ferrous ions (Fe^{2+}) in soil solution increases (Sahrawat, 2003).

Bronzing in wetland rice was first reported by Woodhouse in 1913 from the rice grown in wetlands of Champaran and Dharbanga districts of Orissa (Sahu, 1968). According to a survey of the rice cultivating areas, about 42 per cent of the wetland rice showed bronzing symptoms (Verma, 1991). The formation of iron plaque, as an exclusion mechanism in the roots of rice plants limits the absorption of minerals, such as iron itself (Snowden and Wheeler, 1995; Deng *et al.*, 2009). The important criterion for iron toxicity in submerged rice soils includes a pH less than 6.5, high reserve acidity, reducible iron content, salt content etc. (Ponnamperuma, 1976).

Sahrawat *et al.* (1996) reported a decline in lowland rice yield by 12 to 100 per cent depending on the intensity of iron toxicity and tolerance of the cultivar. Sahu (2001) reported that iron toxicity in wetland rice is a complex nutrient disorder and the deficiencies of various other nutrients *viz*. P, K, Mg, Mn and Zn plays an important role. Ottow (1981) stated that as the organic matter content of the soils increases, the more intensive will be the ferrous ion accumulation.

Singh and Singh (1988) reported that the symptoms of iron toxicity occur in rice in about 50 to 55 days after transplanting. Iron toxicity during the vegetative stages showed reduced plant height and dry matter accumulation with the shoot being more affected than the root biomass (Fageria *et al.*, 1984).

The amount of iron plaques on field-grown rice roots were significantly related to the type of soil, growth stage and the rice cultivars (Chen *et al.*, 1980a). Chabbi (1999) testified that iron forms a precipitate on the surface of roots in *Juncus bulbosus*, which mainly consists of goethite. Predominance of ferrihydrite precipitates was reported on *Phalaris arundinacea* (Hansel *et al.*, 2001). They also reported that iron plaque existed as a continuous precipitate or as an amorphous coating with an uneven distribution on the roots in the field and laboratory conditions.

Culture solutions with iron concentration in the range 10 to 1680 mg L^{-1} or higher showed iron toxicity symptoms (Narteh and Sahrawat, 1999). They also reported severe iron toxicity symptoms in the soil solution during the field experiments with Fe^{2+} ions in the range of 50 to 150 mg L^{-1}. Appearance of iron toxicity is also influenced by the reduction products such as sulphides and other organic acids apart from the excess ferrous ion concentration in soil solution (Breemen and Moormann, 1978).

Field experiment studies on iron toxicity in West Africa showed that both iron tolerant and susceptible varieties had high concentration of total iron ranging above the critical limit of 300 mg kg^{-1} plant dry weight (Sahrawat, 2000). Audebert and Sahrawat (2000) reported that the best and the sustainable results against iron toxicity could be obtained by a combination of iron tolerant varieties, improved soil, water and nutrient management practices.

Sahrawat *et al.* (2001) concluded from his field experiments that iron toxicity can be reduced by the application of nutrients such as P, K and Zn whose requirement is increased under iron toxicity situations. The reduced condition of submerged soils is highly related to iron toxicity, which increases the concentration and uptake of ferrous form of iron (Fe^{2+}). Iron toxicity has been observed in flooded soils with a pH below 5.8 when aerobic and pH below 6.5 when anaerobic.

Indirect iron toxicity is caused due to the nutrient imbalance in plants and this is more common in lowland rice compared to direct iron toxicity (Fageria *et al.*, 2006). The major form of iron uptake by plants is ferrous (Fe^{2+}) ion (Lindsay and Schwab, 1982). So, iron has to be reduced to Fe^{2+} form for uptake by crop plants. The lower pH of the rhizosphere solubilizes Fe^{3+} to Fe^{2+} form. Weathering of parent materials releases significant amounts of nutrients in the soil solution, including iron. When the Fe^{2+} concentration of reduced or submerged soils is high, its uptake may be in excess than plant demand and becomes toxic to rice plants. Ponnamperuma (1976) reported that the ferrous ion concentration in most soils increases upon flooding and reaches a maximum after 2 to 5 weeks after submergence.

The reduction of Fe^{3+} to Fe^{2+} is expressed by the equation:

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

The ferric ion in soil is converted into ferrous ion in the redox potential range of +180 to +150 millivolts (Ponnamperuma, 1976). Apart from the reduction of Fe^{3+} to Fe^{2+}, manganese $(Mn)^{4+}$ is reduced to Mn^{2+}, nitrate (NO_3^-) to dinitrogen (N_2), sulphate (SO_4^{2-}) to hydrogen sulphide (H_2S), carbon dioxide (CO_2) to methane (CH_4), and H^+ to H_2 in submerged soils (Ponnamperuma, 1977).

Breemen and Moormann (1978) reported that high salinity caused due to sodium chloride or magnesium chloride also increased the iron uptake thus aggravating iron toxicity. Adams (1984) stated that soil pH is highly variable in nature due to the dynamic nature of the different soil processes and the interaction of these processes with plants and microorganisms. With the increase in soil pH, iron gets converted to less soluble forms, and finally to the oxide forms Fe_2O_3.

Yamauchi (1989) reported that the reduction in severity of bronzing and increase in dry matter production of rice plants could be achieved through the application of potassium sulphate. As the severity of bronzing decreases, the accumulation and concentration of potassium in the shoots were found to increase. It was reported that the iron concentration was decreased by the dilution effect caused by the increase in dry matter production.

Fageria *et al.* (1990) stated that the solubility and availability relationships for iron are very complex and has not been defined completely. But, the principal iron toxicity inducing factors are release of iron from parent material to soil solution, change in redox potential, increase in ionic strength, low soil fertility, low soil pH, soil organic matter content, microbial activities, interaction with other nutrients and plant genetic variability.

Iron interaction with other nutrients may be antagonistic, synergistic, or neutral depending on the growth response of plants. If the growth response is greater with two combined factors when compared to the sum of their individual effects, then it is a positive interaction and when the combined effects are less, then the interaction is negative (Sumner and Farina, 1986; Fageria *et al.*, 1990).

Interaction of nutrients can be measured in terms of influence of one nutrient on the uptake of other nutrients. Antagonistic interactions with other nutrients were found to reduce the availability of iron to rice plants and vice versa. Such type of negative interactions results from interactions that occur either internally or externally to the root surface. The externally occurring interactions are usually precipitation or similar reactions that reduce the chemical availability of the nutrients. The interactions that influence absorption or utilization processes alters the effectiveness of a nutrient by reducing its physiological availability (Fageria *et al.*, 1990).

Olsen and Watanabe (1979) reported that the interaction of iron with manganese is antagonistic in nature. Fageria *et al.* (1981) reported that the rice plants developed resistance to iron toxicity with the advancement of age of plants.

Ponnamperuma *et al.* (1955) reported iron toxicity in rice plants when the soluble iron in soil solution was more than 300 to 500 mg kg^{-1}. Wells *et al.* (1993) reported that the critical range for iron concentration in the plant tissue was in the range of 70 to 300 mg kg^{-1}. Fageria *et al.* (1981) reported from his experiments that the toxic level of iron in the whole plant tops was 680 mg kg^{-1} in 20 days old plants and 850 mg kg^{-1} in 40 days old plants. But, the toxic concentrations also depend on the rice cultivars.

Makerim *et al.* (1991) stated that the clay content of iron toxic soils grouped under Ultisols and Oxisols were normally high. Complexed iron fraction constituted 15 to 40 per cent of the total iron in reduced paddy fields (Yu, 1976).

Zhang *et al.* (1998) reported the inhibition of zinc uptake by rice roots due to the adsorption of Zn^{2+} on the precipitates of iron hydroxide as iron plaque on roots. The presence of high iron content in soil suppresses the absorption of copper by rice (Das, 2014).

2.5 Alleviation of iron toxicity

The presence of adequate amount of silicon and potassium in the soil solution were found to increase the oxidizing power of rice roots and thereby decreased the excessive iron uptake by the plants (Tadano, 1976; Yoshida, 1981).

Application of potassium in higher doses increases the root oxidising power of rice, and results in oxidation of ferrous form to ferric form and thus excludes this ion from uptake. But, the application of potassium chloride to iron toxic soils adds up the problem whereas, application of potassium sulphate helps in alleviating the problem. Proper application of fertilizers helps in improving the productivity of iron toxic soil (Ismunadji *et al*., 1989). The rice yield was found to increase from 2958 to 5594 kg ha^{-1}. They also reported that the percentage of empty grains or chaffinesss can be reduced up to 30 per cent on application of potash in these iron toxic soils.

Breemen and Moormann (1978) opined that iron toxicity can be alleviated by liming the soil, delaying the planting or through late flooding to avoid excess iron in the early stages and providing sufficient iron in the reproductive phase of the plant development.

Nurlaeny *et al*. (1996) reported that liming increased the shoot dry weight in soyabean and corn grown on acid soils of tropical regions. Zaini *et al*. (1990) suggested that intermittent drainage could help in reducing the severity of iron toxicity. Benckiser *et al*. (1984) suggested that calcium and magnesium plays an important role in alleviating iron toxicity in rice.

Immobilisation of phosphorus by iron and aluminium can be reduced by application of lime in acid soils and thereby improve the phosphorus in soil solution (Fageria and Baligar, 2008).

2.6 Aluminium toxicity

Aluminium toxicity is a major constraint limiting the crop production in the acid soils of tropical and subtropical regions. About 25 to 80 per cent of yield losses are reported depending upon the species of the plants (Sade *et al.*, 2016). It is severe in soils with low base saturation and poor calcium and magnesium contents, thereby leading to a reduction in rice yield (Vitorello *et al*, 2005).

When the pH is above 5, the water-soluble aluminium content is low and it increases when the pH falls below 5 and becomes considerably higher at soil reaction below 4.5 (Nomoto and Kisida, 1959). When the soil becomes more acidic, aluminium is solubilized into the most phytotoxic form $Al\ (H_2O)_6^{3+}$ dominant in Al^{3+} ion (Matsumoto, 2000).

Rice is an aluminium tolerant crop having different levels of tolerance to aluminium (Ishikawa *et al.*, 2000), and the tolerance level varies with the cultivars (Jan and Pettersson, 1993). Aluminium toxicity is a major nutrient disorder which affects the rice productivity in uplands and lowland acid sulphate soils (Vasconcelos *et al.*, 2002). Rice is not an aluminium accumulator (Chen and Shen, Institute of Soil Science, CAS, China, unpubl. res.). Shen and Ma (2001) reported much less accumulation of aluminium in the rice shoots compared to that of buckwheat. Kochian *et al.* (2004) reported that aluminium toxicity is usually localized to the root apex region.

Pavar and Marshall (1934) reported that aluminium toxicity causes poor root penetration and reduced plant growth. The reduction in root growth restricts the uptake of water and nutrients thus leading to poor growth of plants by disturbing the metabolism in plants. Roy and Bhadra (2014) stated that toxicity of aluminium also inhibits shoot growth by inducing nutrient (P, Ca and Mg) deficiencies, drought stress and hormonal imbalances. They also concluded from their hydroponic culture studies on rice that the toxic levels of aluminium in the nutrient solution was found to significantly reduce the seedling root growth and shoot length, number of primary roots, number of leaves per seedling, seedling fresh and dry weights.

Wang *et al.* (2008) reported that aluminium could alleviate H^+ and Cu^{2+} toxicity. Root length is usually used as a criterion for determining the tolerance to aluminium toxicity in rice (Zhang *et al.*, 2007).

2.7 Alleviation of aluminium toxicity

Aluminium toxicity can be alleviated conventionally with the application of phosphorus (Chen *et al.*, 2012). Calcium application was reported to decrease the aluminium content in root tips without displacement (Shen *et al.*, 1993). Aluminium toxicity could also be alleviated by the application of magnesium in wheat which is similar as in the case of calcium application (Watanabe and Okada, 2005).

Secretion of organic acid like malic acid from the roots of wheat was reported as an aluminium tolerance mechanism in crops like wheat (Delhaize *et al.*, 1993), maize (Pellet *et al.*, 1995) and citric acid in soybean (Yang *et al.*, 2000). But, Ishikawa *et al.* (2000) reported that secretion of organic acid from roots is not a primary mechanism for aluminium tolerance in rice.

Watanabe and Okada (2005) reported that application of sodium at ionic strength similar to calcium application was found to alleviate aluminium toxicity in rice cultivars. Soil amendments help in reducing aluminium toxicity to an extent, but are expensive and impractical due to the problem of subsoil acidity in acid sulphate soils.

Phosphogypsum contains the elements calcium, sulphate in major amounts and phosphorus, silicon and fluorine in substantial amounts. It is a by-product of the phosphoric acid industry and their addition as amendments helps in the formation and retention of aluminium hydroxyl polymers (Illera *et al.*, 2004b). It contains mainly calcium sulphate and small contents of phosphorus and fluorine. About 2.4 million tons of phosphogypsum are produced in Brazil every year (Freitas, 1992). The use of phosphogypsum as an amendment in acid soils can be an alternative option for the disposal of such a bulky by-product of the fertiliser industry.

Phosphorus application reduces the solubility of aluminium in the growth medium resulting in reduction of its toxicity (Wright, 1937). The precipitation of aluminium on application of phosphorus occurs not only in the growth media, but also within and on the root surface (Vlamis, 1953).

Elisa *et al.* (2016) concluded from their study that application of calcium silicate on acid sulphate soils induced a positive effect on soil pH by increasing the pH from 2.9 (initial) to 3.5 and exchangeable aluminium by reducing it from 4.26 (initial) to 0.82 c mol (P^{+}) kg^{-1}. Thus, calcium silicate can be used in alleviating aluminium toxicity. Elisa *et al.* (2016) concluded from their incubation studies that application of 2 and 3 Mg ha^{-1} calcium silicate showed a significant decrease in the exchangeable aluminium content at 30 and 120 days of incubation.

Dietzel *et al.* (2009) recommended liming as a remedy for correction of aluminium toxicity. The positive response of lime application to rice yield in continuously flooded soils was experimented and confirmed by Khunthasuvon *et al.* (1998). Reeve and Sumner (1972) suggested that aluminium toxicity can be overcome by self-liming effect wherein, the hydroxyl ions are displaced by the sulphate ions from hydrous oxides of aluminium and iron. Noble *et al.* (1988) reported the reduction in Al^{3+} activity by the formation of soluble $AlS0_4^{+}$ ion pair in roots of soybean grown in nutrient solution.

Rabileh *et al.* (2015) reported that the amelioration of infertile acid sulphate soils can be done by application of appropriate rates of amendments like lime, basalt, gypsum etc. alone or with their combinations. The application of such ameliorants helps in increasing the soil pH, reduces aluminium toxicity, supplies calcium and magnesium resulting in improved growth and development of rice.

Addition of organic matter to the soil acts as an additional source of nutrients, reduces fixation of phosphorus, aluminium and manganese toxicity, and leaching of the nutrients (Baligar and Fageria, 1999).

2.8 Effect of silicon on crops

Silicon is a beneficial element which helps in the growth of rice. It is concentrated in plant tissues in quantities similar to that of macronutrients. Significant reduction in the damages caused due to various abiotic stresses like drought, salinity, nutrient imbalance, as well as biotic stresses like insect, pests have been reported by the application of silicon (Nakata *et al.*, 2008).

Farnaz *et al.* (2012) reported that the application of silicon helps in reducing the severity of fungal diseases like blast and sheath blight of rice. Potassium silicate application at the rate of 12 gram per nursery bed was effective in controlling the occurrence of blast of paddy (Maekawa *et al.*, 2001).

Plants absorb silicon in the form of mono-silicic acid $Si(OH)_4$ (Rodrigues & Datnoff, 2005). The silicon content in the tissues of most terrestrial plants varies from 0.1 to 10 per cent on a dry weight basis (Ma and Takahashi, 2002). There have been reports of silicon deficiency in highly organic soils, as these soil contain low amount of minerals (Elawad & Green, 1979). Silicon is regarded as an "agronomically essential element" in Japan and hence, silicate fertilizers have been applied to paddy soils.

Temperate regions have reported higher rice productivity compared to the tropics (Rodrigues & Datnoff, 2005) because, the amount of silicon in the temperate region soils is about 5 to 10 times higher than its amount in the tropics (Foy, 1992). Bowen *et al.* (1992) confirmed that foliar applications of silicon increase the resistance against pathogens in plant species which do not absorb silicon efficiently. Silicon fertilization has found to increase both the quality and quantity of crops such as rice and sugar cane (Korndorfer & Lepsch, 2001).

Barcelo *et al.* (1993) reported that silicon is efficient in reducing aluminium toxicity. Ma *et al.* (1997) suggested that amelioration of aluminium toxicity in corn roots was due to the formation of complexes of aluminium and silicon in solution, instead of any physiological effect of silicon on the corn plants. They also reported that the concentration of phyto-toxic ion, Al^{3+} was reduced in the presence of silicon and this decrease was paralleled by an increase in root length.

In some species, a high proportion of about 85 to 90 per cent of the aluminium ions taken up by the plant roots remains in the apoplast (Clarkson, 1967). Co-precipitation of the two elements in the plant roots is considered as a possible mechanism for the detoxification of aluminium by silicon (Hodson and Evans, 1995).

Zsoldos *et al.* (2013) confirmed that application of silicon to the plants growing in an acidic medium, not only helps in ameliorating aluminium toxicity in plants, but also stimulates root elongation at low concentration of aluminium.

Monocot plants generally contain higher concentration of silicon compared to dicot plants. This can be related to the higher ratio of 'mineral cation : mineral anion' uptake in dicots than in monocots. An increase in the rhizospheric pH is caused by the excess of anions absorbed in the presence of anionic silicon. This eventually leads to an efflux of hydroxyl ions and, thus could significantly decrease the aluminium uptake (Wallace, 1992).

Ma *et al.* (1989) observed a remarkable increase / decrease in the percentage of filled spikelets on addition / removal of silicon during the reproductive stage. Okuda and Takahashi (1961b), based on their studies suggested that application of silicon after panicle initiation stages had a remarkable effect on the plant height, grain weight and uptake of silicon.

An increase in the weight of one thousand grains was reported by Mizuno (1987) with the increase in the silicon content of the hull in rice. Silicon plays an important role in alleviating various abiotic stresses *viz.* salinity, metal toxicity, drought stress, nutrient imbalance etc. by the mechanism of accumulation of silica on the surface of the tissues (Ma, 2004).

Liang *et al.* (1994) reported that the grain yield, spike number and filled grain percentage and grain to shoot ratio of the silicon treated rice in calcareous soils showed a significant increase as compared to the control. Li *et al.* (2012) reported that Mn toxicity in rice can be alleviated through silicon application and thereby decrease the accumulation of manganese in the shoots.

2.9 Submergence of soils

The submergence of acid soils for a prolonged period decreases the availability of nutrients such as sulphur, boron, copper and zinc (Karan *et al.*, 2014). The availability of sulphur under flooded condition is reduced due to the formation of sulphides. They also reported that liming of acid soils reduces the availability of S, Cu, Fe, Zn, Mn and Al but increases the availability of boron irrespective of the soil moisture regime. An increase in pH value to neutrality was observed due to the continuous submergence of acid soils.

The sulphur availability in lowland paddy decreases due to the slower mineralisation of organically bound sulphur (Bell and Dell, 2008). Patnaik and Mandal (1982) reported that the submergence period and redox potential influences the reduction in micronutrient availability due to increase in concentration of iron and bicarbonate concentration. Ponnamperuma (1972) reported that the submergence of soils increases the concentration of H_2CO_3, HCO^{3-} and CO_3^{2-} in the soil solution which may lead to the precipitation of zinc and copper as their carbonates.

2.10 Salinity as a constraint

Salt stress is becoming one of the key factors that restrict agricultural productivity, especially in irrigated areas and in rainfed coastal areas (Castillo *et al.*, 2000). Boron has been found in toxic levels in saline and sodic soils (Hutchison & Viets, 1969).

Rice is a crop which is tolerant to salinity during germination, becomes sensitive during early seedling growth, and finally becomes more tolerant as it matures (Hakim *et al.*, 2010). Rice production has mostly been observed to be affected by soil salinity. In India, an area of about 4 million hectare saline soil is under rice production (Paul and Ghosh, 1986). The soil in Kaipad tracts is saline hydromorphic having an acidic soil pH throughout the depth of soil profiles (Samikutty, 1977).

The typical symptoms of salt injury in rice include stunted growth, rolling of leaves, white colour of leaf tip, drying of the older leaves, poor root growth etc. (Ponnamperuma and Bandyopadhya, 1980). Noreen and Ashraf (2008) have reported reduced plant growth rates, loss of turgor, premature senescence and abscission of leaves due to the high concentration of soluble salts in the root zone of sunflower plants.

Akbar (1975) reported adverse effects of high levels of chloride on nitrate and phosphate uptake under saline environment in rice seedlings. Rahman *et al.* (2012) reported that the growth of plumule as well as the radicle decreased significantly with increasing arsenic and sodium chloride concentration. Almansouri *et al.* (2001) reported that seed germination and seedling establishment are inhibited or delayed by salt and osmotic stresses in wheat. High salinity is detrimental to plant growth as it causes different nutritional disorders by decreasing the uptake of cations, such as potassium and calcium, and also of anions such as phosphorus and nitrate (Asch *et al.*, 2000).

Ehrler (1960) dealt with the various effects of salinity levels on rice grown in nutrient solution and found out that the grain yield was much more affected than the growth. He also reported that the composition of the salt added (sodium chloride, sodium sulphate or calcium chloride) had no specific effect on the growth or yield of the plants.

Pearson (1959) reported that all growth criteria were not affected to the same degree by salinity. He also found that the plant height, number of tillers, straw dry weight, grain weight etc. were reduced at different extents when the electrical conductivity was 11dS m^{-1}.

Maas and Hoffman (1977) reported that the germination ability of seeds under saline conditions varies from one crop to another. 'Kuthiru and Orkayama' are reported to be saline tolerant land races from Kaipad tracts of Kerala. Ezhome-1 and Ezhome-2 which are saline tolerant, non-lodging and high yielding varieties have been released using the local land races as donor parents (Vanaja and Mammootty, 2010).

Ponnamperuma (1994) opined that the crop yield markedly decreases with an increase in salt concentration, but the threshold concentration and yield decrease vary with the crop species and cultivar. Khatun *et al.* (1995) reported that the panicle lengths, number of spikelets per panicle and 1000 grain weight were significantly affected by salinity.

Turan and Aydin (2005) opined that the uptake of nutrients like iron, manganese, zinc and copper was increased in crop plants grown under salinity stress. High salt concentration increases osmotic stress (Mohanty *et al.*, 2002) and leads to the accumulation of excess amount of sodium in plants (Zhu, 2001).

A drastic decrease in the potassium content of salt-sensitive rice varieties was observed due to salinity. The salt susceptible rice cultivars have low ratio of K/Na in leaves and high grain yield reduction under salinity (Asch *et al.*, 2000). The rice cultivars which are salt tolerant accumulates less amounts of sodium, chlorine, zinc and proline and more amounts of potassium at roots and shoots than salt-sensitive varieties. Transport of phosphorus from roots to shoot was inhibited in the salt-sensitive cultivars.

Lipman *et al.* (1926) investigated, on the effects of varying concentrations (0 to 15,000 ppm) of sodium chloride in solution culture on the growth of wheat, barley, and peas, and found out that sodium chloride concentrations in the range 500 to 1,000 ppm suppressed the growth particularly in the early stages, but higher concentrations may stimulate it. Adverse effects on spike length, paddy and straw yield were observed due to salinity (Ehsan-Ul-Haq *et al.*, 2009).

2.11 Remediation of salinity effect on crop

External supply of boron significantly improved panicle length over control up to 6.0 kg B ha^{-1} in saline and up to 3.0 kg B ha^{-1} in saline sodic soil. A significant decrease in Na^+ concentration was observed as a result of boron application up to 1.5 kg ha^{-1} in saline as well in saline-sodic soils over control.

Boron application at the rate of 1.5 $kgha^{-1}$ to salt affected soils (saline and saline-sodic), improved number of tillers per plant, panicle length, straw and paddy yield of all rice (Ehsan-Ul-Haq *et al.*, 2009).

The high level of Ca^{2+} in saline soil provides relief to boron toxicity (Lal *et al.*, 1979). Excess boron is assumed to combine with Ca^{2+} to form a compound which is no longer toxic to the plant (Werkhoven, 1964).

2.12 Effect of gypsum as an amendment

The electrical conductivity and exchangeable sodium percentage values were found to decrease on application of a mixture of farm yard manure and gypsum (Abou El-Defan *et al.*, 2005). Wong *et al.* (2009) proposed that the adverse soil properties associated with sodic soils were found to reduce on addition of organic matter in conjunction with gypsum.

It was reported by Raza *et al.* (2001) that broadcasting of gypsum reduced the sodium adsorption ratio of soil by 59 per cent at 0 to 30 cm depth and 8 per cent at 30 to 60 cm depth. Gong *et al.* (2006) have reported on the role of silicon in alleviating salt stress in rice. Matoh *et al.* (1986) proposed that the deposition of silica in the leaves reduced the transpiration and thereby helped in decreasing the accumulation of salt.

2.13 Effect of phosphogypsum as an amendment

Carvalho and van Raij (1997) concluded from their experiments that acid subsoil containing low amounts of calcium or toxic aluminium contents can be ameliorated by the use of phosphogypsum at the rate of 10 mmol Ca^{2+} dm^{-3} of soil. Calcium carbonate was reported to reduce the activity of Al^{3+} by increasing the pH.

Cameron *et al.* (1986) opined that application of phosphogypsum would be more effective in reducing the toxicity caused by aluminium than by the use of pure calcium sulphate due to the presence of fluorine in phosphogypsum. Fluorine is an anion capable of forming more stable complexes with aluminium than SO_4^{2-}.

The fresh root weight of Komatsuna *Brassica rapa* L. cv. Natsurakuten was found to increase by 31 per cent on application of phosphogypsum at the rate of 0.30 g kg^{-1} compared to limestone (Takasu *et al.*, 2006). Phosphogypsum has calcium in soluble form which is capable of correcting subsoil acidity also when it is applied to the surface (Deepa, 2008; Alcordo and Recheigl, 1993).

Alva *et al.* (1990) stated that the positive effects of phosphogypsum in reclamation of acidic soils are related to the reduction in mobile aluminium concentration. A reduction in mobile aluminium by 7 to 40 per cent was observed on saturating the soil with 2 g L^{-1} phosphogypsum solution.

According to Vyshpolsky *et al.* (2010), the negative effects of excess Mg^{2+} in soil structure can be overcome by the application of phosphogypsum in irrigated areas. Vukadinovic *et al.* (2016) reported that phosphogypsum and gypsum can be used as excellent substitutes for carbochalk and other liming materials in neutralizing the excess of aluminium in acid soils or sodium in alkaline soils.

The application of phosphogypsum as a fertilizer at the rate of 100 to 600 kg ha^{-1} was reported to show a significant increase in yield in about 50 types of crops (Hilton, 2006). Soratto *et al.* (2008) noted from his studies on rice cultivation that the application of phosphogypsum when combined with lime showed positive effects on the amount of sulphur in leaves and yield.

2.14 Effect of lime on soil

The role of different liming materials such as burnt lime or quick lime, slaked lime, calcite, dolomite and limestone in reducing the solubility of aluminium, iron, manganese etc. and increasing the availability of nutrients like calcium, phosphorus and crop yields were reported by Mandal *et al. (*1975) and Tripathi *et al.* (1997).

Amelioration of acid soils by the use of conventional liming materials such as calcium oxide, calcium carbonate, calcium hydroxide etc. in ameliorating acid soils are limited to the depth of incorporation only, due to their low mobility and solubility (Brown and Munsell, 1938; Pearson *et al.*, 1973; Recheigl *et al.*, 1985; Sumner *et al.*, 1986; Farina and Channon, 1988).

Prasad *et al.* (1984) studied on the beneficial effects of application of lime at the rate of 2.5 t ha^{-1} in a strongly acidic soil cultivated with barley and maize and reported that it helped in promoting the availability of calcium and phosphorus with higher yield. Liming is one of the best management options in ameliorating soil acidity for successful crop production. Liming at the rate of 2 t ha^{-1} in laterite soil had increased the soil pH by two units by decreasing the exchangeable aluminium content (Enright, 1984).

Application of lime at the rate of 18.4 t ha^{-1} showed a significant increase in the concentration of calcium, magnesium and potassium concentration in the top soil (Blaszcyk *et al.*, 1986). A reduction in the extractable and exchangeable iron, aluminium and manganese in acid soils was reported on application of lime (Bishnoi *et al.*, 1987). Gama (1987) proposed that the release of non-exchangeable potassium and slight magnesium fixation seen in acid soils could be achieved through the application of calcium carbonate.

Martini *et al.* (1977) reported that increase of soil pH from 4.8 to 5.7 and reduction of exchangeable aluminium content to 1.5 c mol (P^+) kg^{-1} soil is an effective means of optimising the yield rather than raising the pH to neutrality. Sumner *et al.* (1986) reported that addition of lime deep into the soil helped in increasing the development of roots and thereby resulted in higher crop yields.

2.15 Role of magnesium sulphate

The levels of magnesium present in the soil are declining over time due to crop removal, soil erosion and leaching losses. High levels of potassium, calcium and low soil pH, temperature and dry soil conditions also contribute to magnesium deficiency. Bhaskar *et al.* (2013) reported that the application of magnesium sulphate at the rate of 3 g m^{-2} showed significant increase in growth and grain yield compared to the control. The uptake of magnesium is highly influenced by the availability of other cations like NH_4^+, Ca^{2+} and K^+ (Romheld and Kirkby, 2007).

Yamauchi and Winslow (1989) based on their studies in upland rice reported that nitrogen, potassium, silicon and magnesium were necessary to produce high dry matter. They also reported that magnesium and silicon were necessary for protecting the rice plants against grain discolouration and in increasing the grain yield by an average of 34 per cent.

Materials and methods

3. MATERIALS AND METHODS

An investigation entitled "Dynamics of iron and aluminium toxicity on rice (*Oryza sativa* L.) in saline hydromorphic soils of Kaipad" was carried out at College of Agriculture, Padannakkad during the academic year 2015 to 2017. The objectives of the study were to investigate the status of iron and aluminium in saline hydromorphic soils of Kaipad, evaluate the performance of popular rice varieties to varying levels of iron and aluminium concentration at different salinity levels, and examine amelioration strategies for iron and aluminium toxicity. The study was carried out in four parts.

Part A: Collection of soil samples and analysis of physical and chemical properties
Part B: Incubation study to know the release pattern of nutrients in the soil
Part C: Solution culture experiment
Part D: Pot culture experiment

The various materials and methods falling under this study are given in this chapter.

3.1 COLLECTION OF SOIL SAMPLES FROM KAIPAD AREA AND ANALYSIS OF THEIR PHYSICAL AND CHEMICAL PROPERTIES

Kaipad tracts, comprising the saline hydromorphic soils are distributed in the north Malabar districts of Kozhikode, Kannur and Kasaragod of Kerala. These coastal wetlands lies between 11.25°N to 12.5°N and 75.0°E 75.77°E.

As a part of the study, representative surface soil samples were collected from 15 selected locations of Kaipad areas comprising of Muttil and Cherukunnu (Fig. 1) panchayath during the first week of April 2016 to assess the different physical and chemical properties. The depth of sampling was 0 to15 cm. The GPS data for the site of sampling were also recorded. The soil samples collected from each site was brought to College of Agriculture, Padannakkad, dried under shade, labelled and stored in clean polythene bags. The moisture percentages of the fresh soil samples were estimated gravimetrically. The details of the location along with GPS coordinates are given in Table 1. The various physical and chemical properties of soil samples such as bulk density, textural analysis, pH, electrical conductivity, organic carbon, available N, P, K, Ca, Mg, S, Fe, Zn, Cu, Mn, B, Si, exchangeable Na and Al and cation exchange capacity were estimated using the standard procedures given in Table 2.

Table 1: Details of the location along with GPS coordinates

S. No.	**Locations**	**North latitude**	**East longitude**
1.	Punnachery	12° 016' .28 "	75° 17' 20".88
2.	Punnachery	12° 017'. 78"	75° 17' 19".85
3.	Punnachery	12° 015'.79"	75° 17' 18".55
4.	Punnachery	12° 019'.15"	75° 17' 16".09
5.	Valiyamthuruthy Kaipad	12° 012'.68"	75° 18' .056
6.	Pallikkara	12° 032'.74"	75° 16' 14".06
7.	Muttil Vadakk (Pallikkara Moolaaykkil)	12° 029'.81"	75° 16' 15".01
8.	Muttil	12° 030'.39"	75° 16' 17".42
9.	Muttil	12° 030'.62"	75° 16' 18".72
10.	Muttil (Fallow land)	12° 028'.40"	75° 16' 60".25
11.	Muttil (Fallow land)	12° 020'.21"	75° 16' 20".15
12.	Muttil Vadakk	12° 014.80"	75° 10' 20".70
13.	Muttil (Near Juma Masjid)	12° 013'.39"	75° 16' 34".16
14.	Muttil	12° 019'.92"	75° 16' 33".61
15.	Dam road	11° 059'. 45"	75° 16' 42".34

Table 2: Analytical methods followed for soil analysis

S. No.	**Parameters**	**Method**	**Reference**
1.	Particle density	Pycnometer method	Black *et al.* (1965)
2.	Bulk density	Undisturbed core sample method	Black *et al.* (1965)
3.	Porosity*	Derived	Black *et al.* (1965)
4.	Textural analysis	International pipette method	Robinson (1922)
5.	Soil Ph	pH meter	Jackson (1958)
6.	EC	Conductivity meter	Jackson (1958)
7.	Organic carbon	Chromic acid wet digestion method	Walkley and Black (1934)
8.	Available N	Alkaline permanganate method	Subbaiah and Asija (1956)
9.	Available P	Bray extraction and photoelectric colorimetry	Jackson (1958)
10.	Available K	Flame photometry	Pratt (1965)
11.	Available Ca	Atomic absorption spectroscopy	Jackson (1958)
12.	Available Mg	Atomic absorption spectroscopy	Jackson (1958)
13.	Available S	Photoelectric colorimetry	Massoumi and Cornfield (1963)
14.	Available Fe	Atomic absorption spectroscopy	Sims and Johnson (1991)
15.	Available Zn	Atomic absorption spectroscopy	Emmel *et al.* (1977)

Table 2 continued-

16.	Available Cu	Atomic absorption spectroscopy	Sims and Johnson (1991)
17.	Available Mn	Atomic absorption spectroscopy	Sims and Johnson (1991)
18.	Available B	Hot water extraction method (photoelectric colorimetry)	Lindsay and Norwell (1978)
19.	Available Si	Inductively coupled plasma optical emission spectrometry (ICP-OES)	Korndorfer *et al.* (2001)
20.	Exchangeable Al	Atomic absorption spectroscopy	Ciesielski *et al.* (1997)
21.	Exchangeable Na	Flame photometry	Jackson, 1958
22.	CEC	0.1 *M* Barium chloride solution	Hendershot and Duquette (1986)

*Porosity (%) = (1-Bulk density/Particle density) x 100

Plate 1: Collection of soil samples from a depth of 0 to 15 cm (7.5 YR 3/4)

Plate 2 (A): Kaipad field, an overview during April

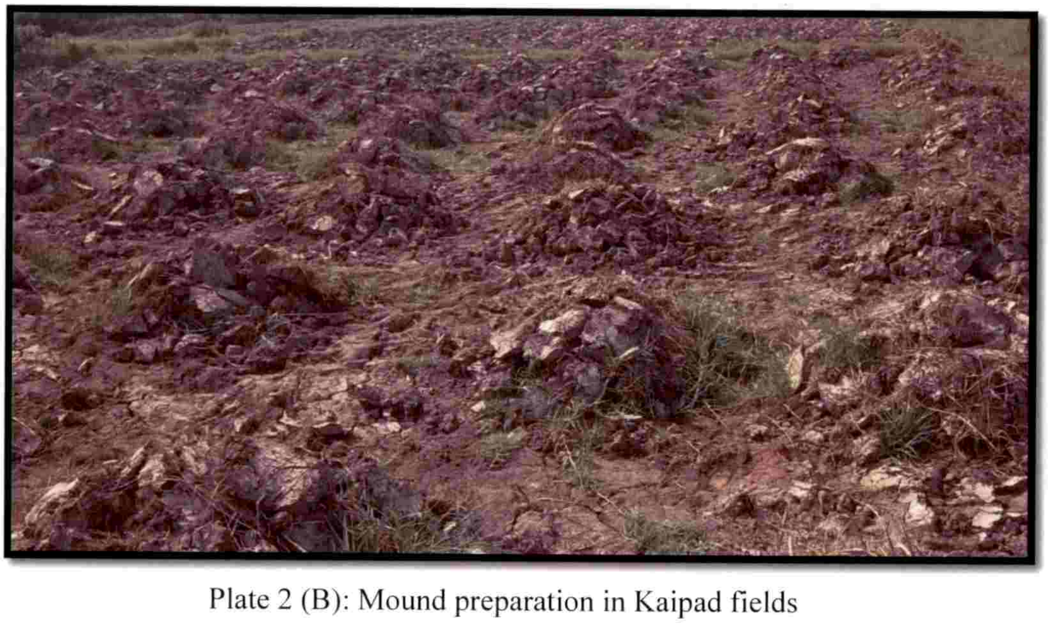

Plate 2 (B): Mound preparation in Kaipad fields

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3.2 INCUBATION STUDY

The representative saline hydromorphic soil samples collected from the Kaipad fields of Punnachery having GPS coordinates 12° 017'. 78" N and 75° 17' 19".85 E were used for the incubation study and pot culture experiment. Incubation study was carried out to study the release pattern of iron and aluminium from these saline hydromorphic soils under subsequent submergence. The levels of submergence were 5 cm and 10 cm.

Plastic pots of five litre capacity (with no drainage holes) were used for the incubation experiment. One kilogram soil was weighed and filled in the pots. Five centimeter level of submergence was maintained for the treatments T_1 to T_4 and ten centimeter level of submergence for the treatments T_5 to T_8. The loss of water through evaporation in the submergence levels were maintained by adding water once in every three days. The amounts of water to be added to the pots were measured by the difference in their weight loss at a specific interval of three days. The duration of the incubation study was 120 days.

3.2.1 Treatment details

Duration : 120 days
Design : Factorial CRD (Factorial Completely Randomized Design)
Treatments : 8 (4 treatments at two submergence levels)
Replications : 3

The treatment details are:

T_1- Lime as per KAU POP, 2011

T_2 - Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum at the rate of 500kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

The treatments T_1 toT_4 were maintained at 5 cm level of submergence and the same treatments were also maintained at 10 cm level of submergence. The soil samples were analyzed for pH, electrical conductivity, organic carbon, available N, P, K, Ca, Mg, S, Fe, Zn, Cu, Mn, B, Si, exchangeable Na and Al using the standard procedures given in Table 2 at 30, 60, 90 and 120 days after incubation. The procedure of wet analysis was carried out for the above parameters. Gravimetric method was followed to find out the moisture content in the soil samples. The initial fresh weight of the sample (W_1) was taken. Then the sample was kept in hot air oven at 105°C for 24 hours until a constant weight was obtained. The weight (W_2) of the sample was taken after drying. The moisture content was calculated using the formula,

$$\text{Percent moisture} = [(W_1 - W_2)/W_2] \times 100$$

where, W_1= Initial fresh weight ; W_2= Dry weight

The chemical composition of different ameliorants used in this study is epitomized in Table 3.

Table 3: Chemical composition of ameliorants used in the study

S. No.	Ameliorant	Composition
1.	Lime	Ca - 40 %
2.	Phosphogypsum	Ca - 220 g kg^{-1} P - 3 g kg^{-1} S - 170 g kg^{-1} F - 22 g kg^{-1}
3.	Magnesium sulphate	Mg - 9.1% S - 14%

Plate 3: Incubation study to know the release pattern of nutrients

Table 4: Physical and chemical properties of soil sample used for pot culture and incubation studies

S. No.	Parameter	Value
	I. Physical properties	
1.	Particle density (Mg m^{-3})	2.58
2.	Bulk density (Mg m^{-3})	1.10
3.	Pore space (%)	57.78
4.	Moisture (%)	55.38
5.	Mechanical composition	
a)	Sand (%)	50.90
b)	Silt (%)	15.60
c)	Clay (%)	33.50
d)	Textural class	Clay
	II. Chemical properties	
1.	pH	3.60
2.	EC (dS m^{-1})	27.10
3.	Organic carbon (g kg^{-1})	23.4
4.	Organic matter (%)	4.02
5.	CEC (c mol/kg)	74.60
6.	Available N (kg ha^{-1})	756.40
7.	Available P (kg ha^{-1})	45.10
8.	Available K (kg ha^{-1})	3325.81
9.	Exchangeable Na (c mol (P^+) kg^{-1})	1080
10.	Available Ca (mg kg^{-1})	1400

11.	Available Mg (mg kg^{-1})	43.60
12.	Available S (mg kg^{-1})	926.84
13.	Available B (mg kg^{-1})	1.63
14.	Available Fe (mg kg^{-1})	728
15.	Available Mn (mg kg^{-1})	9.21
16.	Available Zn (mg kg^{-1})	3.33
17.	Available Cu (mg kg^{-1})	4.68
18.	Exchangeable Al (c mol (P^{+}) kg^{-1})	314
19.	Available Si (mg kg^{-1})	54.5

3.3 SOLUTION CULTURE EXPERIMENT

The experiment was conducted by maintaining a nutrient solution (Hoagland's solution) containing 3 levels of iron (400, 800, 1200 mg L^{-1}), 2 levels of aluminium (15 and 30 mg L^{-1}) and 2 levels of salinity (5 and 10 dS m^{-1}) along with one control. The two selected varieties Kuthiru and Ezhome-1 were evaluated for their tolerance to varying levels of iron and aluminium coupled with salinity. Conical flasks of 250 mL capacity were used for the experiment. 200 mL of the Hoagland's solution containing the respective treatments were transferred to the flasks. The pH and the stability of the solution were also observed. The pH of the treatments was in the range of 2.4 to 2.8.

Table 5: Composition of Hoagland's solution used in the study (Hoagland and Arnon, 1950)

Chemicals	**Formula**	**Per litre of nutrient solution**
Potassium nitrate	KNO_3	5 mL of 1 *M*
Calcium nitrate	$Ca(NO_3)_2.4H_2O$	5 mL of 1 *M*
Monopotassium phosphate	KH_2PO_4	1 mL of 1 *M*
Magnesium sulphate	$MgSO_4.7H_2O$	2 mL of 1 *M*
Micronutrient stock solution		1 mL of stock solution
Iron chelate	Fe-EDTA	1-5 mL of 1000 mg L^{-1}

Micronutrient stock solution		
Boric acid	H_3BO_3	2.86 g
Manganese chloride – 4 hydrate	$MnCl_2.4H_2O$	1.81 g
Zinc sulphate – 7 hydrate	$ZnSO_4.7H_2O$	0.22 g
Copper sulphate – 5 hydrate	$CuSO_4.5H_2O$	0.08 g
85% Molybdic acid	MoO_3	0.02 g

3.3.1 Treatment details

Crop : Rice

Varieties : Kuthiru and Ezhome-1

Design : Factorial CRD (Factorial Completely Randomized Design)

Treatments : 26 (13 treatments and 2 varieties)

Replications : 3

The treatment combinations were as follows for each variety along with one control for V_1 (Ezhome-1) and V_2 (Kuthiru).

$F_1A_1S_1$	**$F_1A_2S_1$**	**$F_1A_1S_2$**	**$F_1A_2S_2$**
$F_2A_1S_1$	**$F_2A_2S_1$**	**$F_2A_1S_2$**	**$F_2A_2S_2$**
$F_3A_1S_1$	**$F_3A_2S_1$**	**$F_3A_1S_2$**	**$F_3A_2S_2$**

F_1 - 400 mg L^{-1}	**A_1 - 15 mg L^{-1}**	**S_1 - 5 dS m^{-1}**
F_2 - 800 mg L^{-1}	**A_2 - 30 mg L^{-1}**	**S_2 - 10 dS m^{-1}**
F_3 - 1200 mg L^{-1}		

The seeds were placed for germination in a petriplate with moistened filter paper and 14 days old uniformly grown plants were selected from the lot for solution culture. Different combinations of iron, aluminium coupled with salinity were given as treatments to observe the tolerance of rice plants to these treatments. The nutrient solution was changed once in every 3 to 5 days. Fe (III)-EDTA was used as the source for different levels of iron, aluminium ammonium sulphate for aluminium and sodium chloride for different levels of salinity induction. The plants were allowed to grow and observations were recorded after 7 days.

The treatments were monitored for concentrations of iron, aluminium and sodium in whole plants as well as in plant roots. The roots of the plants were dipped in 0.1 *N* HCl and were analyzed for Fe and Al in atomic absorption spectrophotometer. Plant height, root length and root dry weights were recorded. Whole plant analysis and root partitioning studies were also carried out for

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various parameters like total N, P, K, Fe, Mn, Cl, Al and Na following the standard procedures given in Table 6. The patterns of iron accumulation in roots were observed under a microscope by studying the cross-section of the roots. Root CEC (Mitsui and Ueda, 1963) and chlorine content (Volhard's method) in roots were also analyzed separately.

Table 6: Analytical methods followed for plant analysis of solution culture and pot culture experiments

Parameters	**Method**	**Reference**
Total nitrogen	Microkjeldahl method	Jackson (1958)
Total phosphorus	Diacid digestion of the plant samples followed by colorimetric estimation in spectrophotometer by Vanadomolybdate yellow colour method	Piper (1966)
Total potassium	Diacid digestion followed by filtration and estimation using flame photometry	Piper (1966)
Total sodium	Diacid digestion followed by filtration and estimation using flame photometry	Piper (1966)
Total calcium	Diacid digestion followed by filtration and estimation using atomic absorption spectroscopy	Hanlon and DeVore (1989)
Total magnesium	Diacid digestion followed by filtration and estimation using atomic absorption spectroscopy	Piper (1966)
Total sulphur	Turbidimetric method and estimation using spectrophotometer	Massoumi and Cornfield (1963)
Total iron, manganese, zinc and copper	Diacid digestion followed by filtration and estimation using atomic absorption spectroscopy	Isaac and Kerber (1971)

Total boron	Dry ashing of plant tissue followed by determination using spectrophotometer	Berger and Troug (1939)
Total silicon	Microwave digestion and estimation using inductively coupled plasma optical emission spectrometry (ICP-OES)	Haysom & Ostatek-Boczynski (2006)
Total aluminium	Diacid digestion of plant samples followed by filtration and analysis using ICP-OES (Model: Optima 8000)	Piper (1966)
Total chlorine and chlorine content in roots	Volhard's method	Volhard *et al.* (1874)

Plate 4: Solution culture using Hoagland's solution

3.4 POT CULTURE EXPERIMENT

Pot culture experiment was carried out at COA, Padannakkad during the month of July to October 2016 with the two selected rice varieties Kuthiru and Ezhome-1 in the saline hydromorphic soils of Kaipad collected from Punnachery region. Kuthiru is a saline tolerant land race having duration of 110 to120 days. 'Ezhome-1' is a popular high yielding long duration (135 -140 days) variety developed by crossing Jaya and Kuthiru. Cement pots (with no drainage holes) of diameter 42 cm and height 37 cm were used in the experiment. Each pot was filled with 22.5 kg of the composite soil sample. PVC pipes of 45 cm length and 5cm diameter with small perforations at the basal region were erected at the centre of the pots to collect the leachate. The leachate containing salts entered the pipes through the perforations and the leachate was removed using a syringe connected to a tube. The electrical conductivity of the soil in the pots had reduced to 3.9 dS m^{-1} due to the continuous washing of dissolved salts in the heavy rain. The respective treatments were imposed to the respective pots. The seeds of the two rice varieties were germinated in a petriplate. The germination percentages of the seeds were also observed. The germination percentages of Kuthiru and Ezhome-1 were 95 percent and 98 percent respectively. The germinated seeds were transferred to a potting mixture containing sand, soil and vermicompost in the ratio 3:1:1. When the rice plants attained a sufficient growth *i.e.*, after 25 days, the rice seedlings were transplanted to the pots and the water level in the pots were maintained at 5 cm. Two healthy rice seedlings each were maintained in respective pots. Fertilizer application to the plants was followed as per the KAU Package of Practices, 2011. The biometric observations were recorded at 30, 60 days after transplanting and at harvest. Soil analysis for the various parameters like pH, electrical conductivity, organic carbon, available N, P, K, Ca, Mg, S, Fe, Zn, Cu, Mn, B, Si and exchangeable Na and Al were estimated using the standard procedures given in Table 2.

The plant samples were collected at the time of harvest. These plant samples were then oven dried and analyzed for total concentration of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Si, Cl, Al and Na following the standard analytical methodologies given in Table 6. Data were recorded on agronomic parameters such as plant height (cm) and number of leaves at 30, 60 days after transplanting and at harvest.

The yield parameters like number of productive tillers, number of grains per panicle, grain yield (g/plant), chaffiness (%), 1000 grain weight (g), and straw yield (g/plant) were also noted down at the time of harvest. The high yielding variety Ezhome-1 was harvested during the first week of October 2016 (110 days) and the local variety Kuthiru was harvested during the second week of October 2016 (117 days).

3.4.1 Design and treatment details of pot culture experiment

Crop : Rice
Varieties : Kuthiru and Ezhome-1
Design : Factorial CRD (Factorial Completely Randomized Design)
Treatments : 14 (7 treatments and 2 varieties)
Replications : 3

The treatment details are:

T_1-Lime as per KAU POP, 2011

T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011)

T_3-Phosphogypsum at the rate of 500kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Lime as per KAU POP + potassium silicate -0.25% +0.25 % Boron

T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25% boron

T_6- Phosphogypsum at the rate of 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron

T_7- Absolute control

3.4.2 Biometric observations

3.4.2.1 Plant height

The height of each rice plant was measured using a metre scale from the base of the culm to the tip of the shoot at 30 and 60 DAT. The plant height at harvest was measured from the base of the culm to the tip of the longest panicle. The mean was then worked out and was expressed in centimeter (cm).

Percentage increase in plant height = (initial value – final value)/ initial value × 100

3.4.2.2 Number of leaves

The total number of leaves was noted down at 30, 60 days after transplanting and at harvest.

3.4.2.3 Number of productive tillers/ panicles

The numbers of panicles bearing the productive tillers per plant was counted at the time of harvest and the mean was calculated.

3.4.2.4 Number of grains per panicle

The total number of grains per panicle was counted manually and the mean was calculated.

3.4.2.5 Grain yield

The weight of total grains from each plant in the pot was estimated in grams and the mean of each treatment were worked out and expressed in grams per plant.

3.4.2.6 1000 grain weight

Thousand numbers of grains were randomly selected from the produce of each pot and their weight was recorded in grams and mean was worked out.

3.4.2.7 Chaffiness percentage

Chaffiness percentage was calculated treatment-wise from the given formula and the mean was calculated and expressed in percentage.

Chaffiness (%) = (Total number of unfilled grains/Total number of grains from a plant) x 100

3.4.2.8 Straw yield

The dry weights of paddy straw harvested from each plant in the pots were recorded and mean was worked out and expressed in gram per plant.

Figure 1: Schematic layout of pot culture experiment- (E- Ezhome-1; K- Kuthiru)

T_1R_3E	**T_7R_3E**	**T_6R_3E**	**T_3R_3K**	**T_6R_3K**	**T_1R_3K**
T_3R_3E	**T_5R_3E**	**T_2R_3E**	**T_4R_3E**	**T_4R_3K**	**T_5R_3K**
T_5R_1E	**T_4R_1E**	**T_1R_2E**	**T_7R_2K**	**T_7R_3K**	**T_2R_3K**
T_6R_1E	**T_7R_2E**	**T_2R_2E**	**T_5R_2K**	**T_6R_1K**	**T_1R_1K**
T_3R_1E	**T_6R_2E**	**T_5R_2E**	**T_4R_2K**	**T_7R_1K**	**T_2R_1K**
T_2R_1E	**T_7R_1E**	**T_3R_2E**	**T_2R_2K**	**T_6R_2K**	**T_3R_1K**
T_1R_1E	**T_4R_2E**	**T_1R_2K**	**T_3R_2K**	**T_5R_1K**	**T_4R_1K**

Plate 5 (A): Kuthiru rice seedlings

Plate 5 (B): Ezhome-1 rice seedlings

Plate 5 (A) & (B): Kuthiru and Ezhome-1 seedlings in potting mixture

Plate: 6 (A)

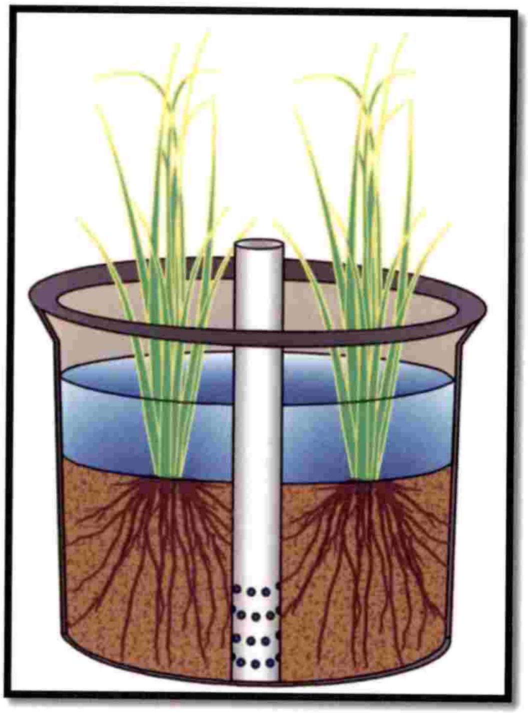

Plate: 6 (B)

Plate 6 (A) & (B): Original and 3-D image of the PVC pipe arrangement for collection of leachate

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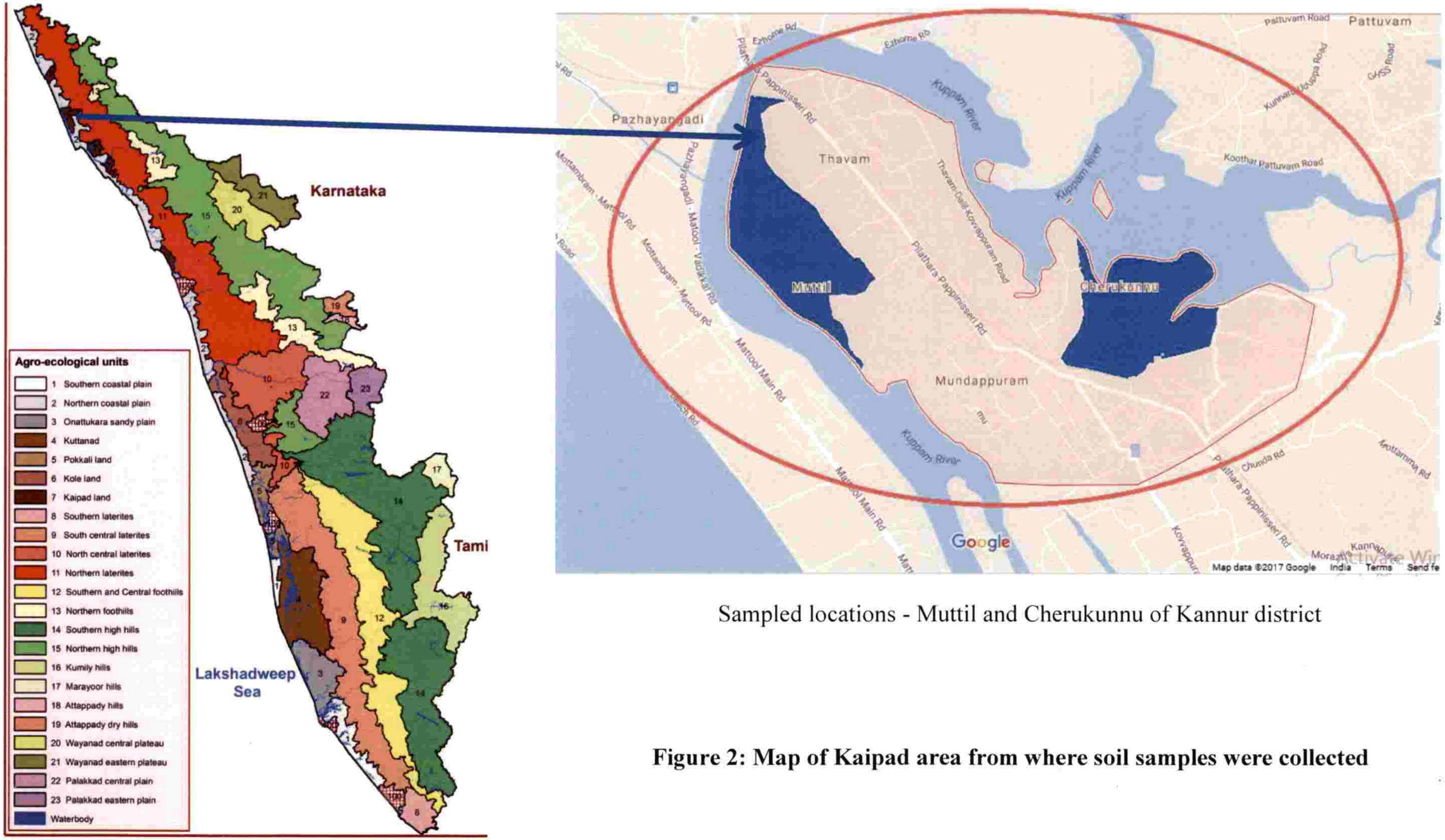
Plate 7: Transplanted seedlings



Agro-ecological zones of Kerala (7-Kaipad land)

Sampled locations - Muttil and Cherukunnu of Kannur district

Figure 2: Map of Kaipad area from where soil samples were collected

3.5 STATISTICAL ANALYSIS

The data obtained from initial soil analysis, incubation study, pot culture and solution culture were analyzed statistically and tested for its significance using OPSTAT software.

Results

4. RESULTS

An investigation on "Dynamics of iron and aluminium toxicity on rice (*Oryza sativa* L.) in saline hydromorphic soils of Kaipad" was carried out at College of Agriculture, Padannakkad during the academic year 2015 to 2017. The objectives of the study were to investigate the status of iron and aluminium in saline hydromorphic soils of Kaipad, evaluate the performance of popular rice varieties to varying levels of iron and aluminium concentration at different salinity levels, and examine amelioration strategies for iron and aluminium toxicity. The study was carried out in four parts.

Part A: Collection of soil samples and analysis of physical and chemical properties
Part B: Incubation study to know the release pattern of nutrients in the soil
Part C: Solution culture experiment
Part D: Pot culture experiment

The statistically analysed results of the various physical and chemical properties of soil, plant analysis studies, growth attributes, yield attributes etc. are given below in this chapter.

4.1 COLLECTION OF SOIL SAMPLES AND ANALYSIS OF PHYSICAL AND CHEMICAL PROPERTIES

Surface soil samples were collected from 15 locations of Kaipad comprising the areas of Muttil and Cherukunnu panchayath during the first week of April 2016. These soil samples were brought to COA, Padannakkad and were analysed for different physical properties like particle size distribution, bulk density and chemical properties like pH, electrical conductivity, organic carbon, available N, P, K, Ca, Mg, S, Fe, Zn, Cu, Mn, B, Si, exchangeable Al and Na and cation exchange capacity. The mean and range values of the analytical results obtained for different physical and chemical properties are given in Tables 7 and 8 respectively. The range, mean and standard deviation of chemical properties of the samples are given in Table 9.

4.1.1 Physical properties of soil

The bulk density varied from 1.06 Mg m^{-3} in location number 11 to 1.17 Mg m^{-3} in location number 9 with a standard deviation of 0.032. The textural classification revealed that eleven of the sampled locations had sandy clay loam texture. The texture varied from sandy loam to sandy clay loam as in Table 7. The sand content varied from 47.32 to 68.32 per cent. The silt content ranged from 12.14 to 27.31per cent. Clay content varied between 17.15 to 28.14 per cent. The moisture percentage (Appendix II) in the soil samples varied from 15.27 per cent to 86.76 per cent in location number 10 to location number 7. The mean (31.98 per cent) and standard deviation values (19.38) were also obtained.

4.1.2 Chemical properties of soil

4.1.2.1 Soil pH

The soil pH values of the sampled sites ranged from 3.40 to 6.48 with a mean value of 4.85. The highest and lowest pH was recorded in the locations 5 and 10 respectively (Table 9). The standard deviation was 0.81.

4.1.2.2 Electrical conductivity

The electrical conductivity varied from 9.72 dS m^{-1} in location number 2 to 29.00 dS m^{-1} in location number 15 with a mean electrical conductivity of 18.55 and standard deviation of 5.96. The data is elucidated in Table 8.

4.1.2.3 Organic carbon

The organic carbon varied from 5.30 to 33.40 g kg^{-1} (Table 9) with the least percentages observed in location number 13 and highest in location number 11. The standard deviation in the values was 6.80.

4.1.2.4 Available nitrogen

Available nitrogen content of the soils varied from 173.47 kg ha^{-1} to 1083.80 kg ha^{-1} with a mean value of 544.95 kg ha^{-1} and standard deviation of

220.19. The highest available nitrogen was recorded in location number 11 and the lowest in location number 13 as in Table 8.

4.1.2.5 Available phosphorus

The maximum available phosphorus content observed was 50.27 kg ha^{-1} (location number - 9) and the minimum was 8.65 kg ha^{-1} (location number - 6) as shown in Table 9. The mean value of available phosphorus was 23.77 kg ha^{-1} with a standard deviation of 14.15.

Table 7: Physical properties of soil samples from different locations of Kaipad

Location	**Particle size distribution**			**Texture**	**Bulk density (Mg m^{-3})**
	Sand (%)	**Silt (%)**	**Clay (%)**		
1	56.08	21.34	20.17	Sandy clay loam	1.15
2	58.64	19.95	21.41	Sandy clay loam	1.10
3	59.32	16.29	24.39	Sandy clay loam	1.16
4	59.64	17.56	21.20	Sandy clay loam	1.12
5	64.32	16.10	17.40	Sandy loam	1.15
6	60.14	14.32	24.28	Sandy clay loam	1.13
7	54.32	16.40	28.14	Sandy clay loam	1.16
8	68.32	12.14	17.15	Sandy loam	1.10
9	56.34	19.95	22.58	Sandy clay loam	1.17
10	47.32	25.14	26.12	Sandy clay loam	1.09
11	49.65	27.31	20.20	Loam	1.06
12	51.14	22.02	26.05	Sandy clay loam	1.13
13	61.90	13.20	22.70	Sandy clay loam	1.11
14	55.64	25.61	18.60	Sandy loam	1.15
15	48.57	23.17	25.20	Sandy clay loam	1.10

4.1.2.6 Available potassium

The available potassium was very high in the locations and varied from 1239.02 to 4630.05 kg ha^{-1}. The mean potassium content was 2808.81 kg ha^{-1} with a standard deviation of 1031.45. The highest value was recorded in location number 10 and the lowest in 13 as specified in Table 9.

4.1.2.7 Available calcium

The highest value of 3275.00 mg kg^{-1} (location number - 10) and a lowest value of 826.25 mg kg^{-1} (location number -13) of calcium was recorded in these sites. The mean value of calcium recorded was 1919.67 mg kg^{-1} with a standard deviation of 615.19 as revealed in Table 9.

4.1.2.8 Available magnesium

A maximum value of 43.60 mg kg^{-1} (location number - 2) and a minimum value of 21.30 mg kg^{-1} (location number - 13) magnesium were observed on analysis of the soil samples from these locations. The mean value and standard deviation obtained were 35.71 and 5.85 respectively as shown in Table 9.

4.1.2.9 Available sulphur

The available sulphur content (Table 8) in the sites varied from 748.77 mg kg^{-1} in location number 7 to 1534.62 mg kg^{-1} in location number 3 with a mean value of 35.71 mg kg^{-1} and standard deviation of 277.08.

4.1.2.10 Available iron

The available iron content in these soils varied from 702 mg kg^{-1} in location number 13 to 1250 mg kg^{-1} in location number 11. The mean value of iron content was 1017.13 mg kg^{-1} with a standard deviation of 195.24 as exhibited in Table 9.

4.1.2.11 Available zinc

The available zinc values ranged from 1.81 to 11.50 mg kg^{-1} in locations 6 and 11 respectively. The mean value of available zinc was recorded as 4.33 mg kg^{-1} with a standard deviation of 2.75 as disclosed in Table 9.

4.1.2.12 Available copper

The available copper content in the sites ranged from 2.07 to 6.78 mg kg^{-1} in locations 6 and 4 respectively as indicated in Table 8. The mean value was recorded as 4.41 mg kg^{-1} with a standard deviation of 1.31.

4.1.2.13 Available manganese

Location number 10 recorded the maximum available manganese content of 25.46 mg kg^{-1} and the minimum (3.4 mg kg^{-1}) in location number 12 with the mean value and standard deviation being 12.71 mg kg^{-1} and 5.98 respectively as specified in Table 8 and 9.

4.1.2.14 Available boron

The available boron content in the sampled locations ranged from 1.29 to 1.79 mg kg^{-1} in locations 15 and 12 respectively with a mean boron content of 1.61 mg kg^{-1} and the standard deviation observed was 0.13 as revealed in Table 9.

4.1.2.15 Available silicon

The maximum available silicon content of 195.00 mg kg^{-1} was observed in location number 11 and the minimum of 48.90 mg kg^{-1} in location number 3. The standard deviation was 45.14 and the mean value 109.52 mg kg^{-1} as represented in Table 9.

Table 8: Chemical properties of soil samples from different locations of Kaipad

Parameter **Location**	**pH**	**$EC_{2.5}$ ($dS\ m^{-1}$)**	**Org. C ($g\ kg^{-1}$)**	**Avail. N ($kg\ ha^{-1}$)**	**Avail. P ($kg\ ha^{-1}$)**	**Avail. K ($kg\ ha^{-1}$)**	**Avail. Ca ($mg\ kg^{-1}$)**	**Avail. Mg ($mg\ kg^{-1}$)**	**Avail. S ($mg\ kg^{-1}$)**
1	4.72	14.30	17.50	577.65	35.44	2738.9	1216.25	37.25	1314.25
2	3.96	27.00	23.40	756.4	45.21	3325.81	1400.00	43.60	926.84
3	4.66	22.00	24.00	778.98	9.77	3717.08	2125.00	41.50	1534.62
4	5.08	18.50	16.50	536.25	29.30	3130.17	1875.00	39.90	1529.09
5	3.99	18.80	16.30	526.48	11.21	2086.78	1462.50	29.95	1437.21
6	3.40	24.00	14.70	477.92	8.65	1369.45	2250.00	34.85	897.34
7	5.33	12.60	15.30	494.86	11.28	2869.32	1825.00	35.25	748.77
8	3.67	19.80	13.40	434.64	23.27	2151.99	2587.50	34.30	1316.99
9	5.02	25.00	11.30	365.03	50.27	1825.93	1625.00	28.55	1452.20
10	5.67	17.60	22.80	739.84	14.76	4630.05	3275.00	42.05	994.52
11	6.48	12.00	33.40	1083.8	17.14	3391.02	2675.00	36.90	955.07
12	5.23	29.00	14.30	466.63	15.94	4463.2	1925.00	34.60	994.20
13	5.26	16.70	5.30	173.47	12.29	1239.02	826.25	21.30	813.71
14	5.17	11.25	11.30	373.21	28.40	1983.21	1763.27	40.70	859.71
15	5.07	9.72	11.21	389.12	43.65	3210.25	1964.28	34.90	1189.23

Table 8 *contd.*: Chemical properties of soil samples from different locations of Kaipad

Parameter	**Avail. Fe (mg kg^{-1})**	**Avail. Zn (mg kg^{-1})**	**Avail. Cu (mg kg^{-1})**	**Avail. Mn (mg kg^{-1})**	**Avail. B (mg kg^{-1})**	**Avail. Si (mg kg^{-1})**	**Exch. Al (mg kg^{-1})**	**Exch. Na (mg kg^{-1})**	**CEC (c mol (P^{+}) kg^{-1})**	**ESP (%)**
Location										
1	850	2.11	5.58	13.6	1.7	80.60	249	760	74.61	4.43
2	728	3.33	4.68	9.21	1.63	54.50	314	1080	61.74	7.61
3	1220	2.91	5.23	20.8	1.55	48.90	254	960	88.07	4.74
4	809	4.96	6.78	15.5	1.5	108.00	266	880	57.57	2.43
5	950	3.98	3.9	17.1	1.55	139.00	212	700	59.91	5.08
6	1210	1.81	2.07	4.65	1.64	93.60	160	830	26.78	13.48
7	1230	7.51	5.62	17.9	1.77	111.80	368	740	104.22	3.09
8	1050	4.06	3.27	13.2	1.53	68.10	204	820	77.46	4.60
9	991	1.93	3.44	11.7	1.56	163.00	168	730	65.11	4.87
10	1240	7.66	5.97	25.46	1.76	647.90	434	960	184.46	2.26
11	1250	11.5	4.00	8.9	1.66	671.90	381	760	124.89	2.64
12	1180	5.62	2.54	3.4	1.79	110.50	245	840	45.26	8.06
13	702	3.39	4.57	7.52	1.7	124.40	223	530	21.91	10.51
14	895	2.14	3.65	9.45	1.53	82.60	256	650	55.28	5.11
15	952	1.98	4.91	12.24	1.29	76.30	213.6	580	42.72	5.90

Table 9: Minimum and maximum values, mean and standard deviation of chemical properties of 15 soil samples of Kaipad

S.No.	**Parameter**	**Range**		**Mean value**	**Standard deviation**
		Minimum value	**Maximum value**		
1	pH	3.40	6.48	4.85	0.81
2	EC (dS m^{-1})	9.72	29.00	18.55	5.96
3	Organic carbon (g kg^{-1})	5.30	33.40	16.77	6.80
4	Available nitrogen (kg ha^{-1})	173.47	1083.80	544.95	220.19
5	Available phosphorus (kg ha^{-1})	8.65	50.27	23.77	14.15
6	Available potassium (kg ha^{-1})	1239.02	4630.05	2808.81	1031.45
7	Available calcium (mg kg^{-1})	826.25	3275.00	1919.67	615.19
8	Available magnesium (mg kg^{-1})	21.30	43.60	35.71	5.85
9	Available sulphur (mg kg^{-1})	748.77	1534.62	1130.92	277.08
10	Available iron (mg kg^{-1})	702.00	1250.00	1017.13	195.24
11	Available zinc (mg kg^{-1})	1.81	11.50	4.33	2.75
12	Available copper (mg kg^{-1})	2.07	6.78	4.41	1.31
13	Available manganese (mg kg^{-1})	3.40	25.46	12.71	5.98
14	Available boron (mg kg^{-1})	1.29	1.79	1.61	0.13
15	Available silicon (mg kg^{-1})	48.90	195.00	109.52	45.14
16	Exchangeable aluminium (c mol (P^{+}) kg^{-1})	160.00	434.00	263.17	78.92
17	Exchangeable sodium (c mol (P^{+}) kg^{-1})	530.00	1080.00	788.00	146.93
18	CEC (c mol (P^{+}) kg^{-1})	21.91	184.46	79.33	46.29

4.1.2.16 Exchangeable aluminium

The exchangeable aluminium contents in the sites varied in their concentration from 160 (c mol (P$^+$) kg^{-1}) in location 6 to 434 (c mol (P$^+$) kg^{-1}) in location 10 as denoted in Table 8. The mean value of aluminium was 263.17 (c mol (P$^+$) kg^{-1}) and the standard deviation was calculated as 78.92.

4.1.2.17 Exchangeable sodium

Tables 8 and 9 gives the data on exchangeable sodium. The highest exchangeable sodium content (1080 (c mol (P$^+$) kg^{-1})) was observed in location number 2 and the lowest value (530 (c mol (P$^+$) kg^{-1})) was observed in location number 13. The mean sodium content was 760 (c mol (P$^+$) kg^{-1})^1 among the locations having a standard deviation of 146.93.

4.1.2.18 Cation exchange capacity (CEC)

Maximum CEC (184.46 c mol kg^{-1}) was observed in location number 10 and the minimum (21.91 c mol kg^{-1}) was observed in location number 13 with the mean value being 79.33 c mol kg^{-1} as demarcated in Table 9.

4.2 INCUBATION STUDY

The representative saline hydromorphic soil samples collected from the Kaipad fields of Punnachery were used for the incubation study. The study was carried out to know the release pattern of iron and aluminium from these saline hydromorphic soils under subsequent levels of submergence. The treatments T_1 to T_4 were maintained at two levels of submergence (5 cm and 10 cm). The soil samples were then analyzed for pH, electrical conductivity, organic carbon, available N, P, K, Ca, Mg, S, Fe, Zn, Cu, Mn, B, Si, and exchangeable Al and Na at 30, 60, 90 and 120 days after incubation (DAI). The statistically analyzed results were interpreted as given below.

4.2.1 Effect of amendments on chemical properties of soil

4.2.1.1 Soil pH

Result of the effect of treatments, levels of submergence and their interaction on soil pH at 30, 60, 90 and 120 days of the incubation study were tabulated and analyzed statistically and is presented in Table 10.

The submergence levels S_1 (5 cm) and S_2 (10 cm) showed no significant effect on the soil pH at 30 and 90 DAI. However, at 60 (4.92) and 120 (5.10) DAI, S_2 showed significantly higher pH.

There was significant difference between the treatments at 30, 60, 90 and 120 DAI. On comparing the treatments at 30, 60 and 90 DAI, the treatments T_1 showed significantly higher soil pH (4.91, 5.02, 5.09 respectively) which was on par with treatment T_3 (4.85, 4.98, 5.07 respectively). However, at 120 DAI, the treatment T_3 (5.14) showed significantly higher pH which was on par with T_1 (5.12).

When the interaction of submergence and treatments was considered, there was no significant difference found at 30, 90 and 120 DAI. However, at 60 DAI, the treatment T_1 (5.07) showed a significantly higher pH which was on par with T_3 (5.05) at 10 cm level of submergence.

4.2.1.2 Electrical conductivity

The values of EC in response to treatments, submergence levels and their interaction to electrical conductivity at 30, 60, 90 and 120 DAI is represented in Table 11.

There was no significant difference with respect to electrical conductivity between the two submergence levels at 30, 90 and 120 DAI whereas, significantly higher EC was observed in S_1 (7.36 dS m^{-1}) at 60 DAI.

Table 10: Effect of different amendments on soil pH at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	4.89	4.93	4.91	4.98	5.07	5.02	5.07	5.11	5.09	5.12	5.13	5.12
T_2	4.75	4.72	4.74	4.85	4.84	4.85	4.92	4.97	4.95	4.98	5.08	5.03
T_3	4.81	4.88	4.85	4.90	5.05	4.98	5.06	5.08	5.07	5.13	5.15	5.14
T_4	4.68	4.65	4.67	4.81	4.82	4.82	4.88	4.89	4.89	4.94	5.04	4.99
Mean	4.78	4.80		4.89	4.94		4.98	5.02		5.04	5.10	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	0.05	NS		0.015	0.032		0.016	NS		0.014	0.029	
T	0.08	0.16		0.021	0.046		0.023	0.049		0.019	0.041	
S x T	0.11	NS		0.030	0.065		0.032	NS		0.027	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

Table 11: Effect of different amendments on electrical conductivity (dS m^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	7.27	7.30	7.29	7.88	6.03	6.96	8.90	6.63	7.77	9.27	7.13	8.20
T_2	8.10	8.60	8.35	6.73	7.10	6.92	7.10	8.33	7.72	8.53	8.57	8.55
T_3	6.80	6.53	6.67	6.30	5.70	6.00	7.13	6.83	6.98	9.47	8.60	9.03
T_4	9.23	9.30	9.27	8.53	8.13	8.33	9.67	8.37	9.02	9.80	9.33	9.57
Mean	7.85	7.93		7.36	6.74		8.20	7.54		9.27	8.41	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	0.30	NS		0.18	0.39		0.57	NS		0.53	NS	
T	0.42	0.90		0.26	0.55		0.81	NS		0.75	NS	
S x T	0.60	NS		0.36	0.78		1.15	NS		1.06	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

The treatments showed no significant difference in electrical conductivity at 90 and 120 DAI. However, the treatments T_3 showed significantly lower electrical conductivity at 30 and 60 DAI (6.67 and 6.00 dS m^{-1} respectively). This was on par with T_1 (7.29 dS m^{-1}) at 30 DAI.

4.2.1.3 Organic carbon

The data on the organic carbon content of soil at 30, 60, 90 and 120 DAI are given in Table 12.

There were no significant effect of treatments on the organic carbon content of soil at both levels of submergence throughout the incubation period compared to control.

As far as the effects of treatments are considered, T_1 recorded significantly superior organic carbon content at 30 (19.2 g/kg) and 60 (11.1 g/kg) DAI. Treatment T_1 was on par with T_2 (18.7 g/kg) and T_3 (18.5 g/kg) at 30 DAI. However at 90 and 120 DAI, T_2 (8.1, 6.8 g/kg respectively) had a significantly higher organic carbon content which was on par with T_1 (7.2, 6.0 g/kg) and T_3 (7.1, 6.0 g/kg) respectively.

The submergence *vs.* treatments interactions was found to be non-significant at 30 and 60 DAI whereas, T_2 at 5 cm submergence levels recorded significantly higher organic carbon at 90 and 120 DAI (9.7, 8.0 g/kg respectively) whereas, at 120 DAI, T_2 at 5 cm submergence level was on par with T_1 (6.9 g/kg) at 10 cm.

4.2.1.4 Available nitrogen

Table 13 represents the data on available nitrogen at 30, 60, 90 and 120 DAI.

The submergence levels had no significant influence on the available nitrogen status at 30, 60, 90 and 120 DAI.

On considering the effect of treatments, T_3 (356.28 kg ha^{-1}) showed significantly highest available nitrogen content at 30 DAI which was on par with T_2 (356.26 kg ha^{-1}) and T_1 (355.65 kg ha^{-1}) compared to control. The treatment T_2 recorded

Table 12: Effect of different amendments on organic carbon status (g kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	19.55	18.90	19.20	11.40	10.80	11.10	5.50	8.90	7.20	5.10	6.90	6.00
T_2	19.33	18.10	18.70	10.10	8.40	9.30	9.70	6.50	8.10	8.00	5.60	6.80
T_3	18.90	18.00	18.50	8.30	6.50	7.40	8.00	6.20	7.10	6.40	5.50	6.00
T_4	14.70	15.80	15.30	7.50	6.30	6.90	6.20	5.60	5.90	5.40	4.70	5.10
Mean	18.10	17.70		9.30	8.00		7.40	6.80		6.20	5.70	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	0.46	NS		0.33	0.70		0.32	NS		0.31	NS	
T	0.66	1.40		0.47	0.99		0.45	0.97		0.44	0.94	
S x T	0.93	NS		0.66	NS		0.64	1.37		0.62	1.33	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

Table 13: Effect of different amendments on available nitrogen content (kg ha^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	30 DAI			60 DAI			90 DAI			120 DAI		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	350.19	361.11	355.65	368.36	366.76	367.56	388.06	394.18	391.12	401.11	404.96	403.03
T_2	362.90	349.61	356.26	370.16	365.33	367.74	401.03	411.81	406.42	414.83	417.89	416.36
T_3	370.13	342.42	356.28	372.42	360.24	366.33	390.35	392.53	391.44	401.02	399.29	400.16
T_4	332.88	337.50	335.19	347.50	348.52	348.01	371.22	366.90	369.06	380.02	377.47	378.75
Mean	354.03	347.60		364.61	360.21		387.67	391.35		399.25	399.90	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	3.90	NS		3.63	NS		4.87	NS		4.07	NS	
T	11.81	11.81		5.14	10.98		6.89	14.73		5.76	12.31	
S x T	16.70	16.70		7.26	NS		9.74	NS		8.14	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

significantly higher available nitrogen content at 60, 90 and 120 DAI (367.74, 406.42, 416.36 kg ha^{-1} respectively). At 60 DAI, T_2 (367.74 kg ha^{-1}) was on par with T_1 (367.56 kg ha^{-1}) and T_3 (366.33 kg ha^{-1}).

The interaction between levels of submergence and treatments were found non-significant at 60, 90 and 120 DAI. At 30 DAI, T_3 at 5 cm submergence level showed significantly high available nitrogen content (370.13 kg ha^{-1}) which was on par with T_2 at 5 cm (362.90 kg ha^{-1}) and T_1 at 10 cm (361.11 kg ha^{-1}).

4.2.1.5 Available phosphorus

The data on available phosphorus content as influenced by treatments are presented in Table 14.

The submergence levels S_1 and S_2 did not differ significantly with respect to available phosphorus content at 30 and 60 DAI. At 90 and 120 DAI, S_1 recorded significantly higher (36.55, 38.30 kg ha^{-1} respectively) amount of available phosphorus content.

When the effect of treatments on the status of available phosphorus was evaluated, it was observed that T_3 showed significantly higher available phosphorus content (60.17 kg ha^{-1}) at 30 DAI. The treatment T_3 showed significantly maximum available phosphorus content at 60, 90 and 120 DAI (42.29, 37.56, 39.43 kg ha^{-1} respectively) which was on par with the treatment T_1 (40.46, 36.51, 38.08 kg ha^{-1} respectively).

There was no significant difference between the submergence level and treatment interaction at 30, 60, 90 and 120 DAI.

4.2.1.6 Available potassium

The statistical data on the available potassium content at 30, 60, 90 and 120 DAI is given in Table 15.

Table 14: Effect of different amendments on available phosphorus content (kg ha^{-1}) at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	55.96	55.05	55.51	40.52	40.40	40.46	36.71	36.31	36.51	38.32	37.84	38.08
T_2	57.37	56.01	56.69	40.01	39.66	39.83	37.07	33.91	35.49	39.25	35.36	37.31
T_3	60.36	59.99	60.17	42.59	41.98	42.29	38.18	36.94	37.56	39.77	39.08	39.43
T_4	55.35	54.35	54.85	38.53	39.30	38.92	34.25	34.03	34.14	35.86	35.21	35.54
Mean	57.26	56.35		40.41	40.34		36.55	35.30		38.30	36.87	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	0.93	NS		0.64	NS		0.50	1.061		0.52	1.12	
T	1.31	2.81		0.90	1.922		0.70	1.501		0.74	1.59	
S x T	1.86	NS		1.27	NS		0.99	NS		1.05	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

Table 15: Effect of different amendments on available potassium content (kg ha^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	1180	1162	1751	1231	1190	1211	1251	1207	1229	1228	1181	1204
T_2	1177	1193	1185	1242	1211	1226	1269	1218	1244	1243	1201	1222
T_3	1193	1170	1182	1257	1191	1221	1275	1222	1249	1251	1215	1233
T_4	1143	1124	1133	1182	1150	1166	1194	1165	1179	1175	1128	1152
Mean	1173	1162		1226	1185		1247	1203		1224	1182	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	15.64	NS		13.77	29.44		13.05	27.91		13.72	29.34	
T	22.11	NS		19.47	41.63		18.46	39.47		19.41	41.50	
S x T	31.27	NS		27.53	NS		26.11	NS		27.45	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

There were no significant differences between the submergence levels S_1 and S_2 at 30 DAI with respect to available potassium content. The submergence level S_1 (1226, 1247, 1224 kg ha^{-1} respectively) recorded significantly higher available potassium content than S_2 (1185, 1203, 1182 kg ha^{-1} respectively) at 60, 90 and 120 DAI.

With respect to treatments, there was no significant difference between the treatments regarding the available potassium status at 30 DAI. At 60 DAI, T_2 showed significantly highest available potassium content (1226 kg ha^{-1}) which was on par with T_3 (1221 kg ha^{-1}) and T_1 (1211 kg ha^{-1}). At 90 and 120 DAI, the treatment T_3 (1249, 1233 kg ha^{-1} respectively) showed significantly higher available potassium contents which were on par with T_2 (1244, 1222 kg ha^{-1} respectively) and T_1 (1229, 1204 kg ha^{-1} respectively).

The interaction effect was not significant at 30, 60, 90 and 120 DAI.

4.2.1.7 Available calcium

The data on available calcium at 30, 60, 90 and 120 DAI are tabulated as in Table 16.

There were no significant differences in the two submergence levels at 30, 60, 90 and 120 DAI.

Among the treatments, T_3 recorded significantly higher available calcium content at 30 DAI (1699 mg kg^{-1}), 60 (1744 mg kg^{-1}), 90 (1783 mg kg^{-1}) and 120 DAI (1790 mg kg^{-1}) and it was on par with T_1 (1734, 1766, 1775 mg kg^{-1} respectively) at 60, 90 and 120 DAI. Significantly lower available calcium content was recorded in control.

The available calcium content with respect to interaction effects was not significant at 30, 60, 90 and 120 DAI.

Table 16: Effect of different amendments on available calcium content (mg kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	1675	1679	1677	1732	1736	1734	1764	1769	1766	1769	1782	1775
T_2	1623	1626	1625	1684	1675	1680	1713	1714	1714	1721	1721	1721
T_3	1698	1701	1699	1741	1748	1744	1778	1787	1783	1787	1793	1790
T_4	1624	1627	1625	1682	1678	1680	1721	1713	1717	1724	1718	1721
Mean	1655	1658		1710	1709		1744	1746		1750	1753	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	4.15	NS		5.35	NS		6.47	NS		6.48	NS	
T	5.87	12.54		7.56	16.16		9.16	19.58		9.17	19.60	
S x T	8.30	NS		10.69	NS		12.95	NS		12.96	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

Table 17: Effect of different amendments on available magnesium content (mg kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	64.17	64.83	64.50	71.50	70.62	71.06	73.54	73.92	73.73	76.39	76.89	76.64
T_2	67.50	68.00	67.75	72.72	72.63	72.68	74.48	75.67	75.07	78.12	78.20	78.16
T_3	66.00	66.71	66.36	70.27	70.44	70.35	72.33	72.47	72.40	75.69	75.78	75.74
T_4	62.17	63.24	62.70	68.19	69.04	68.61	69.81	70.90	70.36	72.84	73.61	73.23
Mean	64.96	65.70		70.67	70.68		72.54	73.24		75.76	76.12	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	0.59	NS		0.71	NS		0.69	NS		0.62	NS	
T	0.83	1.78		1.01	2.16		0.97	0.97		0.88	1.88	
S x T	1.18	NS		1.43	NS		1.38	NS		1.24	1.24	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

4.2.1.8 Available magnesium

Table 17 gives the data on available magnesium content at 30, 60, 90 and 120 DAI.

No significant difference was observed between the submergence levels at 30, 60, 90 and 120 DAI.

Treatment T_2 showed significantly higher available magnesium content (67.75 mg kg^{-1}) at 30 DAI which was on par with T_3 (66.36 mg kg^{-1}). At 60 and 120 DAI, treatment T_2 (72.68, 78.16 mg kg^{-1} respectively) showed significantly higher available magnesium content which was on par with T_1 (71.06, 76.64 mg kg^{-1} respectively). The treatment T_2 also showed significantly higher available magnesium content (75.07 mg kg^{-1}) at 90 DAI.

The interaction was found statistically non-significant at 30, 60 and 90 DAI. However at 120 DAI, T_2 (76.12 mg kg^{-1}) at 10 cm level of submergence showed significantly higher available magnesium content which was on par with T_2 (78.12 mg kg^{-1}) at 5 cm submergence level.

4.2.1.9 Available sulphur

The statistically analyzed data of the available sulphur content under two submergence levels with different treatments at 30, 60, 90 and 120 DAI are given in Table 18.

There were no significant differences with respect to submergence levels on available sulphur content at 30, 60, 90 and 120 DAI.

The treatments T_3 recorded significantly higher sulphur content at 30 (624.91 mg kg^{-1}), 60 (567.22 mg kg^{-1}), 90 (453.11mg kg^{-1}) and 120 (391.35 mg kg^{-1}) DAI. However, at 30 and 120 DAI, T_3 (624.91, 391.35 mg kg^{-1}) was found to be on par with T_2 (619.88, 387.87 mg kg^{-1} respectively).

There was no significant difference between the submergence level and treatment interaction at 30, 60, 90 and 120 DAI.

4.2.1.10 Available iron

Table 19 illustrates the data on available iron content at 30, 60, 90 and 120 DAI.

There was no significant difference among the levels of submergence at 30, 60, 90 and 120 DAI on available iron content of soil.

At 30 and 120 DAI, the treatment T_1 (911.01, 937.62 mg kg^{-1} respectively) recorded significantly minimum value of available iron content which was on par with T_3 (919.20, 951.86 mg kg^{-1} respectively). At 60 and 90 DAI, the treatment T_3 (907.17, 940.98 mg kg^{-1} respectively) showed significantly minimum available iron content. At 60 DAI, T_3 was found to be on par with T_1 (914.03 mg kg^{-1}) whereas at 90 DAI, it was on par with T_2 (944.99 mg kg^{-1}) and T_1 (947.11 mg kg^{-1}) respectively.

No significant difference was observed between the interactions at 30, 60, 90 and 120 DAI.

4.2.1.11 Available zinc

Table 20 gives the data on available zinc at 30, 60, 90 and 120 DAI.

The submergence levels S_1 and S_2 showed no significant difference in available zinc at 30, 60 and 90 DAI. However, at 120 DAI, submergence level S_2 at 10 cm showed significantly higher available zinc (0.88 mg kg^{-1}).

Among the treatments, T_3 showed significantly higher available zinc (2.88 mg kg^{-1}) content at 30 DAI. At 60, 90 and 120 DAI, the treatments T_1 recorded significantly lowest status of available zinc (1.33, 0.93, 0.61 mg kg^{-1} respectively). In case of 120 DAI, the treatment T_1 (0.60mg kg^{-1}) was on par with T_2 (0.75 mg kg^{-1}) and T_3 (0.82 mg kg^{-1}).

The submergence *vs.* treatments interaction was non-significant at 30, 90 and 120 DAI. However at 60 DAI, the treatment T_4 at 10 cm submergence level had significantly higher available zinc (1.75 mg kg^{-1}) which was on par with T_2 (1.75 mg kg^{-1}) at 5 cm and T_4 (1.62 mg kg^{-1}) at 5 cm.

Table 18: Effect of different amendments on available sulphur content (mg kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	614.73	615.18	614.95	543.27	54132	542.29	437.49	438.90	438.20	381.34	379.01	380.18
T_2	618.43	621.34	619.88	554.38	552.70	553.54	448.31	447.37	447.84	388.51	387.22	387.87
T_3	624.50	625.33	624.91	566.28	568.15	567.22	452.56	453.66	453.11	391.31	391.38	391.35
T_4	613.09	614.26	613.68	541.56	542.91	542.24	437.21	440.75	438.98	376.80	375.38	376.09
Mean	617.69	619.03		551.37	551.27		443.89	445.17		384.49	383.25	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	1.62	NS		3.06	NS		1.56	NS		1.90	NS	
T	2.29	4.90		4.32	9.24		2.21	4.71		2.68	5.74	
S x T	3.24	NS		6.11	NS		3.12	NS		3.79	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

Table 19: Effect of different amendments on available iron content (mg kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	909.86	912.15	911.01	923.07	904.99	914.03	952.44	941.78	947.11	944.81	930.44	937.62
T_2	925.83	922.73	924.28	925.94	924.15	925.04	947.98	942.00	944.99	964.12	960.71	962.42
T_3	921.16	917.24	919.20	903.94	910.40	907.17	941.56	940.39	940.98	957.36	946.36	951.86
T_4	946.24	936.83	941.54	936.53	949.67	943.10	976.72	970.03	973.38	976.29	992.71	984.50
Mean	925.77	922.24		922.37	922.30		954.68	948.55		960.65	957.56	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	4.16	NS		4.66	NS		3.63	NS		5.23	NS	
T	5.88	12.57		6.59	14.08		5.14	10.99		7.39	15.80	
S x T	8.31	NS		9.31	NS		7.27	NS		10.45	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

4.2.1.12 Available copper

The results of the soil analysis at 30, 60, 90 and 120 DAI for the copper content are presented in Table 21.

There were no significant differences in the content of available copper at two submergence levels 30, 60, 90 and 120 DAI.

At 30, 60, 90 and 120 DAI, the treatment T_1 recorded significantly lowest (2.18, 1.09, 0.69 and 0.44 mg kg^{-1}) available copper content. At 30 DAI, the treatment T_1 was found to be on par with T_4 (2.27 mg kg^{-1}). The available copper content observed in T_1 was on par with T_2 at 90 DAI. Thereafter at 90 and 120 DAI, T_1 was on par with T_2 (0.48 mg kg^{-1}) and T_3 (0.50 mg kg^{-1}) respectively.

The submergence and treatment interaction was found non-significant at 30, 60, 90 and 120 DAI.

Table 20: Effect of different amendments on available zinc content (mg kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	2.55	2.51	2.53	1.31	1.35	1.33	0.87	1.00	0.93	0.62	0.59	0.61
T_2	2.74	2.60	2.67	1.67	1.37	1.52	1.17	1.15	1.16	0.71	0.79	0.75
T_3	2.92	2.83	2.88	1.48	1.45	1.47	1.18	1.20	1.19	0.68	0.96	0.82
T_4	2.57	2.75	2.66	1.62	1.75	1.69	1.22	1.47	1.45	0.82	1.17	1.00
Mean	2.69	2.67		1.52	1.48		1.11	1.20		0.71	0.88	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	0.048	NS		0.05	NS		0.06	NS		0.08	0.17	
T	0.068	0.146		0.07	0.157		0.08	0.18		0.11	0.24	
S x T	0.096	NS		0.10	0.222		0.12	NS		0.16	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

Table 21: Effect of different amendments on available copper content (mg kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	2.15	2.21	2.18	1.07	1.15	1.09	0.64	0.74	0.69	0.42	0.46	0.44
T_2	2.95	2.83	2.89	1.51	1.15	1.33	0.80	0.80	0.80	0.48	0.48	0.48
T_3	2.29	2.38	2.33	1.46	1.42	1.44	0.87	0.90	0.89	0.47	0.54	0.50
T_4	2.17	2.37	2.27	1.34	1.36	1.35	0.94	0.86	0.90	0.63	0.60	0.61
Mean	2.39	2.45		1.33	1.27		0.81	0.83		0.50	0.52	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	0.06	NS		0.07	NS		0.04	NS		0.02	NS	
T	0.09	0.194		1.00	0.21		0.05	0.12		0.03	0.07	
S x T	0.13	NS		0.14	NS		0.08	NS		0.05	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

4.2.1.13 Available manganese

The data on available manganese in incubation study at 30, 60, 90 and 120 DAI is represented in Table 22.

There were no significant differences between the submergence levels S_1 and S_2 as well the submergence *vs.* treatment interaction at 30, 60, 90 and 120 DAI.

When the treatments were considered, T_1 exhibited significantly minimum values at 30 (11.21 mg kg^{-1}), 60 (7.09 mg kg^{-1}), 90 (8.98 mg kg^{-1}) and 120 (9.74 mg kg^{-1}) DAI.

4.2.1.14 Available boron

The statistically tabulated data on available boron at 30, 60, 90 and 120 DAI is given in Table 23.

The submergence levels S_1 and S_2 showed no significant difference on available boron content at 30 and 60 DAI. However, at 90 and 120 DAI, S_1 (1.07, 1.06 mg kg^{-1} respectively) at 5 cm recorded significantly superior available boron content. The treatments T_2 recorded significantly maximum available boron content (1.18, 1.11, 1.10, 1.10 mg kg^{-1} respectively) which was found to be on par with T_1 (1.16, 1.07, 1.05 mg kg^{-1} respectively) at 30, 60, 90 and 120 DAI.

The submergence and treatment interaction was statistically non-significant at 30, 60, 90 and 120 DAI.

Table 22: Effect of different amendments on available manganese content (mg kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	10.95	11.48	11.21	7.10	7.07	7.09	9.03	8.93	8.98	9.78	9.69	9.74
T_2	12.09	12.16	12.12	10.23	10.95	10.59	11.79	11.97	11.88	12.48	12.49	12.49
T_3	12.06	11.60	11.83	8.83	9.15	8.99	11.04	10.98	11.01	11.66	11.52	11.59
T_4	12.14	13.24	12.69	10.86	10.91	10.89	12.01	12.33	12.17	12.75	12.89	12.82
Mean	11.81	12.12		9.23	9.52		10.97	11.05		11.67	11.65	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	0.19	NS		0.24	NS		0.20	NS		0.22	NS	
T	0.26	0.56		0.33	0.71		0.28	0.59		0.32	0.68	
S x T	0.37	NS		0.47	NS		0.39	NS		0.44	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

Table 23: Effect of different amendments on available boron content (mg kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	1.15	1.17	1.16	1.12	1.09	1.10	1.09	1.05	1.07	1.08	1.03	1.05
T_2	1.19	1.18	1.18	1.10	1.11	1.11	1.10	1.09	1.10	1.10	1.09	1.10
T_3	1.07	1.04	1.06	1.03	0.97	1.00	1.00	0.95	0.98	1.00	0.95	0.98
T_4	1.02	1.00	1.01	1.07	0.97	1.02	1.07	0.96	1.02	1.07	0.96	1.02
Mean	1.11	1.10		1.08	1.03		1.07	1.01		1.06	1.01	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	0.02	NS		0.02	NS		0.02	0.05		0.02	0.04	
T	0.03	0.065		0.03	0.07		0.03	0.06		0.03	0.06	
S x T	0.04	NS		0.05	NS		0.04	NS		0.04	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

4.2.1.15 Available silicon

Table 24 illustrates the data on available silicon content at 30, 60, 90 and 120 DAI.

The submergence levels had no significant effect on available silicon content at 30, 60, 90 and 120 DAI. Among the treatments, T_3 (66.84, 62.79 mg kg^{-1} respectively) exhibited significantly high values of available silicon content at 30 and 60 DAI which was on par with the treatments T_2 (66.49, 62.27 mg kg^{-1} respectively). The treatment T_3 presented significantly superior available silicon at 90 DAI which was on par with the treatments T_2 (55.53 mg kg^{-1}) and T_1 (54.48 mg kg^{-1}). The treatments were found to be non-significant at 120 DAI.

The interactions also had no significant differences in the available silicon contents at 30, 60, 90 and 120 DAI.

4.2.1.16 Exchangeable aluminium

The tabular form of the data on exchangeable aluminium content at 30, 60, 90 and 120 DAI are as in Table 25.

No significant difference was observed in between the submergence levels as well as the submergence *vs.* treatment interaction at 30, 60, 90 and 120 DAI.

On considering the treatments, the treatment T_3 (214.67 c mol (P$^+$) kg^{-1}) recorded significantly minimum value with respect to exchangeable aluminium content at 30 DAI which were on par with the treatments T_1 (215.00 c mol (P$^+$) kg^{-1}) and T_2 (222.00 c mol (P$^+$) kg^{-1}) respectively. However, at 60 and 120 DAI, a significantly minimum value of exchangeable aluminium was observed in the treatments T_3 (172.17, 100.83 c mol (P$^+$) kg^{-1}respectively) which were on par with T_1 (178.17, 105.83 c mol (P$^+$) kg^{-1} respectively). In case of 90 DAI, the least aluminium content was observed in soil treated with lime alone (137.67 c mol (P$^+$) kg^{-1}) which was on par with T_3 (140.17 c mol (P$^+$) kg^{-1}).

Table 24: Effect of different amendments on available silicon content (mg kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	65.36	65.85	65.61	61.17	61.37	61.27	54.11	54.85	54.48	48.22	48.70	48.46
T_2	66.65	66.33	66.49	65.25	62.28	62.27	55.40	55.66	55.53	47.75	48.66	48.21
T_3	66.81	66.87	66.84	62.83	62.74	62.79	55.59	55.53	55.56	49.02	48.7	48.75
T_4	64.66	64.93	64.79	60.29	60.72	60.51	53.78	53.34	53.56	47.00	46.98	46.99
Mean	65.87	66.00		61.64	61.78		54.72	54.84		48.00	48.20	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	0.39	NS		0.34	NS		0.46	NS		0.46	NS	
T	0.55	1.17		0.48	1.02		0.65	1.38		0.65	NS	
S x T	0.77	NS		0.68	NS		0.92	NS		0.92	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

Table 25: Effect of different amendments on exchangeable aluminium content (c mol (P^+) kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	216.00	215.00	215.00	176.00	180.33	178.17	139.00	136.33	137.67	107.33	104.33	105.83
T_2	221.33	222.67	222.00	198.67	195.67	197.17	163.67	167.00	165.33	117.33	125.67	121.50
T_3	215.33	214.00	214.67	172.00	172.33	172.17	139.00	141.33	140.17	99.33	102.33	100.83
T_4	237.67	236.00	236.83	215.33	214.00	214.67	185.67	181.00	183.33	143.67	146.00	144.83
Mean	222.58	221.92		190.50	190.58		156.83	156.42		116.92	119.58	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	2.89	NS		3.70	NS		4.33	NS		3.44	NS	
T	4.09	8.74		5.23	11.18		6.12	13.08		4.87	10.41	
S x T	5.78	NS		7.39	NS		8.65	NS		6.88	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

4.2.1.17 Exchangeable sodium

The data on exchangeable sodium at 30, 60, 90 and 120 DAI are given in Table 26.

The submergence levels S_1 and S_2 showed no significant difference with respect to exchangeable sodium content at 30, 60, 90 and 120 DAI.

At all the intervals of 30, 60, 90 and 120 DAI, there were no significant differences between the submergence levels S_1 and S_2 as well as the submergence *vs.* treatment interaction with respect to exchangeable sodium content.

On comparing the effect of treatments on the exchangeable sodium content at 30, 60, 90 and 120 DAI, the treatment T_1 (1199.33, 1125.00, 1092.83, 1068.67 (c mol (P^+) kg^{-1}) respectively) recorded the lowest value and the highest values were recorded in control.

4.3 SOLUTION CULTURE EXPERIMENT

The experiment was conducted by maintaining a nutrient solution (Hoagland's solution) containing 3 levels of iron (400, 800, 1200 mg L^{-1}), 2 levels of aluminium (15 and 30 mg L^{-1}) and 2 levels of salinity (5 and 10 dS m^{-1}) along with one control. The two selected varieties Kuthiru and Ezhome-1 were evaluated for their varying levels of tolerance to iron and aluminium coupled with salinity. The details of treatments are given in Table 27.

Table 26: Effect of different amendments on exchangeable sodium content (c mol (P^+) kg^{-1}) of soil at 30, 60, 90 and 120 DAI

Treatment	**30 DAI**			**60 DAI**			**90 DAI**			**120 DAI**		
	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**	S_1-5 cm	S_2-10 cm	**Mean**
T_1	1207	1191	1199	1134	1115	1125	1098	1087	1092	1067	1070	1068
T_2	1518	1510	1514	1425	1445	1435	1376	1388	1382	1346	1360	1353
T_3	1511	1487	1499	1289	1303	1296	1234	1276	1255	1159	1252	1205
T_4	1536	1528	1532	1418	1409	1414	1387	1383	1385	1359	1351	1355
Mean	1443	1429		1317	1318		1274	1283		1233	1258	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
S	23.98	NS		28.89	NS		29.84	NS		30.18	NS	
T	33.91	72.51		40.85	87.35		42.20	90.22		42.69	91.27	
S x T	47.96	NS		57.78	NS		59.67	NS		60.37	NS	

T_1- Lime as per KAU POP, 2011

T_2- Magnesium sulphate as per KAU POP, 2011 + ½ lime as per KAU POP, 2011

T_3- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011

T_4- Absolute control

Table 27: Treatments used in solution culture experiment

Treatment number	**Composition**	**Combination of iron, aluminium ($mg\ L^{-1}$) and salinity ($dS\ m^{-1}$) respectively**
T_1	$F_1A_1S_1$	400, 15, 5
T_2	$F_1A_2S_1$	400, 30, 5
T_3	$F_1A_1S_2$	400, 15, 10
T_4	$F_1A_2S_2$	400, 30, 10
T_5	$F_2A_1S_1$	800, 15, 5
T_6	$F_2A_2S_1$	800, 30, 5
T_7	$F_2A_1S_2$	800, 15, 10
T_8	$F_2A_2S_2$	800, 30, 10
T_9	$F_3A_1S_1$	1200, 15, 5
T_{10}	$F_3A_2S_1$	1200, 30, 5
T_{11}	$F_3A_1S_2$	1200, 15, 10
T_{12}	$F_3A_2S_2$	1200, 30, 10
T_{13}	Control	Hoagland's solution

The results on the different biometric observations, plant analysis and root partitioning studies are statistically interpreted as given below.

4.3.1 Biometric observations

4.3.1.1 Plant height

The statistical data on the effect of treatments on the two rice varieties and their interaction are illustrated in Table 28.

There were no differences in percentage of increase in plant height between the varieties as well as the variety x treatment interaction.

The lowest significant decrease in plant height (0.46 %) was observed in T_{12}. The other treatments followed the order T_9 (0.51 %), T_8 (0.60 %), T_5 (0.64 %), T_3 (0.65 %), T_6 and T_{11} (0.68 % each), T_4 (0.76 %), T_7 (0.79 %), T_{10} (0.82 %), T_2 (0.89 %), T_1 (1.06 %) and T_{13} (1.97 %). The highest plant height was observed in control (Hoagland's solution).

4.3.1.2 Root length

The data on root length of the rice varieties is given in Table 28.

Among the varieties, significantly lower root length was observed in V_2 *i.e.* Kuthiru (6.42 %) over V_1 *i.e.* Ezhome-1 (8.28 %).

The effect of treatments was significant with respect to percent increase in root length. The results showed that significantly highest increase in root length was recorded in control *i.e.*T_{13} (12.96 %). The lowest significant increase in root length was noted in T_{12} (6.02 %). Among the interactions, lowest significant root length was observed in T_{12} of V_2 (5.01 %) which was on par with the treatments T_{11} (5.08 %) and T_{10} (5.09 %) of Kuthiru variety.

4.3.1.3 Pattern of iron accumulation in roots

The pattern of iron coating on the roots is as shown in Plate 8 (A) and (B). The roots of the variety Kuthiru (1994 $\mu g\ g^{-1}$) showed a significantly higher

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concentration of iron compared to Ezhome-1 (1881 $\mu g\ g^{-1}$). Among all the treatments, the highest iron content was in the roots of T_{12} (1200 mg L^{-1} iron, 30 mg L^{-1} aluminium and 10 dS m^{-1} salinity). There was no iron coating in the roots of control in both varieties.

4.3.1.4 Root dry weight

The dry weights of roots observed are statistically tabulated in Table 28.

A significantly higher root dry weight was observed in V_2 *i.e.* Kuthiru (3.75 mg) over V_1 *i.e.* Ezhome-1(2.46 mg).

On comparing the treatments, the highest significant root dry weight was observed in T_8 (3.45 mg each), which was on par with T_7 (3.33 mg).

From the variety *vs.* treatment interactions, it was noticed that the highest significant root dry weight was observed in T_8 of V_2 (4.50 mg) which was on par with T_7 of V_2 (4.40 mg).

4.3.2 Plant analysis

4.3.2.1 Total nitrogen

The nitrogen concentration in the plants is statistically represented in Table 29.

A significantly superior nitrogen content was observed in variety V_1 (2.60 %) *i.e.* Ezhome-1 compared to V_2 (2.52 %) *i.e.* Kuthiru.

Among the different treatment combinations, the treatment T_9 (2.86 %) recorded the highest significant nitrogen content in plant which was on par with T_{12} (2.84 %) and T_{11} (2.80 %) respectively. The lowest nitrogen content was seen in T_{13} (1.89 %).

While considering the variety x treatment interactions, the treatment T_{12} of V_2 (2.90 %) recorded the highest significant nitrogen content. This was on par with

Table 28: Effect of different levels of iron, aluminium and salinity on plant height, root length and root dry weight

Treatment	**Increase in plant height (%)**			**Increase in root length (%)**			**Root dry weight (mg)**		
	V_1(E)	**V_2(K)**	**Mean**	**V_1(E)**	**V_2(K)**	**Mean**	**V_1(E)**	**V_2(K)**	**Mean**
T_1	1.01	1.12	1.06	8.81	6.88	7.84	2.60	3.80	3.20
T_2	0.98	0.80	0.89	8.75	6.75	7.75	2.70	3.50	3.10
T_3	0.68	0.62	0.65	8.43	6.68	7.56	2.60	3.37	2.98
T_4	0.59	0.93	0.76	8.36	6.40	7.38	2.53	3.23	2.88
T_5	0.59	0.69	0.64	7.60	6.49	7.05	2.60	4.20	3.40
T_6	0.79	0.56	0.68	7.56	6.32	6.94	2.40	4.40	3.40
T_7	0.89	0.69	0.79	7.51	6.48	7.00	2.37	4.30	3.33
T_8	0.76	0.44	0.60	7.37	6.30	6.83	2.40	4.50	3.45
T_9	0.57	0.44	0.51	7.29	5.18	6.24	2.60	3.60	3.10
T_{10}	1.06	0.58	0.82	7.19	5.09	6.14	2.13	3.70	2.92
T_{11}	0.77	0.60	0.68	7.14	5.08	6.11	2.40	3.60	3.00
T_{12}	0.46	0.46	0.46	7.03	5.01	6.02	2.40	3.33	2.87
T_{13}	2.24	1.69	1.97	14.65	10.81	12.73	2.30	3.23	2.77
Mean	0.88	0.74		8.28	6.42		2.46	3.75	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.07	NS		0.096	0.194		0.024	0.049	
T	0.18	0.36		0.245	0.493		0.062	0.125	
V x T	0.25	NS		0.347	0.698		0.088	0.177	

V_1 (E) - Variety 1 (Ezhome-1)

V_2 (K) - Variety 2 (Kuthiru)

Table 29: Effect of different levels of iron, aluminium and salinity on total nitrogen, phosphorus and potassium concentration in rice plants under solution culture

Treatment	**Total N (%)**			**Total P (%)**			**Total K (%)**		
	V_1(E)	**V_2(K)**	**Mean**	**V_1(E)**	**V_2(K)**	**Mean**	**V_1(E)**	**V_2(K)**	**Mean**
T_1	2.37	2.16	2.26	1.37	2.60	1.99	0.42	3.62	2.02
T_2	2.60	2.60	2.60	1.98	2.01	1.99	0.50	2.39	1.45
T_3	2.73	2.29	2.51	2.01	3.22	2.62	0.60	3.36	1.98
T_4	2.55	2.54	2.54	0.91	2.10	1.51	0.67	3.06	1.86
T_5	2.68	2.57	2.62	0.95	0.75	0.85	1.24	1.37	1.31
T_6	2.41	2.61	2.51	0.90	1.70	1.30	1.29	2.36	1.82
T_7	2.70	2.45	2.57	0.38	0.91	0.64	0.83	2.24	1.53
T_8	2.66	2.55	2.66	0.81	0.99	0.64	1.24	2.88	2.06
T_9	2.86	2.81	2.86	1.31	0.72	0.90	1.46	2.44	1.95
T_{10}	2.66	2.66	2.66	2.15	1.12	1.01	2.29	1.84	2.06
T_{11}	2.80	2.77	2.80	1.04	1.02	1.64	0.76	1.66	1.21
T_{12}	2.84	2.90	2.84	0.73	0.80	1.03	0.96	1.49	1.22
T_{13}	1.87	1.92	1.89	1.36	1.33	0.76	1.60	1.39	1.49
Mean	2.60	2.52		1.22	1.48		1.06	2.31	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.02	0.04		0.019	0.039		0.017	0.035	
T	0.05	0.10		0.048	0.100		0.044	0.090	
V x T	0.07	0.15		0.068	0.141		0.062	0.128	

T_9 of V_1 (2.86 %), T_{12} of V_1 (2.84 %), T_{11} of V_1 (2.80 %) and T_{11} of V_2 respectively. The lowest nitrogen content was observed in T_{13} of V_1 (1.87 %).

4.3.2.2 Total phosphorus

The total phosphorus concentration in the plants grown in solution culture experiment is shown in Table 29.

The variety V_2 (1.48 %) recorded the significantly higher concentration of phosphorus compared to V_1 (1.22 %).

The highest concentration of phosphorus was recorded in the treatment T_3 (2.62 %). On the other hand, the lowest amount of phosphorus was in T_7 and T_8 (0.64 % each).

Among the variety x treatment interactions, T_3 of V_2 (3.22 %) recorded the significantly highest amount of phosphorus. The lowest phosphorus was noted in T_9 of V_2 (0.72 %).

4.3.2.3 Total potassium

Table 29 illustrates the analytical result of potassium content in the plants.

Significantly highest concentration of potassium was observed in V_2 (2.30 %) over V_1 (1.06 %). The significantly highest plant potassium content was observed in T_8 and T_{10} (2.06 % each), which was on par with T_1 (2.02 %) and T_3 (1.98 %) respectively. The interaction effect was found to be significant. On considering the variety *vs.* treatment interaction, the significantly highest potassium content was recorded in T_1 of V_2 (3.62 %). However, T_1 of V_1 (0.42 %) recorded the lowest potassium content.

4.3.2.4 Total iron

The total iron content in the rice varieties is illustrated in Table 30.

Significantly lower iron content was observed in the variety V_2 (2769 μg g^{-1}) *i.e.* Kuthiru compared to V_1 *i.e.* Ezhome-1 (2955 μg g^{-1}). The highest significant concentration of iron was present in the treatment T_9 (4522 µg g^{-1}). Among the variety x treatment interactions, the treatment T_9 of V_1 (4823 µg g^{-1}) recorded the highest significant amount of iron.

4.3.2.5 Total manganese

The total content of manganese in rice is shown in Table 30.

The variety V_1 (661.96 µg g^{-1}) showed significantly lower manganese content compared to V_2 (672.02 µg g^{-1}). The treatments revealed that the highest significant manganese content was in T_4 (933.50 µg g^{-1}). The highest significant amount of manganese among the variety x treatment interaction was observed in T_1 of V_2 (990.49 µg g^{-1}).

4.3.2.6 Total chlorine

Table 31 gives the data on total chlorine content in rice plants of solution culture experiment.

There was no significant difference with respect to the total chlorine content in rice plants on comparing the varieties as well as the variety x treatment interaction. Among the treatments, the lowest significant concentration of chlorine was observed in T_{13} (1.09 %) and the highest in T_4 (2.83 %).

4.3.2.7 Total aluminium

The total aluminium content in plants is presented in Table 31.

The variety V_2 recorded maximum significant concentration of aluminium (1.79 %) than V_1 (1.68 %). On comparing the treatments, the highest significant aluminium content was observed in T_{10} (2.11 %) which was on par with T_{11} (2.09 %) and T_9 (2.07 %) respectively.

The effect of variety x treatment interactions revealed that T_{10} of V_1 (2.12 %) recorded the significantly highest aluminium content which was on par with T_{12}

Table 30: Effect of different levels of iron, aluminium and salinity on total iron and manganese concentration in solution culture of rice varieties

Treatment	**Total iron (µg g^{-1})**			**Total manganese (µg g^{-1})**		
	V_1(E)	**V_2(K)**	**Mean**	**V_1(E)**	**V_2(K)**	**Mean**
T_1	1476	1393	1434	860.00	990.49	925.24
T_2	1547	1420	1483	769.50	612.14	690.82
T_3	1489	1462	1475	818.50	953.56	886.03
T_4	1481	1471	1476	878.50	988.50	933.50
T_5	3388	3152	3270	612.00	660.82	636.41
T_6	3423	3218	3320	718.50	744.48	731.49
T_7	3416	3259	3337	687.00	538.86	612.93
T_8	3530	3315	3422	660.50	524.68	592.59
T_9	4823	4221	4522	608.47	566.98	587.73
T_{10}	4619	4309	4464	622.50	674.31	648.40
T_{11}	4536	4291	4413	603.50	642.00	622.75
T_{12}	4441	4262	4351	615.00	690.50	652.75
T_{13}	249	224	236	151.50	149.00	150.25
Mean	2955	2769		661.96	672.02	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	1.188	2.390		0.962	1.936	
T	3.028	6.094		2.452	4.935	
V x T	4.283	8.619		3.468	6.980	

Table 31: Effect of different levels of iron, aluminium and salinity on total chlorine and aluminium concentration in solution culture of rice varieties

Treatment	**Total chlorine (%)**			**Total aluminium (%)**		
	V_1(E)	**V_2(K)**	**Mean**	**V_1(E)**	**V_2(K)**	**Mean**
T_1	2.31	2.05	2.18	1.52	1.84	1.68
T_2	2.52	2.63	2.57	1.60	1.88	1.74
T_3	2.70	2.52	2.61	1.54	1.73	1.63
T_4	2.82	2.85	2.83	1.65	1.79	1.72
T_5	2.40	2.59	2.49	1.75	1.86	1.81
T_6	2.55	2.52	2.53	1.76	1.91	1.83
T_7	2.63	2.42	2.52	1.79	1.95	1.87
T_8	2.49	2.53	2.51	1.81	1.98	1.89
T_9	2.32	2.26	2.29	2.07	2.07	2.07
T_{10}	2.42	2.43	2.42	2.12	2.10	2.11
T_{11}	2.50	2.43	2.47	2.09	2.09	2.09
T_{12}	2.56	2.49	2.52	2.10	2.11	2.10
T_{13}	1.11	1.08	1.09	0.02	0.02	0.02
Mean	2.41	2.37		1.68	1.79	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.02	NS		0.007	0.014	
T	0.06	0.128		0.018	0.036	
V x T	0.09	NS		0.025	0.051	

of V_2 (2.11 %), T_{12} of V_1 and T_{10} of V_2 (2.10 % each), T_9 of V_1 and V_2 (2.07 % each).

4.3.2.8 Total sodium

The statistical data on total sodium is given in Table 32.

The variety V_1 (1.75 %) showed a significantly lower sodium content compared to V_2 (3.04 %). The lowest significant sodium content among the treatments was seen in T_5 (1.37 %). The highest among the treatments was reported in T_4 (3.44 %). The data on variety x treatment interactions revealed that T_1 of V_1 (0.84 %) has the lowest sodium content while, the highest was seen in T_{12} of V_2 (3.45 %).

4.3.3 Iron, aluminium, sodium, chlorine and root CEC of rice roots under solution culture

4.3.3.1 Iron

The data on rice root partitioning study with respect to iron content is given in Table 33.

The roots of the variety V_2 (1994 $\mu g\ g^{-1}$) showed a significantly higher concentration of iron compared to V_1 (1881 $\mu g\ g^{-1}$).

Among all the treatments, the highest iron content was in the roots of T_{12} (2736 $\mu g\ g^{-1}$). On considering the variety *vs.* treatment interactions, the highest iron content was noted in T_{12} of V_2 (2771 $\mu g\ g^{-1}$) which was on par with T_{11} of V_2 (2761 $\mu g\ g^{-1}$).

4.3.3.2 Aluminium

The data on aluminium content in the rice roots is recorded in Table 33.

Significantly higher aluminium content was observed in V_2 (1.78 %) over V_1 (1.59 %). Among all the treatments, the highest significant amount of aluminium was observed in the treatment T_{10} (2.01 %) which was on par with T_9 (1.99 %).

Table 32: Effect of different levels of iron, aluminium and salinity on total sodium content in rice plants under solution culture

Treatment	Total sodium (%)		
	V_1(E)	V_2(K)	Mean
T_1	0.84	2.92	1.88
T_2	0.89	2.28	1.59
T_3	1.23	4.42	2.83
T_4	1.95	4.92	3.44
T_5	1.17	1.56	1.37
T_6	1.55	2.68	2.11
T_7	1.63	3.17	2.40
T_8	2.23	3.34	2.78
T_9	1.89	2.55	2.22
T_{10}	2.17	2.95	2.56
T_{11}	2.42	3.17	2.80
T_{12}	2.55	3.45	3.00
T_{13}	2.21	2.13	2.17
Mean	1.75	3.04	
	SEm(±)	CD (0.05)	
V	0.006	0.012	
T	0.014	0.030	
V x T	0.020	0.042	

Table 33: Root partitioning study on concentration of iron and aluminium in solution culture of rice varieties

Treatment	**Iron (µg g^{-1})**			**Aluminium (%)**		
	V_1(E)	**V_2(K)**	**Mean**	**V_1(E)**	**V_2(K)**	**Mean**
T_1	1008	1025	1016	1.46	1.81	1.63
T_2	1045	1066	1055	1.51	1.87	1.69
T_3	1330	1469	1400	1.57	1.72	1.64
T_4	1419	1554	1486	1.62	1.78	1.70
T_5	2053	2339	2196	1.71	1.84	1.78
T_6	2161	2379	2270	1.73	1.89	1.81
T_7	2322	2426	2374	1.74	1.95	1.85
T_8	2419	2541	2480	1.79	1.96	1.87
T_9	2541	2657	2599	1.89	2.09	1.99
T_{10}	2610	2736	2673	1.93	2.09	2.01
T_{11}	2675	2761	2718	1.82	2.08	1.95
T_{12}	2702	2771	2736	1.85	2.07	1.96
T_{13}	171	202	186	0.016	0.018	0.017
Mean	1881	1994		1.59	1.78	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	1.288	2.592		0.004	0.009	
T	3.284	6.609		0.011	0.023	
V x T	4.645	9.347		0.016	0.033	

V_1 (E) - Variety 1 (Ezhome-1)

V_2 (K) - Variety 2 (Kuthiru)

In the variety *vs.* treatment interactions, the highest significant amount of aluminium has been observed in T_9 and T_{10} of V_2 (2.09 % each) which was on par with T_{11} (2.08 %) and T_{12} (2.07 %).

4.3.3.3 Sodium

The variety V_1 (0.83 %) showed a significantly lower sodium content than V_2 (1.70 %) as in Table 34.

The lowest significant amount of sodium was observed in the treatment T_5 (0.78). On the other hand, highest sodium content was noticed in T_{11} (1.79 %) followed by T_7 (1.57 %). The variety *vs.* treatment interactions showed that the lowest significant sodium was observed in T_1 of V_1 (0.31 %) and the highest in T_2 of V_1 (0.36 %).

4.3.3.4 Chlorine

The data on the chlorine content in roots is expressed in Table 34.

The variety V_2 (0.72 %) showed a significantly lower content of chlorine than V_1 (0.87 %).

On comparing the treatments, the lowest significant concentration of chlorine in roots was seen in T_{13}, which was on par with T_1 (0.63 %). The highest chlorine content was observed in T_7 (0.98 %) followed by T_4 (0.95 %).

The variety *vs.* treatment interactions reveals that the lowest significant content of chlorine was observed in T_{13} of V_2 (0.45 %), which was on par with T_1 of V_2 (0.54 %) and T_2 of V_2 (0.61 %) respectively.

4.3.3.5 Root CEC

The statistical data on the root CEC of rice plants is expressed in Table 34.

The varietal interaction showed that V_2 (3.55 c mol (P^+) kg^{-1}) had a significantly higher root CEC over V_1 (3.46 c mol (P^+) kg^{-1}). The highest significant root CEC

Table 34: Root partitioning study on root CEC, sodium and chlorine in solution culture of rice varieties

Treatment	**Root CEC (c mol (P^+) kg^{-1})**			**Sodium (%)**			**Chlorine (%)**		
	V_1(E)	**V_2(K)**	**Mean**	**V_1(E)**	**V_2(K)**	**Mean**	**V_1(E)**	**V_2(K)**	**Mean**
T_1	2.72	2.89	2.80	0.31	1.69	1.00	2.60	3.80	3.20
T_2	3.38	3.28	3.33	0.36	1.53	0.94	2.70	3.50	3.10
T_3	3.73	3.90	3.81	0.58	2.19	1.38	2.60	3.37	2.98
T_4	4.10	4.06	4.08	0.59	2.30	1.44	2.53	3.23	2.88
T_5	2.76	2.90	2.83	0.65	0.91	0.78	2.60	4.20	3.40
T_6	3.48	3.34	3.41	0.54	1.35	0.94	2.40	4.40	3.40
T_7	3.89	4.02	3.96	0.82	2.33	1.57	2.37	4.30	3.33
T_8	4.30	4.20	4.25	1.17	1.85	1.51	2.40	4.50	3.45
T_9	2.82	2.75	2.78	1.05	1.33	1.19	2.60	3.60	3.10
T_{10}	3.22	3.92	3.57	1.17	1.61	1.39	2.13	3.70	2.92
T_{11}	3.92	4.06	3.99	1.42	2.16	1.79	2.40	3.60	3.00
T_{12}	4.31	4.24	4.27	1.29	1.80	1.54	2.40	3.33	2.87
T_{13}	2.40	2.65	2.52	0.83	1.02	0.93	2.30	3.23	2.77
Mean	3.46	3.55		0.83	1.70		2.46	3.75	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.026	0.053		0.02	0.047		0.024	0.049	
T	0.066	0.136		0.06	0.121		0.062	0.125	
V x T	0.093	0.192		0.08	0.171		0.088	0.177	

was obtained in the treatment T_{12} (4.27 c mol (P^+) kg^{-1}), which was on par with T_8 (4.25 c mol (P^+) kg^{-1}). The lowest root CEC was in T_{13} (2.52 c mol (P^+) kg^{-1}).

Among the variety *vs.* treatment interaction, the highest root CEC was seen in T_{12} of V_1 (4.31 c mol (P^+) kg^{-1}). This was also on par with T_8 of V_1 (4.30 c mol (P^+) kg^{-1}), T_{12} of V_2 (4.24 c mol (P^+) kg^{-1}) and T_8 of V_2 (4.20 c mol (P^+) kg^{-1}) respectively.

4.4 POT CULTURE EXPERIMENT

Pot culture experiment was carried out with the two selected rice varieties Kuthiru and Ezhome-1 in the saline hydromorphic soils from Punnachery region of Kaipad during the month of July to October 2016. The statistical data on growth parameters, yield attributes, soil analysis and plant analysis studies are illustrated in this section.

4.4.1 Effects of amendments on growth parameters

4.4.1.1 Plant height

The effect of amendments on plant height is tabulated as in Table 35.

Significantly highest plant height was observed in the variety V_1 *i.e.* Ezhome-1 at 30, 60 DAT and at harvest (121.71, 134.38, 143.77 cm respectively) as compared to V_2 *i.e.* Kuthiru (57.83, 67.10, 80.66 cm respectively).

The treatments showed no significant difference with respect to plant height at 30, 60 DAT whereas at harvest, the treatment T_6 (120.95 cm) showed the significantly maximum plant height which was on par with T_3 (115.04 cm).

Considering the variety x treatment interaction at 30 DAT, significantly maximum plant height was observed in treatment T_6 of variety Ezhome-1 (129.20 cm). This was on par with T_3 (128.45cm), T_5 (127.20 cm), T_4 (124.73 cm), T_2 (121.50 cm) recorded in Ezhome-1 variety. There was no significant difference

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Table 35: Effect of different amendments on plant height (cm) of rice varieties

Treatment	**30 DAT**			**60 DAT**			**At harvest**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	115.73	60.87	88.02	129.48	69.80	99.64	132.74	87.21	109.98
T_2	121.50	54.78	88.14	131.83	65.62	98.73	142.63	78.07	110.35
T_3	128.45	56.85	92.65	144.41	63.76	104.09	152.13	77.95	115.04
T_4	124.73	48.23	86.48	131.81	64.38	98.10	140.16	79.35	109.76
T_5	127.20	61.02	94.10	131.96	66.50	99.23	134.83	80.73	107.78
T_6	129.20	63.38	96.29	143.93	70.68	107.30	157.78	84.11	120.95
T_7	105.16	59.67	85.13	127.23	68.94	98.09	146.11	77.22	111.67
Mean	121.71	57.83		134.38	67.10		143.77	80.66	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	2.38	4.91		1.35	2.76		1.13	3.27	
T	4.46	NS		2.52	NS		2.10	6.13	
V x T	6.31	12.93		3.57	NS		2.9	8.66	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

in the variety x treatment interaction at 60 DAT. However at harvest stage, treatment T_6 of variety Ezhome-1 showed the significantly highest plant height which was on par with T_3 (152.13 cm) of the same variety.

4.4.1.2 Number of leaves

Table 36 displays the statistical data on the number of leaves of Ezhome-1 and Kuthiru rice varieties at 30, 60 DAT and at harvest.

There was no significant difference in the number of leaves between the two varieties at 30 and 60 DAT whereas at harvest, significantly superior number of leaves (41.00) was recorded with respect to Ezhome-1. The significantly highest numbers of leaves were noticed in treatment T_2 (95.82) which were on par with T_3 (94.40). At harvest stage, significantly highest number of green leaves was observed in T_1 (45.33) which were on par with T_2 (41.50).

While considering the variety *vs.* treatment interaction at 30 DAT, significantly maximum number of leaves were recorded by T_3 of the variety Ezhome-1 which was on par with T_6 of variety V_1, T_4 of variety V_2, T_2 of V_1, T_5 of V_2, T_2 of V_2, T_1 of V_1 and T_3 of V_2 (77.12, 76.50, 76.00, 75.00, 74.66, 72.66, 72 respectively). At 60 DAT, T_3 of variety V_1 (103.66) exhibited the highest significant number of leaves. Finally at harvest stage, treatment T_1 of variety V_1 (51.50) recorded the maximum significant number of leaves which was on par with T_2 of variety V_1 (46.50).

4.4.1.3 Number of productive tillers

The data on the number of productive tillers is as given in Table 37.

Observations recorded between the two varieties showed that the variety V_1 *i.e.* Ezhome-1 (28.64) produced significantly maximum number of productive tillers.

Table 36: Effect of different amendments on number of leaves of rice varieties

Number of leaves	30 DAT			60 DAT			At harvest		
Treatment	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	72.66	63.39	68.03	85.82	83.05	84.43	51.50	39.17	45.33
T_2	76.00	74.66	75.33	93.23	98.42	95.82	46.50	36.50	41.50
T_3	79.18	72.00	75.59	103.66	85.15	94.40	30.33	35.00	32.67
T_4	65.00	76.50	70.75	84.00	84.28	84.14	32.17	30.83	31.50
T_5	60.16	75.00	67.58	79.32	91.32	85.32	41.83	26.67	34.25
T_6	77.12	66.50	71.81	96.50	82.33	89.41	43.80	34.00	38.90
T_7	53.66	71.41	62.54	74.16	80.91	77.54	40.87	27.33	34.10
Mean	71.35	69.11		88.10	86.49		41.00	32.79	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	1.40	NS		1.40	NS		1.22	2.52	
T	2.61	NS		2.61	5.35		2.29	4.72	
V x T	3.70	7.58		3.70	7.57		3.24	6.67	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 $kgha^{-1}$ + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 $kgha^{-1}$ + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

Table 37: Effect of different amendments on the number of productive tillers and number of grains per panicle of rice varieties

Treatment	**Number of productive tillers**			**Number of grains per panicle**		
	V_1(E)	**V_2(K)**	**Mean**	**V_1(E)**	**V_2(K)**	**Mean**
T_1	26.17	28.33	27.25	152.50	123.00	137.75
T_2	27.17	18.83	23.00	162.70	110.00	136.35
T_3	37.67	24.17	30.92	171.00	114.50	142.75
T_4	24.00	26.67	25.33	151.00	114.00	132.50
T_5	28.83	20.83	24.83	159.43	116.00	137.72
T_6	33.50	26.00	29.75	163.07	119.33	141.20
T_7	23.17	17.83	20.50	149.83	124.83	137.33
Mean	28.64	23.24		158.50	117.38	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.63	1.31		1.50	3.10	
T	1.19	2.44		2.81	5.79	
V x T	1.68	3.46		3.98	8.19	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5-Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

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While considering the treatments, the maximum numbers of significant number of productive tillers had been recorded in the treatment T_3 (30.92) which were found to be on par with T_6 (29.75).

The interaction effect of variety *vs.* treatment interaction revealed that the treatment T_3 of variety Ezhome-1 (37.67) produced the highest significant number of productive tillers.

4.4.2 Influence of amendments on yield attributes

4.4.2.1 Number of grains per panicle

The statistically tabulated data on the number of gains per panicle is given in Table 37.

The variety V_1 *i.e.* Ezhome-1(158.50) produced the significantly higher number of grains per panicle between the two varieties.

While considering the treatments, T_3 recorded the highest (142.75) significant number of grains per panicle. This was found to be on par with T_6 (141.20), T_1 (137.75), T_5 (137.72) and T_7 (137.33) respectively.

The variety x treatment interaction showed that T_3 of variety Ezhome-1 yielded the significantly maximum number of grains per panicle (171.00) and this was also on par with T_6 of Ezhome-1 (163.07).

4.4.2.2 Grain yield

The grain yield recorded in the pot culture experiment was statistically analyzed and recorded in Table 38.

A significantly higher grain yield was noticed in the variety Ezhome-1 (74.93 g pot^{-1}) compared to Kuthiru (51.60 g pot^{-1}). A significantly maximum grain yield was observed in the treatment T_6 (73.50 g pot^{-1}) followed by T_3 (68.17 g pot^{-1}). The lowest grain yield was recorded in the plants treated with T_2 (54.17 g pot^{-1}). The highest percentage increase in yield among the treatments with respect to control was found to be highest in T_3 (21.29 %). With respect to variety *vs.* treatment interaction, T_3 of variety Ezhome-1 (96.33 g pot^{-1}) recorded the highest significant yield which was found to be on par with T_6 of Ezhome-1 (96.17 g pot^{-1}).

4.4.2.3 Straw yield

The data for the straw yield at harvest is represented in Table 38.

Among the varieties, Ezhome-1 (49.37 g pot^{-1}) recorded a significantly higher straw yield. The treatment T_3 (40.86 g pot^{-1}) recorded the highest significant straw yield compared to all other treatments. The lowest straw yield was obtained in the plants treated with T_4 (29.71 g pot^{-1}). On comparing the variety x treatment interaction also, T_3 of variety Ezhome-1 (64.95 g pot^{-1}) recorded the highest significant straw yield.

4.4.2.4 Chaffiness

The data on the chaffiness percentage of the rice varieties are statistically presented in Table 38.

A significantly lower percentage of chaffiness was observed in the variety V_2 *i.e.* Kuthiru (44.58 %) compared to V_1 *i.e.* Ezhome-1(56.75 %).

On comparing the treatments, a significantly lower chaffiness percentage (47.18 %) was noticed in treatment T_1 (lime alone) which was on par with T_6 (47.58 %) and T_7 (48.56 %) respectively.

The variety x treatment interactions revealed that significantly lowest chaffiness percentage was observed in treatment T_6 of variety V_1 (41.13 %) which was found to be on par with T_4 of V_1 (41.64 %).

4.4.2.5 One thousand grain weight

The tabulated data on the weight of one thousand grains are represented in Table 39.

Table 38: Effect of different amendments on grain yield, straw yield and chaffiness of rice varieties

Treatment	**Grain yield (g pot^{-1})**			**Straw yield (g pot^{-1})**			**Chaffiness (%)**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V1(E)	V2(K)	**Mean**
T_1	61.00	65.50	63.25	41.47	23.93	32.70	46.09	48.27	47.18
T_2	69.67	42.50	54.17	48.63	25.41	37.02	45.03	61.05	53.04
T_3	96.33	44.83	68.17	64.95	20.44	40.86	45.98	62.85	54.41
T_4	64.17	64.33	64.25	46.26	24.16	29.71	41.64	62.12	51.88
T_5	73.67	43.83	59.83	49.22	16.25	32.74	45.57	58.41	51.99
T_6	96.17	48.33	73.50	49.50	22.32	35.61	41.13	54.03	47.58
T_7	63.53	43.00	60.60	45.59	23.42	34.50	46.61	50.51	48.56
Mean	74.93	51.60		49.37	22.28		56.75	44.58	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	1.06	2.19		0.78	1.61		0.48	0.98	
T	1.99	4.09		1.46	3.01		0.90	1.84	
V x T	2.81	5.78		2.07	4.25		1.27	2.60	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

Table 39: Effect of amendments on 1000 grain weight or seed index of rice varieties

Treatment	**1000 grain weight (g pot^{-1})**		
	V_1(E)	**V_2(K)**	**Mean**
T_1	28.48	20.20	24.34
T_2	27.54	15.73	21.64
T_3	30.73	18.77	24.75
T_4	28.42	18.43	23.43
T_5	27.93	16.65	22.29
T_6	30.43	17.53	23.98
T_7	26.37	15.46	20.92
Mean	28.56	17.54	
	SEm(±)	CD (0.05)	
V	0.36	0.734	
T	0.67	1.374	
V x T	0.94	1.942	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

The variety Ezhome-1 (28.56 g pot^{-1}) showed a significantly higher seed index value compared to Kuthiru (17.56 g pot^{-1}). On comparison of all the treatments, the treatment T_3 (24.75 g pot^{-1}) exhibited a significantly higher weight for one thousand grains which was on par with T_1 (24.34 g pot^{-1}), T_6 (23.98 g pot^{-1}) and T_4 (23.43 g pot^{-1}) respectively.

The variety x treatment interactions for seed index revealed a significantly higher weight in case of T_3 of V_1 (30.73 g pot^{-1}) which was on par with T_6 of V_1 (30.43 g pot^{-1}).

4.4.3 Residual nutrient status of soil

4.4.3.1 Soil pH

The results of soil pH after harvest in pot culture experiment is specified in Table 40.

On evaluating the two varieties, the variety V_2 *i.e.* Kuthiru indicated a significantly higher soil pH (5.30) compared to variety V_1 (5.17) *i.e.* Ezhome-1.

On comparing the treatments, treatment T_4 (5.48) chronicled the significantly highest pH which was on par with T_6 (5.42).

Among the variety x treatment interactions, significantly highest pH was noticed in treatment T_6 of variety V_2 (5.60). The lowest pH was observed in treatment T_7 of variety V_1 (4.21).

4.4.3.2 Electrical conductivity

The results of electrical conductivity of soil in pot culture experiment at harvest are elucidated in Table 40.

No significant differences were witnessed between the two varieties with respect to electrical conductivity.

The least significant value of electrical conductivity was spotted in the treatment T_4 (7.60 dS m^{-1}). This was also found to be on par with T_1 (7.62 dS m^{-1}) and T_6 (8.33 dS m^{-1}) respectively.

Among the variety x treatment interactions, the treatment T_1 of variety V_1 *i.e.* Ezhome-1 (6.63 dS m^{-1}) recorded the least significant electrical conductivity which was on par with T_4 of V_1 (6.73 dS m^{-1}).

The highest electrical conductivity was observed in case of T_7 (control) of variety V_1 (11.67 dS m^{-1}).

4.4.3.3 Organic carbon

Organic carbon content of the soil after harvest is depicted in Table 40.

Significantly, higher organic carbon percent was noticed in variety V_1 *i.e.* Ezhome-1 (14.0 g/kg) compared to V_2 *i.e.* Kuthiru (12.9 g/kg).

Among the treatment mean, T_6 (14.7 g/kg) discerned the significantly highest organic carbon content. The lowest organic carbon was observed in control (T_7 – 11.8 g/kg). There was no significant difference in the variety x treatment interaction.

4.4.3.4 Available nitrogen

The data on the residual available nitrogen content is presented in Table 41.

Among the two varieties, the variety V_1 *i.e.* Ezhome-1 (321.63 kg ha^{-1}) exhibited significantly higher available nitrogen content than Kuthiru (230.10 kg ha^{-1}).

The treatment T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime) recorded the highest significant amount of available nitrogen (302.63 kg ha^{-1}) which was on par with T_6 (265.94 kg ha^{-1}). There was no significant difference in available nitrogen content in the variety x treatment interaction.

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4.4.3.5 Available phosphorus

The available phosphorus content is given in Table 41.

No significant difference was observed on comparing the varieties V_1 *i.e.* Ezhome-1and V_2 *i.e.* Kuthiru. It was noted that the treatment T_4 (34.16 kg ha^{-1}) showed the significantly highest available phosphorus content and this was on par with T_1 (33.35 kg ha^{-1}). The lowest phosphorus content was observed in T_7 (control- 21.64 kg ha^{-1}).

The variety *vs.* treatment interaction revealed that T_6 of V_2 (38.28 kg ha^{-1}) showed a significantly higher available phosphorus content which was on par with T_1 of V_1 (37.88 kg ha^{-1}), T_4 of V_1 (36.87 kg ha^{-1}), T_3 of V_2 (35.62 kg ha^{-1}). The lowest available phosphorus content was witnessed in T_7 of V_1 (control- 20.99 kg ha^{-1}).

4.4.3.6 Available potassium

The statistical data on available potassium is illustrated in Table 41.

The variety Ezhome-1 indicated significantly higher available potassium (2225 kg ha^{-1}) than Kuthiru (2222 kg ha^{-1}). The treatment mean indicated that T_6 (2371 kg ha^{-1}) showed the significantly highest available potassium. The lowest available potassium content was observed in treatment T_3 (2025 kg ha^{-1}).

On comparing the interaction variety x treatment interaction, it was revealed that T_6 of variety V_1 (2474 kg ha^{-1}) showed the significantly highest available potassium content. In addition, this was found to be on par with T_3 of V_1 (2465 kg ha^{-1}). The lowest available potassium content was observed in T_7 of V_2 *i.e.* control (2053 kg ha^{-1}).

4.4.3.7 Available calcium

The available calcium content was significantly higher in V_1 (1690 mg kg^{-1}) than in V_2 (1609 mg kg^{-1}) as in Table 42.

Table 40: Effect of different amendments on pH, electrical conductivity and organic carbon content of soil after harvest of rice

Treatment	**pH**			**EC(dS m^{-1})**			**Org. Carbon (g/kg)**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	5.43	5.34	5.38	6.63	8.60	7.62	14.00	12.50	13.20
T_2	5.28	5.39	5.33	9.07	8.57	8.82	13.50	12.70	13.10
T_3	5.31	5.49	5.40	8.23	8.70	8.47	14.90	13.20	14.00
T_4	5.50	5.45	5.48	6.73	8.47	7.60	14.70	12.80	13.70
T_5	5.22	5.43	5.33	8.93	8.43	8.68	13.70	13.30	13.50
T_6	5.23	5.60	5.42	8.27	8.40	8.33	15.50	13.90	14.70
T_7	4.21	4.39	4.30	11.67	10.73	11.20	11.90	11.70	11.80
Mean	5.17	5.30		8.51	8.84		14.00	12.90	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.015	0.031		0.222	NS		0.18	0.38	
T	0.028	0.058		0.416	0.856		0.34	0.70	
V x T	0.040	0.082		0.588	1.211		0.48	NS	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

Table 41: Effect of amendments on available nitrogen, available phosphorus and potassium status of soil after harvest of rice

Treatment	**Available N (kg ha^{-1})**			**Available P (kg ha^{-1})**			**Available K (kg ha^{-1})**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	305.92	236.97	271.44	37.88	28.82	33.35	2143.33	2136.33	2182.67
T_2	324.55	215.04	269.80	32.96	27.05	30.01	2135.33	2243.67	2170.50
T_3	356.32	248.94	302.63	23.83	35.62	29.73	2465.00	2158.00	2025.33
T_4	311.50	230.76	271.13	36.87	31.45	34.16	2149.66	2125.00	2110.83
T_5	315.28	217.33	266.30	32.15	28.98	30.57	2129.00	2236.33	2138.17
T_6	343.60	248.28	295.94	21.21	38.28	29.75	2474.67	2164.33	2371.33
T_7	294.27	213.38	253.83	20.99	22.28	21.64	2079.33	2053.33	2318.00
Mean	321.63	230.10		29.41	30.36		2225.19	2222.81	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	3.78	7.79		0.86	NS		6.30	12.79	
T	7.07	14.57		1.61	3.31		11.79	24.27	
V x T	10.00	NS		2.27	4.68		16.67	34.32	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

Among the different treatments, T_6 (1803 mg kg^{-1}) indicated the highest significant available calcium content, which was on par with T_3 (1800 mg kg^{-1}). The lowest calcium content was observed in treatment T_2 (1509 mg kg^{-1}).

On considering the variety x treatment interactions, T_3 of V_1 (1826 mg kg^{-1}) indicated significantly highest available calcium content which was on par with T_6 of V_1 (1820 mg kg^{-1}). The lowest calcium content was recorded in T_2 of V_2 (1440 mg kg^{-1}).

4.4.3.8 Available magnesium

The available magnesium content in soil after harvest is indicated in Table 42. The content of available magnesium was significantly higher in the variety V_1 (80.65 mg kg^{-1}) compared to V_2 (77.71 mg kg^{-1}).

On comparing the treatments, T_2 (83.68 mg kg^{-1}) recorded the significantly highest amount of available magnesium. This was found to be on par with T_5 (82.49 mg kg^{-1}). The lowest content of available magnesium was observed in T_7 (75.29 mg kg^{-1}).

Among the variety x treatment interactions, T_2 of V_2 (85.22 mg kg^{-1}) recorded the significantly highest available magnesium content. In addition, this was on par with T_5 of V_1 (83.33 mg kg^{-1}), T_2 of V_1 (82.14 mg kg^{-1}), T_5 of V_2 (81.65 mg kg^{-1}) respectively.

4.4.3.9 Available sulphur

Table 42 shows the statistical data on available sulphur content in pot culture experiment at harvest.

Significantly higher amount of available sulphur was observed in the variety V_2 (523.55 mg kg^{-1}) compared to V_1 (469.05 mg kg^{-1}). The treatment T_6 (580.80 mg kg^{-1}) recorded the highest significant amount of available sulphur. The lowest available sulphur was noticed in T_7 (407.36 mg kg^{-1}). Among the variety *vs.* treatment interaction, significantly highest amount of available sulphur was

Table 42: Effect of amendments on available calcium, magnesium and sulphur status of soil after harvest of rice

Treatment	Available Ca (mg kg^{-1})			Available Mg (mg kg^{-1})			Available S (mg kg^{-1})		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	1744.64	1665.17	1704.90	81.12	78.08	79.60	424.84	436.61	430.73
T_2	1578.95	1440.83	1509.89	82.14	85.22	83.68	529.33	538.53	533.93
T_3	1826.27	1775.03	1800.65	79.67	74.99	77.33	480.27	649.98	565.13
T_4	1736.83	1672.00	1704.41	80.43	76.90	78.66	435.50	427.40	431.45
T_5	1568.40	1453.50	1510.95	83.33	81.65	82.49	523.76	525.66	524.71
T_6	1820.47	1786.02	1803.24	80.15	74.22	77.19	486.80	674.79	580.80
T_7	1556.33	1476.75	1516.54	77.70	72.88	75.29	402.84	411.87	407.36
Mean	1690.27	1609.90		80.65	77.71		469.05	523.55	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	3.90	8.03		0.69	1.43		2.65	5.46	
T	7.30	15.02		1.30	2.67		4.96	10.21	
V x T	10.32	21.25		1.83	3.77		7.02	14.44	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

noticed in T_6 of V_2 (674.79 mg kg^{-1}). The lowest amount was seen in T_7 of V_1 (402.84 mg kg^{-1}).

4.4.3.10 Available iron

The data on available iron is presented in Table 43.

A significantly lower amount of available iron was observed in variety V_2 (353.48 mgkg^{-1}) *i.e.* Kuthiru compared to V_1 (432.83 mg kg^{-1}). The lowest significant amount of available iron was recorded in treatment T_3 (334.67 mg kg^{-1}), which was found to be on par with T_6 (343.33 mg kg^{-1}). The highest iron content (499.83 mg kg^{-1}) was observed in T_7 (control).

The variety x treatment interactions indicated that the treatment T_1 of V_2 (312.33 mg kg^{-1}) recorded the significantly lowest iron content, which was on par with T_4 of V_2 (318 mg kg^{-1}). The highest iron content was observed in T_7 of V_1 (536.67 mg kg^{-1}).

4.4.3.11 Available copper

The data on available copper content in pot culture experiment is illustrated in Table 44.

It was observed that a significantly high available copper content was shown by the variety V_2 (4.19 mg kg^{-1}) compared to V_1 (4.13 mg kg^{-1}). Among the treatments, T_1 and T_4 (4.23 mg kg^{-1}) recorded significantly highest available copper contents which were on par with T_2 (4.16 mg kg^{-1}), T_5 (4.15 mg kg^{-1}), and also T_3 and T_6 (4.13 mg kg^{-1}) respectively. No significant difference was observed with respect to the variety x treatment interaction.

4.4.3.12 Available manganese

The available manganese content of soil at harvest in pot culture experiment is given in Table 43.

Significantly lower available manganese contents were observed in V_1 (2.93 mg kg^{-1}) than V_2 (3.90 mg kg^{-1}). Among the treatments, the lowest significant amount of manganese was observed in T_1 (2.93 mg kg^{-1}), which was on par with T_5 (3.01 mgkg^{-1}) T_2 (3.07 mgkg^{-1}), T_3 (3.23 mg kg^{-1}) and T_6 (3.24 mg kg^{-1}) respectively. The variety x treatment interactions showed that the treatment T_4 of V_1 (2.34 mg kg^{-1}) recorded the significantly lowest manganese. This was on par with the treatments T_1 of V_1 (2.43 mg kg^{-1}), T_6 of V_1 (2.63 mg kg^{-1}), T_5 of V_1 (2.65 mg kg^{-1}), T_3 of V_1 (2.66 mg kg^{-1}), T_2 of V_1 (2.72 mg kg^{-1}) and T_7 of V_1 (2.77 mg kg^{-1}) respectively.

4.4.3.13 Available zinc

Table 43 represents the data on available zinc in pot culture experiment.

On comparing the two varieties, significantly higher available zinc was observed in the variety Kuthiru (1.28 mg kg^{-1}) over Ezhome-1 (1.25 mg kg^{-1}). In case of treatment mean, the treatment T_6 (1.32 mg kg^{-1}) recorded highest significant amount of zinc content which was on par with T_5 (1.31 mg kg^{-1}). The lowest zinc content (1.20 mg kg^{-1}) was detected in T_7 (control). The variety x treatment interaction was non-significant with respect to available zinc.

4.4.3.14 Available boron

The variety V_2 *i.e.* Kuthiru (1.32 mg kg^{-1}) showed significantly higher available boron content compared to V_1 *i.e.* Ezhome-1(1.26 mg kg^{-1}) as in Table 45. Among the treatments, T_4 and T_6 (1.33 mg kg^{-1}) recorded the highest significant boron content which were on par with T_3 (1.29 mg kg^{-1}). In the variety x treatment interactions, the treatments T_4 and T_6 of V_2 (1.34 mg kg^{-1} each) noted the highest significant available boron content, which were on par with T_1 and T_7 of V_2 (1.33 mg kg^{-1} each), T_6 of V_1 (1.32 mg kg^{-1}), T_2 of V_2, T_3 and T_5 of V_1 (1.30 mg kg^{-1}each) and T_3 of V_2 (1.29 mg kg^{-1}) respectively.

4.4.3.15 Available silicon

The residual soil analysis results of available silicon is presented in Table 45.

No significant difference was observed between the varieties and as well as in the variety x treatment interaction. Among the treatments, significantly highest silicon content was observed in the treatment T_1 (75.41 mg kg^{-1}), which was on par with T_4 (75.00 mg kg^{-1}), T_2 (72.76 mg kg^{-1}) and T_6 (71.75 mg kg^{-1}) respectively.

4.4.3.16 Exchangeable aluminium

The data on exchangeable aluminium in pot culture experiment is illustrated in Table 45.

On comparing the two varieties, the variety V_2 *i.e.* Kuthiru (273.67 c mol (P$^+$) kg^{-1}) recorded a significantly lower exchangeable aluminium content over V_1 *i.e.* Ezhome-1 (286.05 c mol (P$^+$) kg^{-1}).

The lowest exchangeable aluminium content was observed in treatment T_3 (269.00 c mol (P$^+$) kg^{-1}) which was found to be on par with T_1, T_6 and T_4 (269.33, 270.83, 275 c mol (P$^+$) kg^{-1}) respectively.

The nethermost exchangeable aluminium content in the variety x treatment interaction was observed in T_6 of V_2 (254 c mol (P$^+$) kg^{-1}) which was on par with T_3 (257 c mol (P$^+$) kg^{-1}), T_1 (266 c mol (P$^+$) kg^{-1}) and T_4 of V_2 (270 c mol (P$^+$) kg^{-1}) respectively.

4.4.3.17 Exchangeable sodium

The statistical data on exchangeable sodium is represented in Table 44.

Significantly lower exchangeable sodium content was observed in V_1 (832.81 c mol (P$^+$) kg^{-1}) compared to V_2 (898.76 c mol (P$^+$) kg^{-1}).

Among the treatments, significantly lowest exchangeable sodium content was observed in the treatment T_4 (803.33 c mol (P$^+$) kg^{-1}) which was on par with T_1 (809.67 c mol (P$^+$) kg^{-1}). The highest exchangeable sodium content was noticed in T_7 (1018.83 c mol (P$^+$) kg^{-1}). The variety *vs.* treatment interactions indicate that the treatment T_4 of variety V_1 (782.67 c mol (P$^+$) kg^{-1}) exhibited the lowest significant value of exchangeable sodium content. This was also found to be on par with the treatments T_1 and T_6 of V_1 (789.33, 793.33 c mol (P^+) kg^{-1}) respectively.

Table 43: Effect of amendments on available iron, manganese and zinc status of soil after harvest of rice

Treatment	**Available Fe (mg kg^{-1})**			**Available Mn (mg kg^{-1})**			**Available Zn (mg kg^{-1})**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	453.00	312.33	382.67	2.43	3.43	2.93	1.24	1.27	1.26
T_2	451.00	358.67	404.83	2.72	3.42	3.07	1.23	1.26	1.24
T_3	339.00	330.33	334.67	2.66	3.80	3.23	1.24	1.25	1.25
T_4	436.00	318.00	377.00	2.34	4.66	3.50	1.26	1.29	1.27
T_5	463.67	353.33	408.50	2.65	3.38	3.01	1.28	1.35	1.31
T_6	348.00	338.67	343.33	2.63	3.87	3.24	1.30	1.33	1.32
T_7	536.67	463.00	499.83	2.77	4.76	3.76	1.20	1.21	1.20
Mean	432.83	353.48		2.60	3.90		1.25	1.28	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	3.21	6.61		0.08	0.17		0.010	0.020	
T	6.10	12.36		0.15	0.32		0.018	0.037	
V x T	8.49	17.48		0.22	0.45		0.025	NS	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kgha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

Table 44: Effect of amendments on available copper and exchangeable sodium content of soil after harvest of rice

Treatment	Available Cu (mg kg^{-1})			Exchangeable Na (mg kg^{-1})		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	4.16	4.30	4.23	789.33	830.00	809.67
T_2	4.08	4.24	4.16	812.67	952.00	882.33
T_3	4.13	4.14	4.13	799.00	859.00	829.00
T_4	4.20	4.26	4.23	782.67	824.00	803.33
T_5	4.12	4.18	4.15	822.00	956.00	889.00
T_6	4.14	4.12	4.13	793.33	863.33	828.33
T_7	4.06	4.11	4.09	1030.67	1007.00	1018.83
Mean	4.13	4.19		832.81	898.76	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.025	0.052		2.54	5.22	
T	0.047	0.097		4.74	9.77	
V x T	0.067	NS		6.71	13.81	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kgha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

Table 45: Effect of amendments on available boron, exchangeable aluminium and available silicon status of soil after harvest of rice

Treatment	**Available B (mg kg^{-1})**			**Exchangeable Al (mg kg^{-1})**			**Available Si (mg kg^{-1})**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	1.19	1.33	1.28	272.67	266.00	269.33	75.53	75.28	75.41
T_2	1.24	1.30	1.25	282.67	287.00	284.83	71.77	73.74	72.76
T_3	1.30	1.29	1.29	281.00	257.00	269.00	69.79	71.62	70.70
T_4	1.32	1.34	1.33	280.00	270.00	275.00	74.38	75.61	75.00
T_5	1.30	1.27	1.28	289.67	285.67	287.67	68.94	72.22	70.58
T_6	1.32	1.34	1.33	287.67	254.00	270.83	71.05	72.45	71.75
T_7	1.20	1.33	1.26	308.67	294.67	301.67	66.82	64.74	65.78
Mean	1.26	1.32		286.05	273.67		71.18	72.24	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.011	0.023		3.02	6.21		0.99	NS	
T	0.021	0.043		5.64	11.61		1.86	3.83	
V x T	0.030	0.061		7.98	16.43		2.63	NS	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

4.4.4 Influence of treatments on the nutrient content in plants in pot culture experiment

4.4.4.1 Total nitrogen

The total nitrogen concentration in the plants during their growth is represented in Table 46.

There was no significant difference between the varieties in the concentration of nitrogen. On comparing the treatments, the highest significant concentration of nitrogen (3.55 %) was observed in treatment T_2 (Magnesium sulphate + ½ lime) which was on par (3.52 %) with T_1 (lime). The variety *vs.* treatment interactions revealed that the significantly highest nitrogen content was observed in the treatment T_3 of variety V_2 (3.62 %), which was on par with T_1 of V_1 (3.59 %), T_2 of V_2 (3.58 %) and T_4 of V_1 (3.53 %) respectively.

4.4.4.2 Total phosphorus

The total concentration of phosphorus is represented statistically in Table 46.

Among the two varieties, the variety V_1 (0.23 %) showed a significantly higher phosphorus concentration compared to V_2 (0.17 %).

The highest significant phosphorus concentration was observed in the treatments T_3 and T_6 (0.23 %) which were on par with T_1 and T_4 (0.22 %) respectively. In the variety x treatment interactions, T_6 of variety V_1 (0.25 %) showed the highest significant content of phosphorus. This was found to be on par with T_1 and T_4 of V_1 (0.23 % each), T_3 of V_2 (0.22 %), T_5 of V_1 (0.22 %), T_6 of V_2 and T_2 of V_1 (0.21 % each) respectively.

4.4.4.3 Total potassium

The total potassium content on plant analysis is as given in Table 46.

The comparison of two varieties revealed that Ezhome-1 (3.45 %) had significantly higher potassium content than Kuthiru (3.28 %).

Table 46: Effect of different amendments on total nitrogen, phosphorus and potassium content of rice varieties in pot culture experiment

Treatment	**Total N (%)**			**Total P (%)**			**Total K (%)**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	3.59	3.45	3.52	0.23	0.20	0.22	3.50	3.27	3.39
T_2	3.51	3.58	3.55	0.21	0.13	0.17	3.38	3.28	3.33
T_3	3.32	3.62	3.47	0.24	0.22	0.23	3.50	3.27	3.39
T_4	3.53	3.39	3.46	0.23	0.20	0.22	3.58	3.30	3.44
T_5	3.46	3.47	3.47	0.22	0.12	0.17	3.44	3.35	3.39
T_6	3.33	3.38	3.36	0.25	0.21	0.23	3.52	3.31	3.42
T_7	3.24	3.21	3.22	0.20	0.11	0.16	3.25	3.18	3.22
Mean	3.43	3.44		0.23	0.17		3.45	3.28	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.016	NS		0.007	0.02		0.02	0.038	
T	0.030	0.063		0.014	0.03		0.03	0.071	
V x T	0.043	0.089		0.020	0.04		0.05	0.100	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

The significantly highest potassium content was seen in the treatment T_4 (3.44 %), which was on par with T_6 (3.42 %), T_1, T_3 and T_5 (3.39 % each) respectively.

The variety x treatment interaction reveals that T_4 of V_1 (3.58 %) recorded the significantly highest potassium content. This was on par with T_6 of V_1 (3.52 %), T_1 and T_3 of V_1 (3.50 % each) respectively. The lowest potassium content among all was observed in T_7 of V_2 (3.18 %).

4.4.4.4 Total calcium

The calcium concentration of the plants is tabulated in Table 47.

A significantly higher concentration of calcium was observed in the variety V_1 *i.e.* Ezhome-1(0.56 %) than V_2 *i.e.* Kuthiru (0.51%).

Among the treatments, T_6 (0.88 %) recorded the highest significant content of calcium. The lowest concentration of calcium content in plants (0.30 %) was observed in T_7 (control). The variety *vs.* treatment did not show any significant differences in their values.

4.4.4.5 Total magnesium

The variety V_2 (0.16 %) *i.e.* Kuthiru, exhibited a significantly higher concentration of magnesium than V_1 *i.e.* Ezhome-1 (0.13 %) as in Table 47.

Among the treatments, the treatment T_5 recorded the highest amount of magnesium (0.17 %) which was on par with T_2 (0.16 %). The lowest magnesium content was expressed in T_4 (0.12 %). There were no significant differences in the variety x treatment interactions.

4.4.4.6 Total sulphur

The data on the total sulphur content in plant analysis is illustrated in Table 47.

Significantly higher content of sulphur was observed in V_2 (0.71 %) over V_1 (0.53%). The significantly highest sulphur contents were observed in T_3 and T_6 (0.77 %), and the lowest value was seen in T_7 (0.44 %). The variety *vs.* treatment

Table 47: Effect of amendments on total calcium, magnesium and sulphur content of rice varieties in pot culture experiment

Treatment	**Total Ca (%)**			**Total Mg (%)**			**Total S (mgkg^{-1})**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	0.58	0.54	0.56	0.11	0.15	0.13	0.48	0.73	0.61
T_2	0.32	0.32	0.32	0.14	0.18	0.16	0.48	0.78	0.63
T_3	0.86	0.76	0.81	0.13	0.16	0.14	0.71	0.83	0.77
T_4	0.61	0.51	0.56	0.13	0.15	0.14	0.47	0.60	0.54
T_5	0.33	0.28	0.31	0.14	0.19	0.17	0.45	0.73	0.59
T_6	0.91	0.85	0.88	0.12	0.16	0.14	0.69	0.86	0.77
T_7	0.30	0.29	0.30	0.10	0.14	0.12	0.44	0.44	0.44
Mean	0.56	0.51		0.13	0.16		0.53	0.71	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.01	0.023		0.002	0.004		0.009	0.02	
T	0.02	0.044		0.003	0.007		0.035	0.04	
V x T	0.03	NS		0.005	NS		0.049	0.05	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kgha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

interactions indicated that T_6 of variety V_2 (0.86 %) showed the highest sulphur content and this was on par with T_3 of V_2 (0.83 %).

4.4.4.7 Total iron

The total iron content observed in the plants grown in pot culture experiment is given in Table 48.

Significantly lower iron content was observed in V_1 *i.e.* Ezhome-1 (332.76 mg kg^{-1}) over V_2 *i.e.* Kuthiru (373.19 mg kg^{-1}). The treatment T_3 (331.33 mg kg^{-1}) recorded the lowest significant iron concentration, which was on par with the treatments T_1 (333.83 mg kg^{-1}), T_6 (338.00 mg kg^{-1}), T_2 (349.83 mg kg^{-1}), T_5 (352.67 mg kg^{-1}) and T_4 (357.83 mg kg^{-1}) respectively. There was no significant difference in iron concentration on considering the variety x treatment interaction.

4.4.4.8 Total manganese

Table 48 gives the data on total manganese concentration of plants grown in pot culture experiment. There was no significant difference between the varieties as well as the variety x treatment interaction. With respect to the treatments, T_1 (13.02 mg kg^{-1}) recorded the least significant amount of manganese which was on par with T_4 (13.32 mg kg^{-1}). The highest manganese concentration was in T_7 (20.17 mg kg^{-1}).

4.4.4.9 Total zinc

Table 48 represents the statistical data on the zinc content in plants.

There were no significant differences between the varieties, treatments as well as the variety x treatment interaction.

4.4.4.10 Total copper

The total copper concentration of plants in pot culture experiment is as in Table 49.

The concentration of copper was non-significant among the two varieties, treatments and the variety *vs.* treatment interaction.

4.4.4.11 Total boron

The statistical data on total boron concentration in the plants are tabulated in Table 50.

There were no significant differences in the total boron concentration in case of varieties as well as the variety *vs.* treatment interaction. However, the effect of treatments was found to vary significantly with respect to boron content. The treatment T_6 (1.26 mg kg^{-1}) recorded the maximum significant boron content which was on par with T_3 (1.23 mg kg^{-1}), T_4 (1.17 mg kg^{-1}) and T_2 (1.16 mg kg^{-1}) respectively. The lowest concentration of boron was observed in T_7 (1.01 mg kg^{-1}).

4.4.4.12 Total silicon

The results of silicon content obtained in plant analysis are represented in Table 49.

There were no significant differences between the varieties as well as variety *vs.* treatment interaction in relation to the concentration of silicon in rice. Among the treatments, the treatment T_6 exhibited the highest significant silicon content (2.70 %), which was on par with T_3 (2.60 %).

4.4.4.13 Total aluminium

The total aluminium in rice is presented in Table 49.

No significant differences were observed between the varieties with respect to total aluminium in rice. On comparing the treatments, aluminium content was significantly lowest in T_6 (5186 c mol (P$^+$) kg^{-1}). In addition, this was on par with T_3 (5187 c mol (P$^+$) kg^{-1}). The highest aluminium content was exhibited in T_7 (5767 c mol (P$^+$) kg^{-1}) followed by T_5 (5614 c mol (P$^+$) kg^{-1}).

Table 48: Effect of different amendments on total iron, manganese and zinc content of rice varieties in pot culture experiment

Treatment	**Total Fe (mg kg^{-1})**			**Total Mn (mg kg^{-1})**			**Total Zn (mg kg^{-1})**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	321.33	346.33	333.83	13.42	12.62	13.02	23.32	22.82	23.07
T_2	324.67	375.00	349.83	16.51	16.29	16.40	24.04	24.40	24.22
T_3	296.00	366.67	331.33	17.77	17.50	17.64	22.77	23.30	23.03
T_4	356.67	359.00	357.83	13.51	13.13	13.32	24.72	23.58	24.15
T_5	326.00	379.33	352.67	16.24	17.17	16.71	24.04	24.72	24.38
T_6	307.33	368.67	338.00	17.05	17.38	17.22	26.65	23.54	24.10
T_7	397.33	417.33	407.33	20.10	20.24	20.17	23.24	25.47	24.36
Mean	332.76	373.19		16.37	16.33		23.83	23.98	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	7.59	15.63		0.23	NS		0.60	NS	
T	14.20	29.24		0.42	0.87		1.12	NS	
V x T	20.08	NS		0.60	NS		1.58	NS	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

Table 49: Effect of different amendments on total copper, aluminium and silicon content of rice varieties in pot culture experiment

Treatment	**Total Cu (mg kg^{-1})**			**Total Al (c mol (P$^+$) kg^{-1})**			**Total Si (%)**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	2.62	2.83	2.73	5562	5537	5549	2.18	2.14	2.16
T_2	2.96	3.16	3.06	5610	5617	5613	2.52	2.42	2.47
T_3	2.90	3.19	3.05	5215	5159	5187	2.41	2.79	2.60
T_4	2.73	2.84	2.79	5540	5506	5523	2.12	2.22	2.17
T_5	2.91	2.84	2.87	5631	5597	5614	2.45	2.51	2.48
T_6	3.02	3.21	3.12	5206	5167	5186	2.67	2.73	2.70
T_7	3.06	3.33	3.20	5699	5836	5767	2.10	2.06	2.08
Mean	2.88	3.06		5494	5488		2.35	2.41	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.11	NS		14.64	NS		0.055	NS	
T	0.21	NS		27.39	56.39		0.103	0.21	
V x T	0.30	NS		38.73	79.74		0.146	NS	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

Table 50: Effect of different amendments on total sodium, boron content of rice varieties in pot culture experiment

Treatment	**Total Na (%)**			**Total Boron (mg kg^{-1})**		
	V_1(E)	V_2(K)	**Mean**	V_1(E)	V_2(K)	**Mean**
T_1	0.23	0.18	0.21	1.10	1.11	1.11
T_2	0.26	0.31	0.28	1.19	1.14	1.16
T_3	0.19	0.24	0.21	1.23	1.23	1.23
T_4	0.27	0.19	0.23	1.15	1.18	1.17
T_5	0.24	0.32	0.28	1.13	1.15	1.14
T_6	0.20	0.23	0.21	1.28	1.24	1.26
T_7	0.32	0.33	0.32	1.04	0.98	1.01
Mean	0.24	0.26		1.16	1.15	
	SEm(±)	CD (0.05)		SEm(±)	CD (0.05)	
V	0.005	0.003		0.027	NS	
T	0.001	0.005		0.051	0.105	
V x T	0.014	0.007		0.072	NS	

T_1-Lime as per KAU POP, 2011; T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3-Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron; T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron; T_6- Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron; T_7-Absolute control

The variety x treatment interaction revealed that the lowest significant concentration of aluminium was seen in T_3 of Kuthiru (5159 c mol (P^+) kg^{-1}). This was also on par with T_6 of Kuthiru (5167 c mol (P^+) kg^{-1}), T_6 (5206 c mol (P^+) kg^{-1}) and T_3 of Ezhome-1 (5699 c mol (P^+) kg^{-1}) respectively. The highest aluminium content was in T_7 of Kuthiru (5836 c mol (P^+) kg^{-1}) followed by T_7 of Ezhome-1 (5699 c mol (P^+) kg^{-1}).

4.4.4.14 Total sodium

The sodium concentration in the rice plants during pot culture experiment is shown in Table 50.

Among the two varieties, the variety Ezhome-1 (0.24 %) recorded a significantly lower sodium content compared to Kuthiru (0.26 %).

The lowest mean significant sodium contents were observed in the treatments T_1, T_3 and T_6 (0.21 % each). The highest sodium content was observed in the treatment T_7 (0.32 %). The variety x treatment interaction indicated that the treatment T_1 of Kuthiru (0.18 %) recorded lowest significant concentration of sodium. This was on par with T_3 of Ezhome-1 and T_4 of Kuthiru (0.19 % each). The highest concentration of sodium was observed in T_7 of Kuthiru (0.33 %).

4.4.4.15 Nutrient ratio ($\sqrt{(Ca^{2+})}/K^+$)

Table 51 gives the data on nutrient ratio of plants in pot culture experiment.

There was no significant difference between the varieties as well as the variety *vs.* treatment interaction. Among the treatments, highest nutrient ratio for calcium to potassium was recorded in T_6 which was on par with T_3.

Table 51: Effect of different amendments on the nutrient ratio in rice plants after harvest

Treatment	$\sqrt{(Ca^{2+})}/K^+$		
	V_1(E)	V_2(K)	Mean
T_1	0.22	0.23	0.22
T_2	0.17	0.17	0.17
T_3	0.27	0.27	0.27
T_4	0.22	0.22	0.22
T_5	0.17	0.16	0.16
T_6	0.27	0.28	0.28
T_7	0.17	0.17	0.17
Mean	0.21	0.21	
	SEm(±)	CD (0.05)	
V	0.003	NS	
T	0.005	0.01	
V x T	0.007	NS	

T_1-Lime as per KAU POP, 2011;

T_2 -Magnesium sulphate + ½ lime (as per KAU POP, 2011);

T_3-Phosphogypsum at the rate of 500 kg ha^{-1} + ½ lime as per KAU POP, 2011;

T_4- Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron;

T_5- Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron;

T_6- Phosphogypsum at the rate of 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron;

T_7-Absolute control

Discussion

5. DISCUSSION

The discussion of the results obtained on the investigation entitled "Dynamics of iron and aluminium toxicity on rice (*Oryza sativa* L.) in saline hydromorphic soils of Kaipad" is presented in this chapter. The investigation was carried out in four parts.

Part A: Collection of soil samples and analysis of physical and chemical properties

Part B: Incubation study to know the release pattern of nutrients in the soil

Part C: Solution culture experiment

Part D: Pot culture experiment

5.1 COLLECTION OF SOIL SAMPLES AND ANALYSIS OF PHYSICAL AND CHEMICAL PROPERTIES OF KAIPAD TRACT

The soils of Kaipad are saline hydromorphic in nature. These soils are found in the North Malabar districts mainly Kannur and Kasaragod lying between 11.25°N to 12.5°N and 75.0°E to 75.77°E. The sites selected for the present investigation included Muttil and Cherukunnu Panchayath of Kannur district. The soil samples were collected from 15 different locations of Kaipad as presented in Figure 2 to assess the physical and chemical properties.

5.1.1 Physical properties of Kaipad soil

The bulk density varied from 1.06 Mg m^{-3} in location number 11 to 1.17 Mg m^{-3} in location number 9. This low bulk density value clearly indicates the richness of organic matter in Kaipad soil, which points towards good soil health. Bulk density is a physical property which is related to numerous factors such as soil moisture, aeration status, root penetration, the content of clay, texture, availability of nutrients for plant use and activity of soil microorganisms, which influences the key soil processes and the productivity of soil (Sakin, 2012).

The soil textural classification revealed that eleven of the sampled locations recorded sandy clay loam texture. The textural classes of the study area varied from sandy loam to sandy clay loam. The sand content varied from 47.32 to 68.32 per cent. The silt content ranged from 12.14 to 27.31per cent. Clay content varied between 17.15 to 28.14 per cent. It is evident that the predominant fraction in the Kaipad soils is sand. The coarse texture of Kaipad soil might be attributed to the saline water intrusions during the monsoon period.

5.1.2 Chemical properties of Kaipad soil

5.1.2.1 Soil reaction (pH)

The soil reaction of the samples analysed during the summer month of April ranged from 3.40 to 6.48 (Table 8) in fifteen different locations of Kaipad. The results revealed that there was a wide variation in pH ranging from ultra-acidic to slightly acidic pH (Figure 3). This is in concordance with the report of Nair and Money (1972). They reported that soil pH of the saline soils of Kerala varied from 3.0 to 6.8. The slightly acidic pH noticed in Kaipad soils might be attributed to the presence of lime shell depositions (Iyer, 1989) as a result of frequent saline water intrusions during the monsoon period. The ultra-acidic pH noticed in Kaipad soils might be related to the presence of pyrite and other iron bearing minerals such as jarosite, limonite etc.

5.1.2.2 Electrical conductivity

The range of electrical conductivity recorded in the soil samples of Kaipad was from 9.72 to 29.00 dS m^{-1}. This high salinity recorded during the summer months might be attributed to the extremely high accumulation of salts during the dry season period. Similar findings on electrical conductivity of Kaipad soil was reported by Chandramohan and Mohanan (2012). They reported that the electrical conductivity of these soils ranged from 10.9 to 19.9 dS m^{-1} during the summer months. These salts get washed away during the onset of monsoon and thus cause a reduction in electrical conductivity of soils, which favours rice cultivation. Saline tolerant rice varieties can be cultivated when the soil electrical conductivity falls below 6 dS m^{-1} (Shylaraj and Sasidharan, 2005). The most popular saline tolerant rice varieties of Kaipad are Kuthiru and Ezhome-1. Kuthiru is a saline tolerant lodging land race widely grown in Kaipad regions and Ezhome-1 is a high yielding long duration variety which is tolerant from low to medium salinity (Vanaja *et al.*, 2015).

5.1.2.3 Organic carbon

The organic carbon status of the sampled locations of Kaipad varied between 5.30 to 33.40 g kg^{-1} over the fifteen locations. About 7 per cent of the sampled locations recorded medium organic carbon content and 93.67 per cent of the sampled locations recorded high organic carbon (Figure 4). The relatively high organic carbon in the Kaipad soils might be attributed to the incorporation of stubbles and straw after harvest of rice crop in the field itself or from the remnants of the rice shrimp cultivation practised in Kaipad during the high saline regime prevailing from November to April. It may also be attributed to the diverse flora and fauna present in the soils of Kaipad.

5.1.2.4 Available macronutrients

The results revealed that the macronutrient content of Kaipad soils was generally very high.

The available nitrogen status of the sampled locations of Kaipad regions varied from 173.47 kg ha^{-1} to 1083.80 kg ha^{-1} with a mean value of 544.95 kg ha^{-1}. About 7 per cent of the sampled locations were low in nitrogen content, 60 per cent medium and 33.7 per cent had high nitrogen content. This medium to high value (Figure 5) of available nitrogen content may be due to the presence of high amount of organic matter in these soils and the faster mineralization of nitrogen due to the activity of micro-organisms (Leiros *et al.*, 1999).

The available phosphorus content varied from 8.65 kg ha^{-1} in location number 6 to 50.27 kg ha^{-1} in location number 10. The available phosphorus contents of about 13.33 per cent of the locations were low, 40 per cent medium

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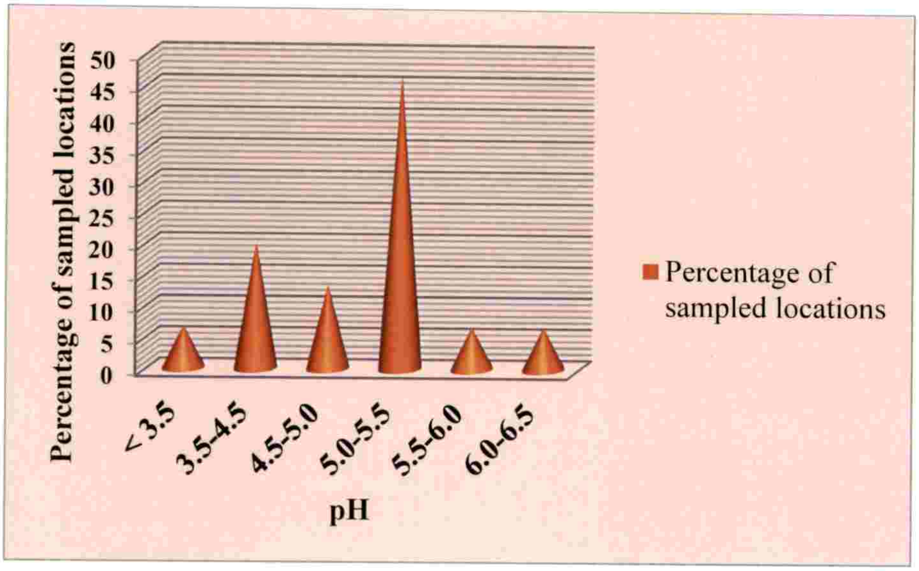

Figure 3: Soil pH in sampled areas of Kaipad

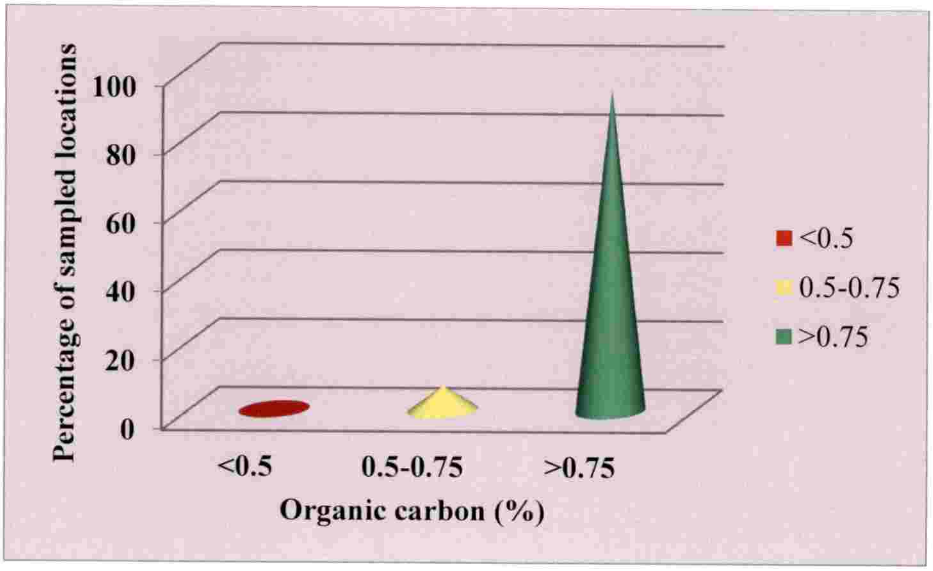

Figure 4: Organic carbon status in sampled locations of Kaipad

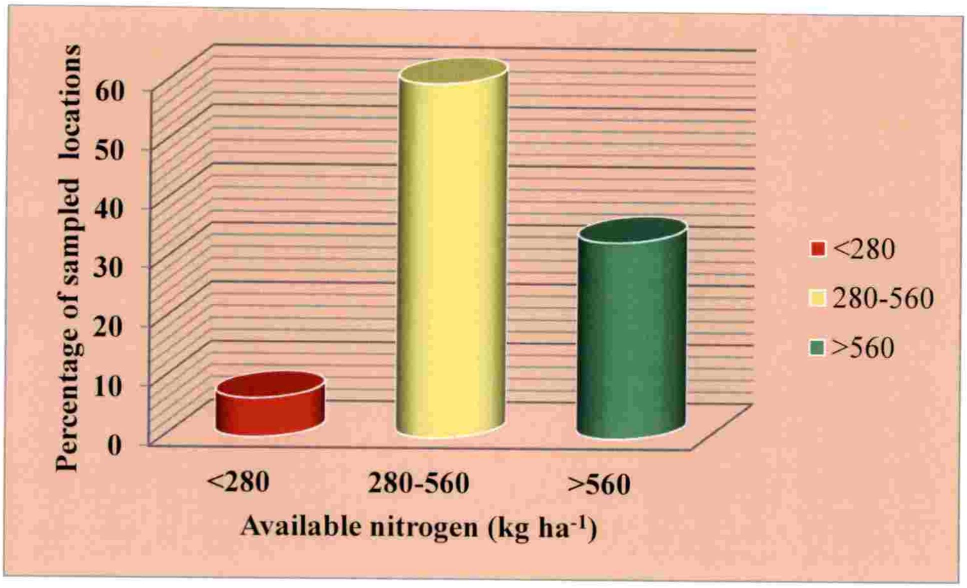

Figure 5: Available nitrogen status in sampled locations of Kaipad

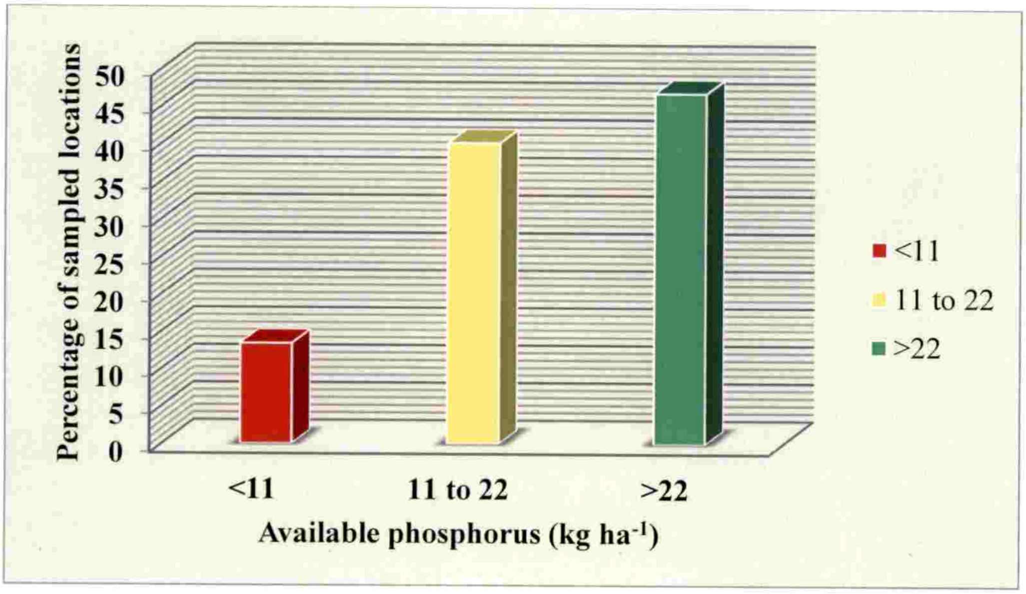

Figure 6: Available phosphorus status in sampled locations of Kaipad

and 46.67 per cent were high as shown in Figure 6. Chandramohan and Mohanan (2012) reported that the available soil phosphorus content in Kaipad soils ranged from 7.2 kg ha^{-1} to 34.2 kg ha^{-1}. Nair and Money (1972) as well as Samikutty (1977) reported that the saline soils of Kerala were deficient in phosphorus contents. Samikutty (1977) reported that these soils are generally poor in phosphates. Padmakumar *et al.* (2002) indorsed that tidal influence in estuarine situations can be linked to the high intensity of plant nutrients such as nitrates and phosphates.

The potassium content observed in all the sampled soils was extremely high ranging from 1239 to 4630 kg ha^{-1} (Figure 7). This may be linked to the incorporation of paddy stubbles in the soil after paddy cultivation or due to the excrements which get deposited during the practice of aquaculture in the high saline periods of November to April. It was reported by Samikutty (1977) that the sodium and potassium contents in these soils are higher than those of the other paddy soils of Kerala. He explained that this is due to the continuous submergence of these soils with salt water for over six to eight months in a year and the recurrent barrage by the brackish waters owing to the tidal effect.

The available calcium contents recorded from the 15 locations were very high ranging from 826.25 mg kg^{-1} to 3275.00 mg kg^{-1}. This extremely high calcium content in the sampled locations might be attributed to the presence of lime shell depositions associated with iron pyrite. The rice shrimp farming practiced in the Kaipad tracts might also have contributed to the high calcium content in the Kaipad soils. Similar findings were reported by Iyer (1989) in the Kaipad soils.

Irrespective of the high available calcium content, the present investigation revealed that the available magnesium content was very low. The status of available magnesium content of the study locations ranged from 21.30 mg kg^{-1} to a maximum value of 43.60 mg kg^{-1} with a mean value of 35.71 mg kg^{-1}. The low magnesium content in the saline hydromorphic soils of Kaipad may be accounted

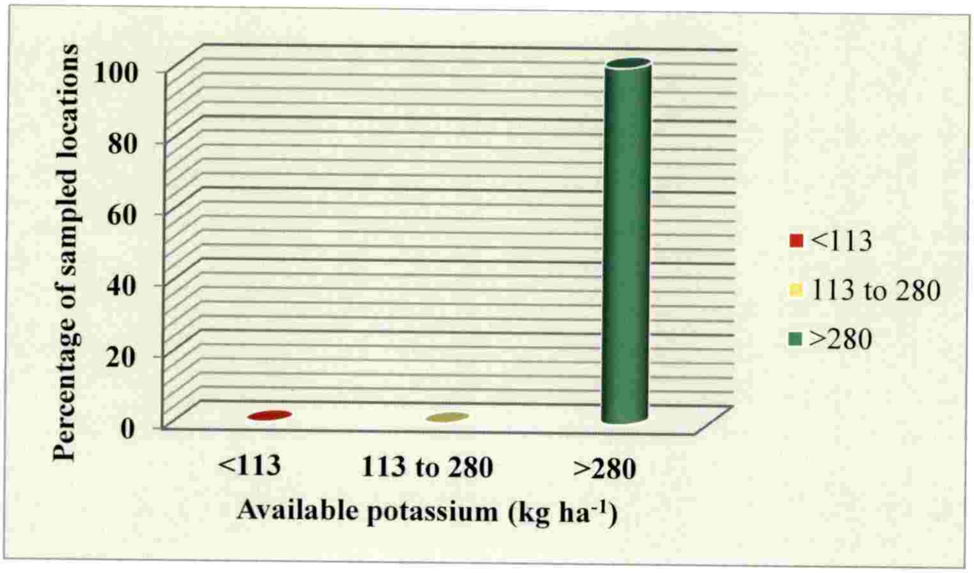

Figure 7: Available potassium status in sampled locations of Kaipad

to the presence of the cation in the exchange complex sites which is not readily available in the soil solution. The low status of magnesium in the saline hydromorphic soils of Pokkali was also reported by Varghese *et al.* (1970) and Samikutty (1977). They had reported that even though magnesium is a major exchangeable cation in the Pokkali soils, the presence of low status of magnesium may be accounted to its existence in the exchangeable complex. Aryalekshmi (2016) reported a magnesium content of 26.17 mg kg^{-1} in Pokkali soils.

The available sulphur content of the soils varied from 748.77 mg kg^{-1} in location number 7 to 1534.62 mg kg^{-1} in location number 3. The high extents of sulphur content can be credited to the presence of moderately high organic matter content in these soils. The high sulphur content may also be attributed to the presence of pyrites and other iron bearing minerals like jarosite (hydrous sulphate of potassium and iron). The presence of pyrites and other iron bearing minerals in Kaipad soils was reported by Iyer (1989).

5.1.2.5 Available micronutrients

The present investigation showed high available micronutrient content in all the sampled locations of Kaipad.

The available iron content in these soils varied from 702 to 1250 mg kg^{-1} which was in toxic levels. Similar trend on iron content which varied from 171 to 2321 mg kg^{-1} was reported by Shylaraj *et al.* (2013) in Pokkali soils. The presence of high iron may be accounted to the presence of soil minerals such as pyrites, jarosite etc. (Iyer, 1989). The availability of iron was found to increase on submergence (Ponnamperuma, 1972). Iron toxicity is a major factor limiting the production of wetland rice, particularly in soils with the presence of high organic matter and impeded drainage (Yoshidha, 1981).

The available manganese content in these soils varied from 3.4 to 25.46 mg kg^{-1}. This revealed that available manganese was adequate in the sampled locations of Kaipad. There had been a report on the low manganese availability due to the presence of high organic matter (Mandal and Mitra, 1982). Malvi (2011) stated that the interaction of iron with manganese is antagonistic in nature. The toxic levels of iron content might have adversely affected the manganese content in the soils of Kaipad.

The available zinc values ranged from 1.81 to 11.50 mg kg^{-1} in the sampled locations. The mean value of available zinc was recorded as 4.33. The values revealed that the available zinc content recorded in the sampled locations of Kaipad was adequate. Zinc forms chelate with the organic matter present in the soil. Chelated forms of zinc do not move through the soil and is not subjected to leaching losses (Schulte).

The available copper content in the sites ranged from 2.07 to 6.78 mg kg^{-1} over the locations. Though the available copper content in the sampled locations were adequate, the status was low as compared to other nutrients. This might be attributed to the presence of copper as an impurity in silicate minerals or carbonates which renders copper unavailable in the soil pool. The organic matter present in the soil binds copper more tightly as compared to other micro nutrients (Schulte and Kelling).

The available boron content in the sampled locations ranged from 1.29 to 1.79 mg kg^{-1}over the locations. The high available boron status in the soils of Kaipad might be due to the incursion of sea water into these areas during the monsoon period. High boron content was observed with increase in salinity. Similar reports on high levels of boron were observed on Pokkali soils by Aditya, (2016).

5.1.2.6 Exchangeable aluminium

The exchangeable aluminium was found in higher concentrations varying from 160 to 434 c mol (P^{+}) kg^{-1}. The high aluminium content may be due to the acidic pH prevailing in those areas. Kochian (1995) also reported that aluminium is an element which gets solubilised into the soil solution at acidic pH values and thus become toxic to plants. The aluminium gets solubilised from silicate clays and hydrous oxides of aluminium at a pH below 5.3, thus increasing the activity of exchangeable aluminium (Aditya, 2016).

5.1.2.7 Available silicon

High available silicon content was observed in these soils varying from 48.90 mg kg^{-1} to 195.00 mg kg^{-1}. The accumulation of oceanic derived or marine derived salt deposits augments the acidity due to various exchange processes (Harriman *et al.*, 1995). Additions of these salts enhances the strength of aqueous Fe^{2+}, Al^{3+} and Si resulting in decreasing pH of these soils (Portnoy and Giblin, 1997).

5.1.2.8 Exchangeable sodium

The exchangeable sodium content in the soils varied from 530 to 1080 c mol (P^+) kg^{-1} which was very high. The presence of high sodium can be linked to the frequent intrusion of sea water containing soluble salts. The ESP of the sampled locations varied from 2.26 to 13.48. Similar findings on exchangeable sodium percentage ranging from 13.7 to 83.3 in Pokkali soils were reported by Samikutty (1977).

5.1.2.9 Cation exchange capacity

The cation exchange capacity varied from 21.91 cmol (P^+) kg^{-1} to 184.46 c mol (P^+) kg^{-1} in location numbers 13 and 10 respectively. This high CEC may be accredited to the interaction between organic matter and clay minerals. Curtin and Rostad (1997) stated that the cation exchange capacity of the clays and the organic matter are held as additives. The richness in organic matter of the soil contributing to high CEC might be accounted to the integrated farming system in which rice and aquaculture is practised together. The incorporation of stubbles in the field after harvest of rice crop (Vanaja, 2013) also adds organic matter to the soil contributing to high CEC. Soumya (2016) conveyed that some regions of Kaipad tracts showed a trend in CEC ranging from 11.67 to 13.7 c mol (P^+) kg^{-1}.

Relatively high values of pH, organic carbon, available nitrogen, potassium and calcium can be attributed to the fallow nature of the sampled sites compared to other sites where rice-fish aquaculture is regularly practised.

5.2 INCUBATION STUDY

Incubation study was carried out to study the release pattern of iron, aluminium and other available nutrients as affected by levels of submergence on addition of amendments from the saline hydromorphic soils of Kaipad. The levels of submergence were 5 cm and 10 cm. The duration of the incubation study was 120 days. The results of the incubation study are discussed in this part of the chapter.

5.2.1 Soil pH

The submergence levels were found to have no significant effect with respect to soil pH at 30 and 90 DAI, whereas the effect was significant at 60 and 120 DAI. The soil pH displayed an increasing trend with increase in duration of incubation. This increase in pH might be attributed to the increase in time of flooding. Comparing the two levels of submergence, the increase in pH was more in 10 cm submergence level. The increase may be due to the more water content at 10 cm submergence level as compared to 5 cm. The trend of soil pH with respect to the treatments is given in Figure 8. Kashem and Singh (2001) reported that the pH was found to increase with the flooding time. They stated that the pH was found to increase by about 2, 1 and 0.6 units in the tannery, city sewage and alum shale soils respectively during 65 days of submergence. The pH of acid soils was found to approach to neutrality on continuous submergence. The treatments had significant effect on the soil pH at all the four periods of incubation. The treatment T_1 (lime as per KAU POP) recorded the significantly highest values of soil pH followed by T_3 (Phosphogypsum + ½ lime). However at 120 DAI, the treatment T_3 recorded significantly higher pH values.

Application of lime helps in raising the soil pH to neutral range which favours the enhanced availability of nutrients for plant uptake. The increase in pH with application of phosphogypsum is due to the presence of calcium in the amendment. The beneficial role of phosphogypsum as amendment was more prominent at 120 DAI because of its continued effect in enhancing Ca in soluble form and thus correcting sub-soil acidity. Deepa (2008) reported that the use of phosphogypsum helps in correcting the soil acidity in acid soils. Silva and Mendonca (2007) stated that in incubation studies, the increase in soil solution pH may be due to the nitrogen mineralization and denitrification or due to the decarboxylation of organic acids.

5.2.2 Electrical conductivity

The addition of amendments showed a steep decline in electrical conductivity from the initial level (27 dS m^{-1}) as represented in Figure 9. Application of phosphogypsum + ½ lime (T_3) recorded the lowest EC at 30, 60 and 90 DAI. The reduction in salinity by about four folds with flooding and addition of amendments might be due to more calcium content in the exchange sites. The regular flooding which results in reduction of salinity results in changes in soil characteristics (de Leon-Lorenzana *et al.*, 2017). The maximum reduction in salinity with days of incubation was recorded in the treatment receiving phosphogypsum + ½ lime (T_3). Phosphogypsum helps in increasing the soil pH by correcting sub-soil acidity through providing more soluble Ca.

5.2.3 Organic carbon

The organic carbon content was found to show a decreasing trend over the four months period. There were no differences between the organic carbon contents in the two submergence levels. On comparing the treatments, T_1 (lime) showed higher organic carbon content at 30 and 60 DAI whereas at 90 and 120 DAI, T_2 (Magnesium sulphate + ½ lime as per KAU POP, 2011) had a significantly higher organic carbon content (8.10, 6.80 g kg^{-1}). Karlik (1995) stated that long term studies have shown a higher leaching of the dissolved

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organic matter on application of calcium carbonate fertilizers in pot, lysimetric and field

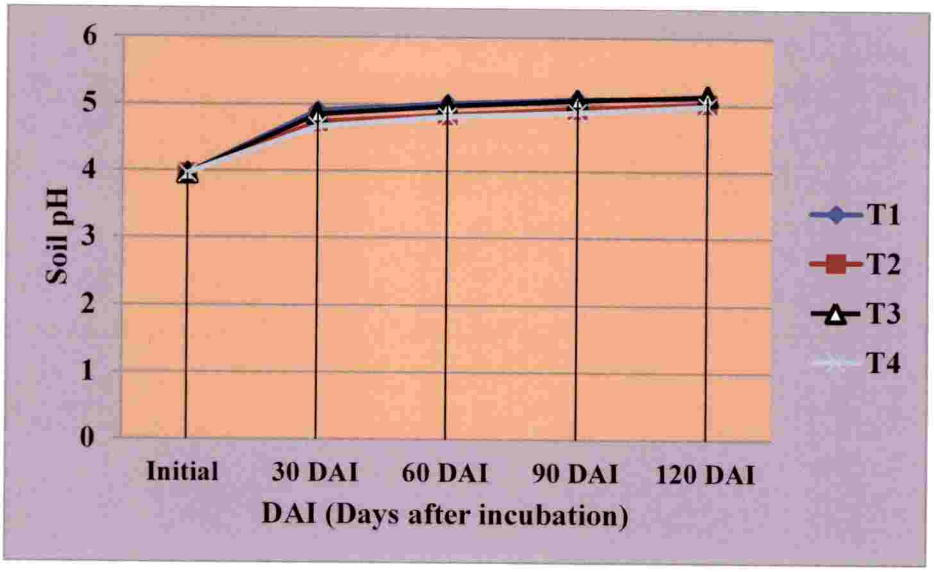

Figure 8: Effect of different amendments on soil pH at 30, 60, 90 and 120 DAI

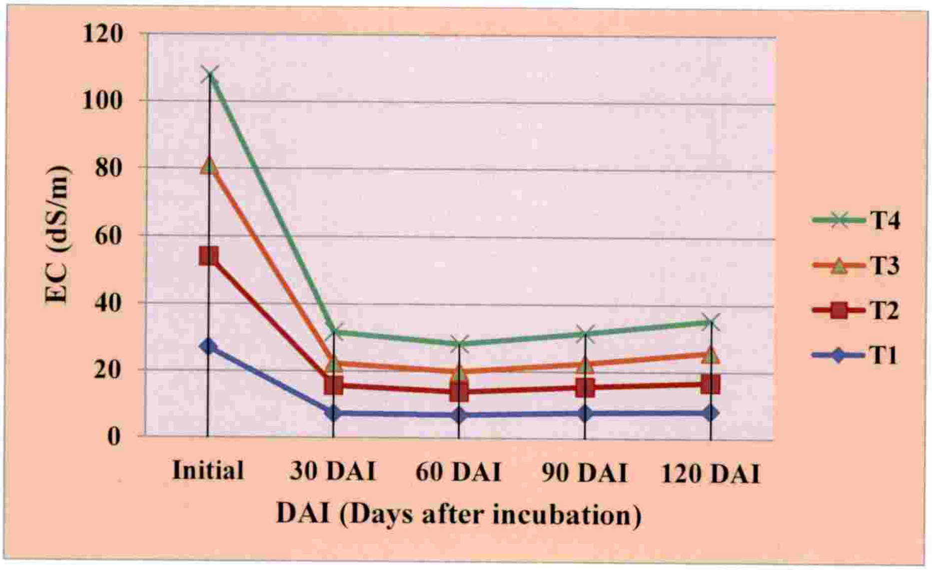

Figure 9: Effect of different amendments on Electrical conductivity at 30, 60, 90 and 120 DAI

experiments. Liming alters the soil structure and thereby soil organic matter content. The physical conditions of soil and biological activities are improved on application of lime (Soon and Arshad, 2005).

5.2.4 Available nutrients

The available nitrogen content exhibited an increasing trend at 30, 60, 90 and 120 DAI. The submergence levels did not show any significant difference in the availability pattern of nitrogen. Among the treatments, T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011) showed higher nitrogen (356.28 kg ha^{-1}) content at 30 DAI. However at 60, 90 and 120 DAI, the treatment T_2 (367.74, 406.42, 416.36 kg ha^{-1} respectively) showed significantly higher available nitrogen content. The increased nitrogen availability with addition of amendments might be attributed to the better biological activity. Liming helps in improving the net mineralization rate of nitrogen. Addition of lime aids in correcting soil acidity and may thus improve the availability of essential plant nutrients like nitrogen. The increase in nitrogen content upon application of magnesium sulphate as amendment might be due to the replacement of nitrate ions by sulphate ions thus enhancing the presence of nitrogen in the soil solution. Nyborg and Hoyt (1978) based on their incubation study reported that liming the soils to a pH of about 6.7 almost doubled the extent of nitrogen mineralised. A similar trend was reported by Cornfield (1959) on addition of one per cent calcium carbonate.

The level of submergence had no significant difference in available phosphorus content at 30 and 60 DAI. However at 90 and 120 DAI, 5 cm level of submergence recorded significantly superior values of soil available phosphorus. When the effect of treatments on the status of available phosphorus was considered, T_3 (phosphogypsum + ½ lime) showed higher available phosphorus content (60.17, 42.29, 37.56, 39.43 kg ha^{-1} respectively) at 30, 60, 90 and 120 DAI. The availability of phosphorus is found to increase with increase in soil pH which can be achieved on application of amendments such as phosphogypsum, lime etc. A significant increase in available phosphorus, exchangeable potassium, sulphate, calcium and magnesium was observed on increasing the application of alkalized (by adding 4 % $Ca(OH)_2$) and unmodified phosphogypsum (Lee *et al.*, 2009). The decrease might have been due to the fixation of phosphorus by iron or aluminium. Ponnamperuma (1972) reported that the availability of phosphorus content in rice soils increases on flooding. Application of amendments solubilises phosphorus, thus enhancing its availability in soil solution

The present study proves that soils of Kaipad are inherently rich in available potassium status. There was significant effect of submergence levels on the available potassium content at 60, 90 and 120 DAI. Among the submergence levels, 5 cm level recorded significantly superior values of available potassium. This might be due to enhanced transformation of non-exchangeable pool of potassium to the exchangeable pool. Application of magnesium sulphate + ½ lime (T_2) recorded higher available potassium content at 60 DAI. This might be due to the beneficial effect of lime containing Ca along with the presence of sulphate in enhancing the availability of potassium at 60 DAI. In case of 90 and 120 DAI, the treatment T_3 (phosphogypsum + ½ lime) showed superior available potassium. A significant increase in available phosphorus, exchangeable potassium, sulphate, calcium and magnesium was observed on increasing the application of alkalized (by adding 4 % $Ca(OH)_2$) and unmodified phosphogypsum (Lee *et al.*, 2009). The primary nutrients like nitrogen, phosphorus and potassium are powerfully attached to the clay particles in acid soils. So, the yield and protein content of the crops grown in such soils is lower than those grown in neutral soils (Kreismane *et al.*, 2011). Liming helps to tackle over this problem. The effect of phosphogypsum on available potassium content was in agreement with the statement of Lee *et al.* (2009). Potassium and magnesium are usually antagonistic elements.

The available calcium contents in the soil were found to increase at 30, 60, 90 and 120 DAI (Figure 10). The treatments had no significant difference at

30 DAI. Higher available calcium contents were observed on the treatment T_3 (phosphogypsum + ½ lime) at 30, 60, 90 and 20 DAI. Application of alkalized phosphogypsum as well as the unmodified phosphogypsum was reported to show an increase in the calcium content in the paddy fields (Lee *et al.*, 2009). Addition of liming materials helps in hovering the soil pH and thus the availability of calcium can be improved. Chambers and Gardner (1951) testified that enormous increase in yield can be brought about by correcting soil acidity in light to medium loam soils through the application of calcium oxide and calcium carbonate. This ascent in soil pH can be attributed to the increased availability of calcium in soil.

The first two months of incubation exhibited a steep inclination in magnesium content of soil. This was followed by a gradual increase over the next two months of incubation. In all the four months of incubation, treatment T_2 (magnesium sulphate + ½ lime) displayed higher magnesium content. The addition of magnesium sulphate along with ½ lime to the soils might have contributed to the increased availability of magnesium in the ameliorated soil. Liming also improves the availability of nutrients by altering the soil pH to neutrality.

The available sulphur was found to decrease over the four months of incubation. The treatments T_3 (phosphogypsum + ½ lime) exhibited higher sulphur contents at 30, 60, 90 and 120 DAI. Phosphogypsum is an effective supplier of calcium and sulphur. This result is in agreement to the report of Karan *et al.* (2014). They reported that extended submergence of acidic wetland soils increased the soil pH and reduced the hydraulic conductivity of acid soils followed by decrease in the availability of sulphur, boron, copper and zinc. They also stated that liming these acid soils resulted in the increased availability of boron, but decreased the availability of sulphur, copper, zinc, iron, manganese and aluminium.

The general trend observed with respect to available iron content (Figure 11) showed an increasing manner up to 120 DAI. The level of submergence had no significant difference on available iron content but, it was observed that the lower concentration of available iron was recorded at 10 cm level of submergence. This shows that iron toxicity could be reduced to a greater extent with 10 cm level of submergence. The application of treatments showed a suggestive effect on iron content over these four months. The diminution in values of iron was least in treatment T_1 (lime) at 30 and 120 DAI. At 60 and 90 DAI, the least iron content was observed in the pots treated with the treatment T_3. Lime was significantly superior in reducing iron toxicity followed by treatment receiving phosphogypsum along with lime. Iron toxicity occurs principally due to the reduced condition of submerged soils and also due to their low pH. Thus, liming is a prime alternative to increase the soil pH. Iron toxicity might also be due to the increased organic matter content as reported by Ottow (1981). Breemen and Moormann (1978) opined that iron toxicity in lowland acid soils can be alleviated by liming the soil, delayed planting or through late flooding to avoid excess iron in the early stages. Benckiser *et al.*, (1984) suggested that addition of calcium and magnesium as amendment plays an important role in alleviating iron toxicity in rice. Immobilisation of phosphorus by iron and aluminium can be reduced by application of lime in acid soils and thereby improve the phosphorus in soil solution (Fageria and Baligar, 2008).

The effect of amendment on available manganese content showed a decreasing trend up to 60 DAI (Table 22). Thereafter, the trend displayed an increasing pattern at 90 and 120 DAI. The decline in the manganese values was mostly evident in the treatment T_1 (lime). Manganese availability was found to decrease on application of calcium carbonate. It might be due to the strong binding of manganous ions with calcium carbonate. In addition, manganese availability was found to decrease with increase in organic matter content (Mandal and Mitra, 1982).

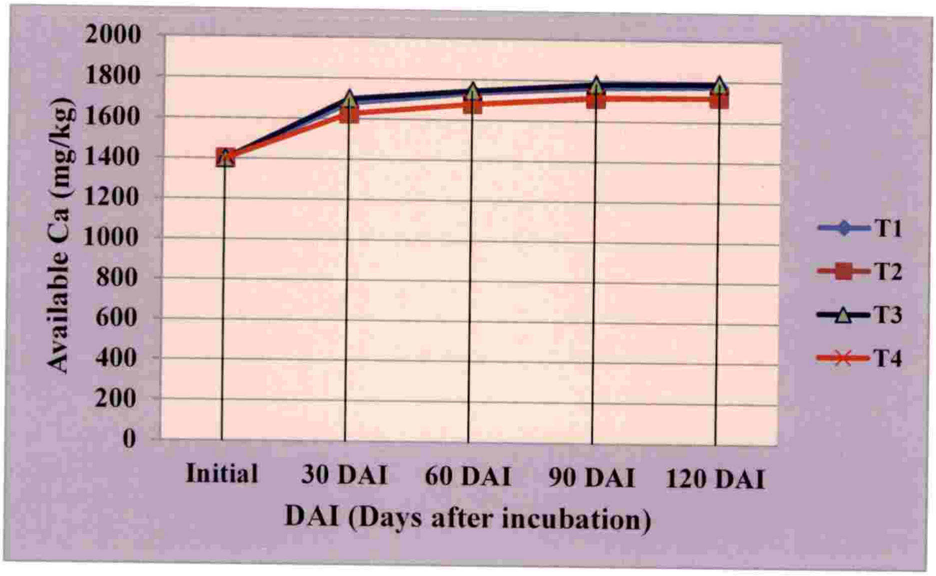

Figure 10: Effect of different amendments on available calcium status at 30, 60, 90 and 120 DAI

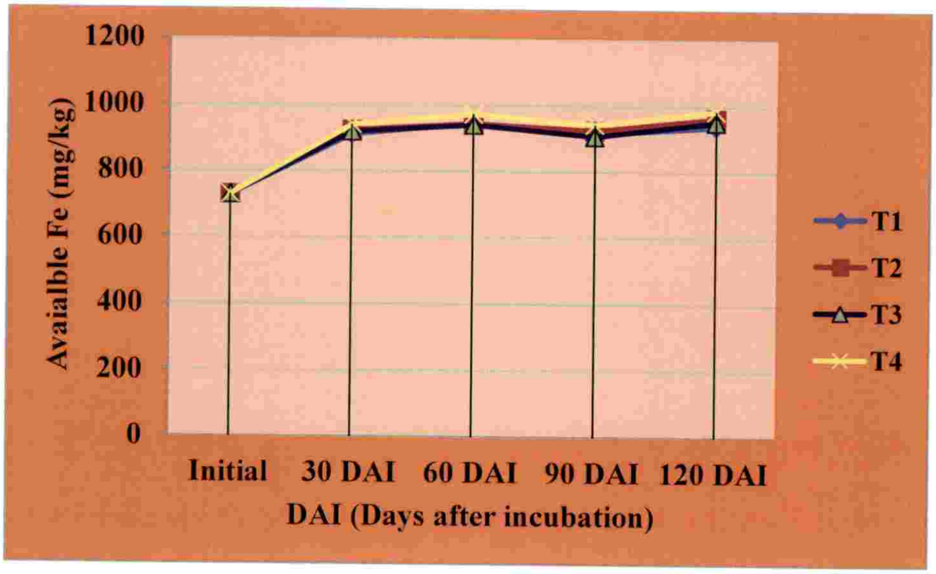

Figure 11: Effect of different amendments on available iron content at 30, 60, 90 and 120 DAI

The available copper contents displayed a declining trend at 30, 60, 90 and 120 DAI. This trend is similar to the incubation studies conducted by Weil and Holah (1989) in submerged Ultisols. Among the treatments, the lowest value of copper content was observed in the treatment T_1 (lime). The solubility of copper is found to decrease with increase in soil pH. It may be due to the adsorption of cuprous ions. Liming helps in increasing the soil pH to a neutral range which results in reduction of toxic ions in the soil.

The submergence levels 5 cm and 10 cm showed no significant difference in available zinc at 30, 60 and 90 DAI. But at 120 DAI, submergence level S_2 at 10 cm showed significantly higher available zinc. This indicates that 5 cm level of submergence reduced toxicity of zinc to a greater extent as compared to 10 cm. The results showed the beneficial effect of lime in lowering zinc toxicity in acid soils.

Among the treatment means, T_1 (lime) showed significantly lowest available zinc content at 30, 60, 90 and 120 DAI. Tlustos *et al.* (2006) studied on the ameliorative effect of 3 g calcium oxide and 5.36 g calcium carbonate. And they found that the soil pH increased up to 7.3 in the treatments with lime and also found that the mobile portion of zinc got reduced by 80 per cent.

A very slow decline in the boron content was observed at 30, 60, 90 and 120 DAI. Though there was no significant difference in the levels of submergence at 30 and 60 DAI, there was profound effect at 90 and 120 DAI. This study reveals that with increase in days of flooding the available boron content was found to decrease. Long term flooding increases the soil pH resulting in reduction in boron content of the acid soils. The treatments T_2 showed higher available boron content at 30, 60, 90 and 120 DAI. The application of magnesium sulphate as amendment increased the availability of boron which might be due to anion exchange of sulphate for borate ions under saline conditions, thus increasing the availability of boron in soluble form.

The available silicon contents showed a declining trend over the four months of incubation. Among the treatments, T_3 (Phosphogypsum + ½ lime) exhibited a grander value of available silicon content at 30, 60 and 90 DAI. The present study revealed that application of phosphogypsum as amendment enhanced the availability of silicon in acid soil. The presence of dioxide silicon in phosphogypsum has a positive part in coagulation of harmful salts and ensures the transformation of sparingly soluble nutrients into forms which are soluble thus increasing the availability of nutrients in soil.

The exchangeable aluminium contents exhibited a steep decline in their availability trends over the four months (Figure 12). The aluminium toxicity was reduced to a minimum level at 30, 60 and 120 DAI by treatment T_3 (214.67 mg kg^{-1}, 172.17, 100.83 mg kg^{-1} respectively) *i.e.* on application of phosphogypsum at the rate of 500 kg ha^{-1} + ½ lime. However at 90 DAI, the least aluminium content was observed in soil treated with lime alone (137.67 mg kg^{-1}). Application of lime and phosphogypsum as soil amendments helps in alleviation of aluminium toxicity, improves the root growth and efficiency of applied nutrients and ultimately benefits the overall growth of cereals like wheat and maize (Toma *et al.*, 1999; Farina *et al.*, 2000a; Caires *et al.*, 2011b). Similar results on the effect of phosphogypsum in alleviating aluminium toxicity was reported by Cameron *et al.*, 1986; Deepa, 2008).

5.2.1.5 Exchangeable sodium

The exchangeable sodium content showed a decreasing trend over the four months of incubation as given in Figure 13. There was no significant difference in sodium content at both the levels of submergence. However, it was observed that with increase in period of flooding, 5 cm level of submergence recorded lower exchangeable sodium content in the soil. Application of lime *i.e.* treatment T_1 (1199, 1125, 1092, 1068 mg kg^{-1} respectively) was found to decrease the exchangeable sodium contents at 30, 60, 90 and 120 DAI. The leaching effect might have contributed to an extent in reducing the salinity levels.

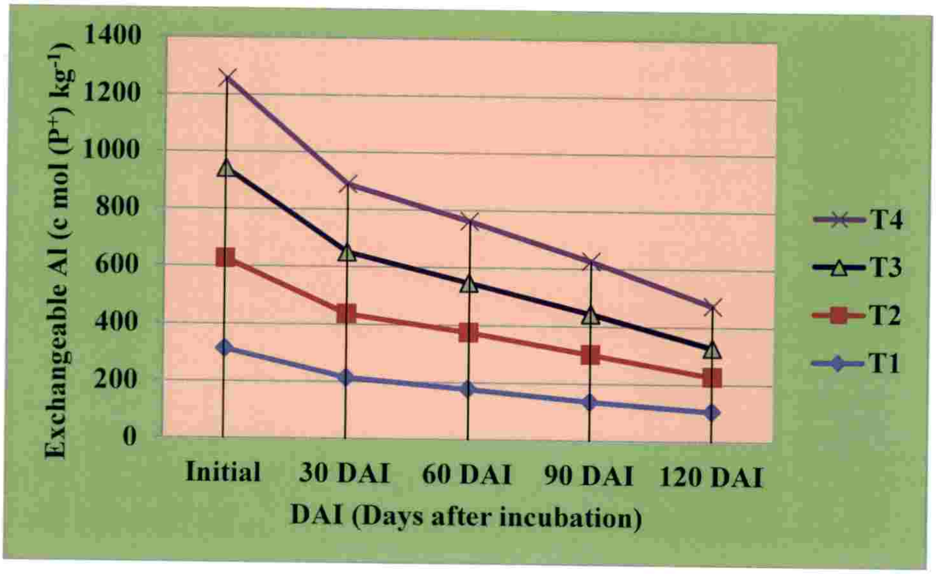

Figure 12: Effect of different amendments on exchangeable aluminium content at 30, 60, 90 and 120 DAI

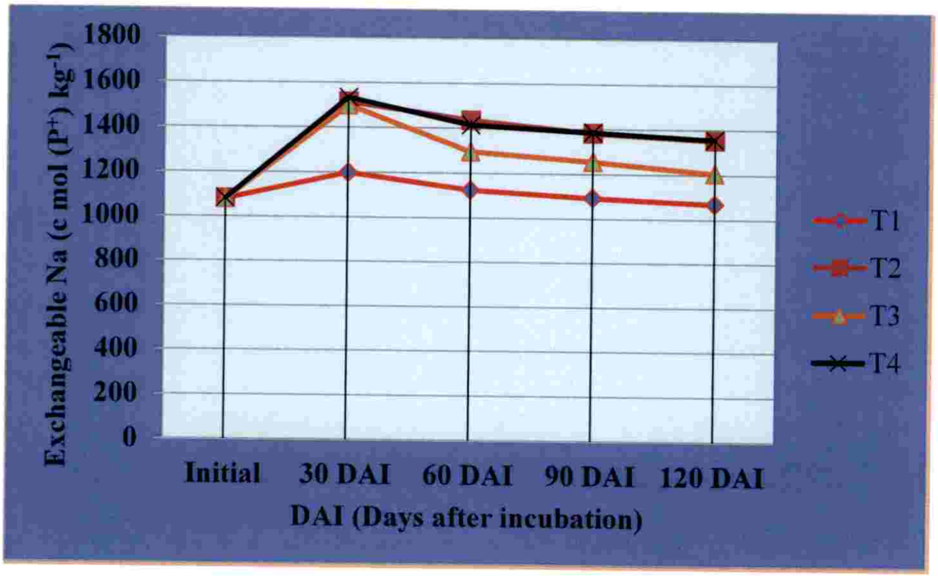

Figure 13: Effect of different amendments on exchangeable sodium status at 30, 60, 90 and 120 DAI

The present investigation proved that application of lime as amendment to saline hydromorphic soils showed a remarkable reduction in the exchangeable sodium content of soil which might be due to the replacement of sodium ions by calcium ions in the soil exchange sites. Application of calcium chloride was found to remove 90 per cent of the total sodium and soluble salts in highly saline-sodic soils (Gharaibeh *et al.*, 2014).

5.3 SOLUTION CULTURE EXPERIMENT

The experiment was conducted by maintaining a nutrient solution (Hoagland's solution) containing 3 levels of iron (400, 800, 1200 mg L^{-1}), 2 levels of aluminium (15 and 30 mg L^{-1}) and 2 levels of salinity (5 and 10 dS m^{-1}) along with one control. The two selected rice varieties Kuthiru and Ezhome-1 were evaluated for their tolerance to iron and aluminium coupled with salinity. Three rice seedlings of fourteen days growth were transferred to the solutions as per the treatment details. The growth of plants were observed for one week period.

5.3.1 Effect of different treatment combinations on the biometric observations

5.3.1.1 Plant height

There were no remarkable differences in percentage of increase in plant height between the varieties as well as the variety x treatment interaction. The lowest significant decrease in plant height was observed in T_{12} (1200 mg L^{-1} iron, 30 mg L^{-1} aluminium and 10 dS m^{-1} salinity). The other treatments followed the order T_9, T_8, T_5, T_3, T_6 and T_{11}, T_4, T_7, T_{10},T_2, T_1 and T_{13}. The highest plant height was observed in control (Hoagland's solution). The treatments receiving the highest levels of iron, aluminium and salinity suppressed the plant growth to the maximum extent, which might be attributed to the reduced nutrient uptake by the rice plants under the toxic levels of the supplied nutrients.

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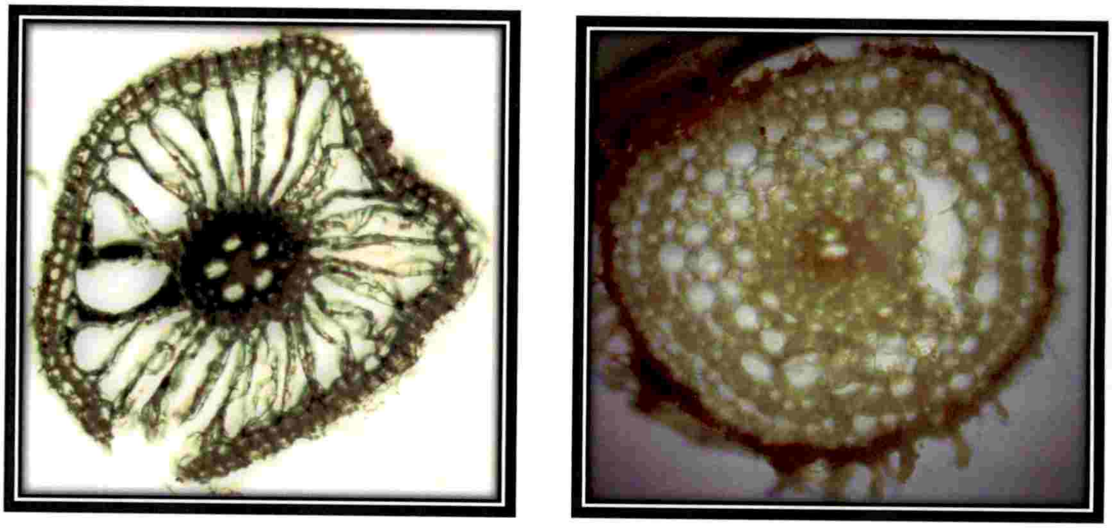
5.3.1.2 Root length

Among the varieties, significantly lower root length was observed in Kuthiru over Ezhome-1, which might be attributed to the mechanism of rice roots of Kuthiru to accumulate the toxic ions in the roots thus preventing its translocation to the above ground plant parts. Alia *et al.* (2015) had reported a negative correlation of rice root length with increased concentration of iron and aluminium. The highest significant reduction in root length was observed in the treatments receiving the highest concentrations of iron, aluminium and salinity. These results showed that the plant root which encounters toxic levels of Fe, Al and salinity have reduced root length, indicating restricted root growth. There was remarkable difference in root length on considering the variety x treatment interaction. The lowest significant root length was observed in T_{12} (1200 mg L^{-1} iron, 30 mg L^{-1} aluminium and 10 dS m^{-1} salinity) of Kuthiru variety. Sharma and Dubey (2007) reported that when the rice seedlings of cultivar Pant-12 were reared in sand cultures for 5 to 20 days with 80 and 160 milli micro molar Al^{3+} concentration, an increase in uptake of Al^{3+} with a parallel decrease in the root and shoot lengths were observed. Awasthi *et al.* (2017) reported that the relative root length of aluminium (25, 50, 100μM) stressed rice roots was found to be decreased over different time frames *viz.*12, 24, 48 hours. But, the reduction was more marked at 48 hours duration.

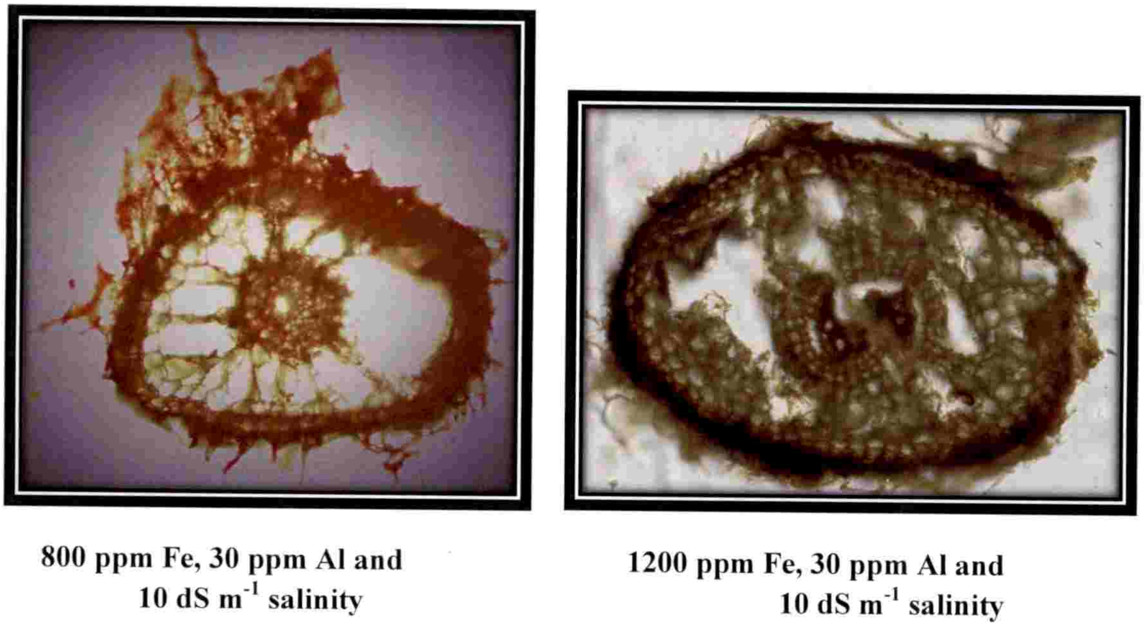
5.3.1.3 Pattern of iron coating around the roots

The patterns of iron coating on the roots were observed. The cross sections of roots were made and observed under the (Axio Lab. A1) microscope of 100X magnification and analysed using Zen image analyser. Formation of iron plaque on the root surface was most prominent in the solution containing 1200 mg L^{-1} of iron in Ezhome-1 and Kuthiru varieties (Plate 8). The thickness of the roots was also measured using the Zen image analyser by taking the average thickness of iron coating around the cross sections. It was observed that there was no iron coating around the root cells of control. Maximum iron coating around the root among the treatments was displayed by solution containing the



Control - Kuthiru

400 ppm Fe, 30 ppm Al and $10\ dS\ m^{-1}$ salinity



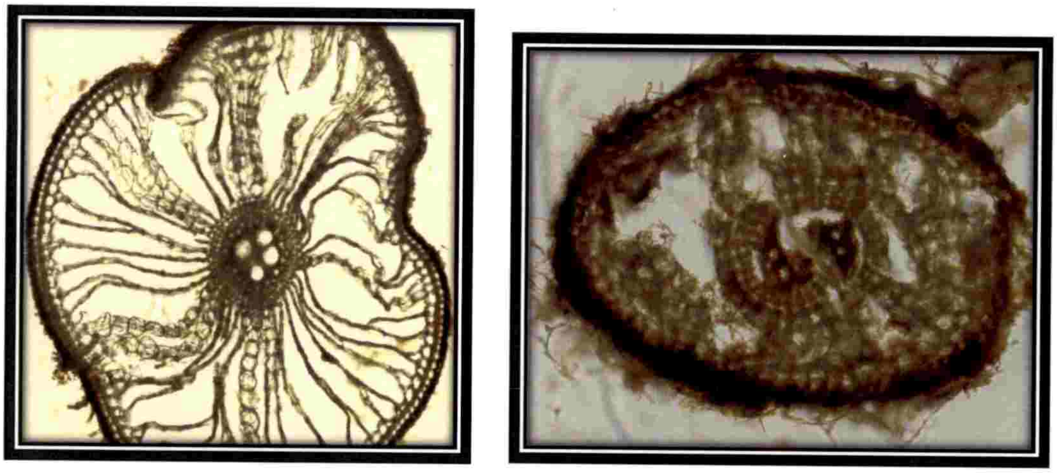
800 ppm Fe, 30 ppm Al and $10\ dS\ m^{-1}$ salinity

1200 ppm Fe, 30 ppm Al and $10\ dS\ m^{-1}$ salinity

Plate 8 (A): Pattern of iron accumulation in roots of Kuthiru

Control- Ezhome-1

400 ppm Fe, 30 ppm Al and 10 dS m^{-1} salinity



800 ppm Fe, 30 ppm Al and 10 dS m^{-1} salinity

1200 ppm Fe, 30 ppm Al and 10 dS m^{-1} salinity

Plate 8 (B): Pattern of iron accumulation in roots of Ezhome-1 treatment T_{12} (1200 mg L^{-1} iron, 30 mg L^{-1} aluminium and 10 dS m^{-1} salinity) as in Plate 8 (A) and (B). The thickness of iron plaque was greater in the variety V_2 (Kuthiru), the local land race of Kaipad which clearly indicates the root exclusion principle for reducing iron and aluminium toxicity, thus preventing its translocation to the above ground plant parts. The study also showed that the roots of the treated rice plants remained as such in the solution even after the drying up of above ground parts of rice plant.

5.3.1.4 Root dry weight

Significantly higher root dry weight was observed in Kuthiru over Ezhome-1. This might be due to the greater accumulation of toxic ions including iron and aluminium in the roots of Kuthiru variety. The treatment T_8 with 800 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and salinity of 10 dS m^{-1} had higher root dry weight. The maximum root dry weight was observed in T_8, which might be due to its effect that T_8 was receiving 800 mg L^{-1} of iron along with high aluminium (30 mg L^{-1}) and salinity (10 dS m^{-1}), resulted in visible iron coating along with sustained root growth. Alia *et al.* (2015) reported that as the concentration of iron and aluminium increases, the rice roots secreted organic acids that chelated Fe and Al, rendering them unavailable for the uptake by rice roots. The variety *vs.* treatment interactions indicated that the highest significant root dry weight was observed in the treatment with 800 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and salinity of 10 dS m^{-1} of Kuthiru variety. This may be due to the effect of high concentration of iron and aluminium in the solution which inhibits the root growth.

5.3.2 Whole plant analysis

Higher nitrogen content was observed in variety Ezhome-1 compared to Kuthiru. The treatment T_9 (1200 mg L^{-1} iron, 15 mg L^{-1} aluminium and 5 dS m^{-1} salinity) recorded the highest total nitrogen content. The lowest nitrogen content was seen in T_{13}. This might be due to the better uptake of nitrogen by the rice roots contributing to enhanced nutrient content in the plant. While considering the variety x treatment interactions, the treatment T_{12} of Kuthiru recorded the highest significant nitrogen content which might be attributed to the native character of the local landrace to absorb more nutrients even under adverse abiotic stress conditions. The lowest nitrogen content was observed in T_{13} (control - Hoagland solution) of Ezhome-1.

The variety Kuthiru recorded the significantly higher amount of phosphorus compared to Ezhome-1. The highest amount of phosphorus was seen in the treatment T_3 (400 mg L^{-1} of iron, 15 mg L^{-1} of aluminium and 10 dS m^{-1} salinity). The significantly highest phosphorus content recorded in the treatments receiving lowest iron concentration (400 mg L^{-1}) might be due to the prominent antagonistic relation between iron and phosphorus. High iron concentration inhibits the uptake of phosphorus by plants. Among the variety x treatment interactions, T_3 of V_2 recorded the highest amount of phosphorus.

Higher potassium content was seen in Kuthiru over Ezhome-1. The higher potassium content recorded in the Kuthiru variety shows its better adaptation to abiotic stresses. High potassium content imparts resistance not only to pest and diseases, but also to abiotic stresses like salinity, nutrient toxicity etc. The significantly highest potassium content was observed in T_8 and T_{10}. On considering the variety *vs.* treatment interaction, the significantly highest potassium content was recorded in T_1 of V_2.

Significantly lower iron content was observed in the variety V_2 *i.e.* Kuthiru compared to V_1 *i.e.* Ezhome-1. The lower concentration of iron recorded in the Kuthiru variety might be due to its ability to accumulate more iron in roots and less accumulation in the above ground plant parts. The highest significant concentration of iron was present in the treatment T_9. High iron concentration provided through the treatment T_9 (1200 mg L^{-1} Fe) significantly enhanced the iron concentration in rice plants. This shows the enhanced capacity of both the varieties to absorb toxic levels of iron. Among the variety x treatment

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interactions, the treatment T_9 of V_1 (1200 mg L^{-1} Fe, 15 mg L^{-1} Al, 5 dS m^{-1} salinity) recorded the highest significant amount of iron.

The variety Ezhome-1 showed significantly lower manganese content compared to Kuthiru. The treatments revealed that the highest significant manganese content was in T_4. The highest significant amount of manganese among the variety x treatment interaction was observed in T_1 of V_2. With high levels of iron, there is antagonistic effect with respect to manganese. The treatment receiving low levels of iron (T_4: 400 mg L^{-1} Fe) recorded significantly high levels of manganese in the rice plant.

There was no significant difference in the total chlorine content on comparing the varieties as well as the variety x treatment interaction. Among the treatments, the highest significant chlorine content was recorded in T_4 (400 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and 10 dSm^{-1} salinity) receiving highest levels of aluminium and salinity whereas, the lowest concentration was observed in T_{13} (control). The high chlorine content might be attributed to the increase in level of salinity.

The variety Kuthiru recorded maximum significant concentration of aluminium than Ezhome-1. This might be due to the capability of the local landrace to accumulate more aluminium in the plant parts without much harmful effect on the yield of rice. On comparing the treatments, the highest significant aluminium content was observed in T_{10} (1200 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and 5 dS m^{-1} salinity). The effect of variety x treatment interactions revealed that T_{10} of Ezhome-1 recorded the significantly highest aluminium content. Awasthi *et al.* (2017) reported that aluminium stress treatment leads to morphological changes of rice seedlings.

The variety Kuthiru recorded significantly higher sodium content compared to Ezhome-1. Even though Kuthiru accumulates more sodium in the plant parts, it has the inherent ability to tolerate high sodium levels. The highest sodium content among the treatments was reported in T_4 (400 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and 10 dS m^{-1} salinity). The data on variety x treatment interactions revealed that T_1 of V_1 (400 mg L^{-1} of iron, 15 mg L^{-1} of aluminium and 5 dS m^{-1} salinity) recorded the lowest sodium content while, the highest was seen in T_{12} of V_2.

5.3.3 Root partitioning studies

The roots of the variety Kuthiru showed significantly higher concentration of iron compared to Ezhome-1. Among all the treatments, the highest iron content was observed in the roots of T_{12} (1200 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and 10 dS m^{-1} salinity) receiving higher levels of iron, aluminium and salinity. The high level of iron taken up through the roots of Kuthiru was well distributed throughout the roots which showed high iron content in the root partitioning studies in Kuthiru variety. On considering the variety *vs.* treatment interactions, the highest iron content was noted in T_{12} of V_2 which was on par with T_{11} of V_2.

Significantly higher aluminium content was observed in Kuthiru over Ezhome-1. Among all the treatments, the highest significant amount of aluminium was observed in the treatment T_{10}. In the variety *vs.* treatment interactions, the highest significant amount of aluminium has been observed in T_9 and T_{10} of V_2. Alia *et al.* (2015) reported that as the concentration of iron and aluminium increases, the rice roots secreted organic acids that chelated Fe and Al, rendering them unavailable for the uptake by rice roots.

The variety Ezhome-1 showed significantly lower sodium content than Kuthiru. The lowest significant amount of sodium was observed in the treatment T_5. On the other hand, highest sodium content was noticed in T_{11} followed by T_7. The variety *vs.* treatment interactions showed that the lowest significant sodium was observed in T_1 of V_1 and the highest in T_2 of V_1.

The variety Kuthiru showed significantly lower concentration of chlorine than Ezhome-1. On comparing the treatments, the lowest significant content of chlorine was seen in T_{13} (control). The highest chlorine content was observed in T_7. The variety x treatment interactions reveals that the lowest significant uptake of chloride was in T_{13} of V_2.

The varietal interaction shows that Kuthiru has a significantly higher root CEC over Ezhome-1. The highest significant root CEC was obtained in the treatment T_{12}. The lowest root CEC was in T_{13}. Among the variety *vs.* treatment interaction, the highest root CEC was seen in T_{12} of V_1. Ram (1980) reported that the uptake of nutrients such as P, K, Fe and Mn was positively linked with the root CEC in most of the paddy and wheat varieties.

5.4 POT CULTURE EXPERIMENT

Pot culture experiment was carried out at COA, Padannakkad with the two selected rice varieties Kuthiru and Ezhome-1 in the saline hydromorphic soils collected from Punnachery region of Kaipad during the month of July to October 2016 (Plate 9). Kuthiru and Ezhome-1 are the most popular varieties of Kaipad. Kuthiru is a saline tolerant land race having duration of 110 to 120 days. 'Ezhome –1' is a popular high yielding long duration (135 - 140 days) variety developed by crossing Jaya and Kuthiru. The results of this study are discussed in this part of the chapter.

5.4.1 Effects of amendments on growth parameters

The highest plant height was observed in Ezhome-1 at 30, 60 DAT and at harvest. The higher plant height of Ezhome-1 might be attributed to the genetic character of the variety (Soumya, 2016). The treatment means showed no differences at 30 and 60 DAT whereas at harvest, the treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron) showed the significantly superior plant height. Considering the variety x treatment interaction at 30 DAT, significantly maximum plant height was observed by treatment T_6 (Phosphogypsum @ 500

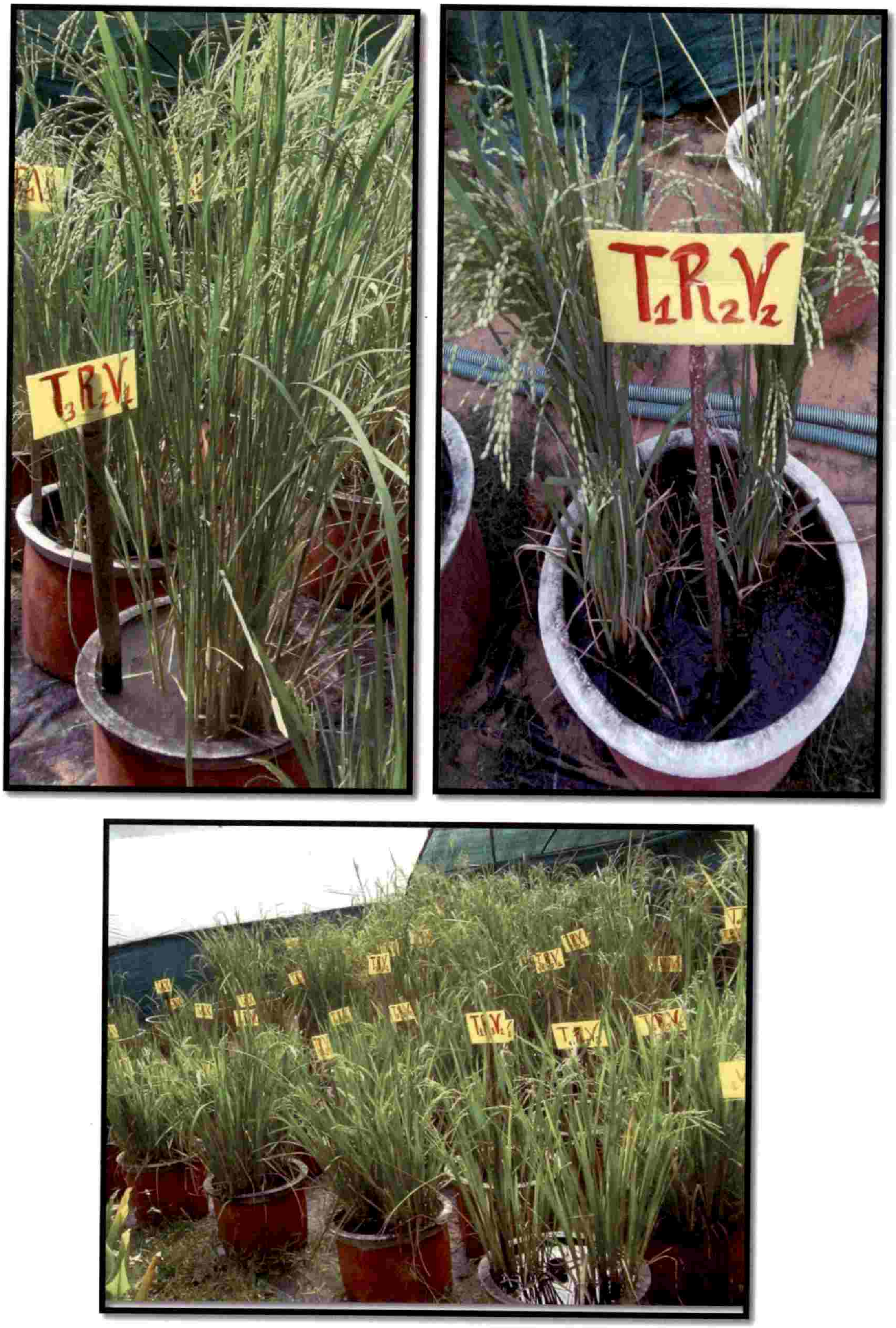

Plate 9: Layout of the pot culture experiment

Plate 10: Iron toxicity symptoms in rice seedlings in pot culture experiment

Control- Kuthiru T_1 - Kuthiru Control- Ezhome-1 T_3 - Ezhome-1

Plate 11: Iron plaque formation in rice roots during the vegetative stage in pot culture experiment

kg ha^{-1} + ½ lime + potassium silicate-0.25% + 0.25% boron) in variety Ezhome-1 (129.20 cm). There was no significant difference in the variety x treatment interaction at 60 DAT. However at harvest stage, treatment T_6 of variety Ezhome-1 showed the significantly highest plant height. Alleviating the aluminium toxicity in saline hydromorphic soils of Kaipad improves the root growth which may ultimately lead to higher growth of plants. Liming helps in raising the pH and thus helps in enhancing the availability of various nutrients required for plant growth. Similar results were obtained by Suswanto *et al.* (2007) on application of 4 t ha^{-1} ground magnesium limestone. This helped in raising the soil pH and also in eliminating iron and aluminium toxicity to an extent. The presence of boron and potassium silicate in the treatment might have boosted the growth of plant due to the greater availability of boron and potassium along with silicon. Barcelo *et al.* (1993) reported that silicon can commendably reduce toxicity of aluminium in maize. Application of 2 to 3 Mg ha^{-1} calcium silicate brought about 74 per cent decrease in the exchangeable aluminium content in acid sulphate soils (Elisa *et al.*, 2016).

There was no remarkable difference in the number of leaves between the two varieties at 30 DAT. The significantly highest numbers of leaves were noticed in treatment T_2 (Magnesium sulphate + ½ lime). At harvest stage, significantly highest numbers of green leaves were observed in T_1 *i.e.* lime which were on par with T_2. While considering the variety *vs.* treatment interaction at 30 DAT, significantly maximum number of leaves were recorded by T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime) of the variety Ezhome-1. At 60 DAT, T_3 of variety V_1 exhibited the highest significant number of leaves. Finally at harvest stage, treatment T_1 of Ezhome-1 recorded the maximum significant number of leaves. Liming might have contributed to the vegetative growth by making the nutrients in the available range through raising the pH. Magnesium plays a major role in chlorophyll formation. Application of magnesium sulphate at the rate of 1.5 and 3 g m^{-2} in rice fields of West Bengal have shown an increase in yield by 6.4 per cent and 17 per cent respectively (Bhaskar *et al.*, 2013).

The number of productive tillers were maximum in Ezhome-1, which is a popular high yielding variety when compared to Kuthiru. Application of the treatment combination of phosphogypsum at the rate of 500 kg ha^{-1} + ½ lime recorded the maximum number of productive tillers (Figure 14). The production of maximum number of productive tillers may be attributed to the positive trait of the varieties and the treatments in overcoming iron and aluminium toxicity. Treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron) recorded similar type of results in number of productive tillers. The presence of boron and potassium silicate must have boosted up the production of tillers. Liu *et al.* (2010) reported an average boost in rice yield of 1.12, 2.47 and 2.98 t ha^{-1} on application of phosphogypsum at the rate of 15, 30 and 45 t ha^{-1} respectively in saline-sodic soils of North-East China. The rise was 161, 191 and 246 per cent respectively for panicles m^{-2} compared to control.

5.4.2 Influence of amendments on yield attributes

The number of grains per panicle was maximum in Ezhome-1 variety (Figure 15). The treatment T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime) produced higher number of grains per panicle. The variety x treatment interaction also showed that T_3 of variety Ezhome-1 yielded the significantly maximum number of grains per panicle. The beneficial effect of phosphogypsum might be due to the presence of Ca, P, S, F, K, Mg etc.

A significantly higher grain yield was observed in the variety Ezhome-1 compared to Kuthiru (Figure 16). A significantly maximum grain yield was observed in the treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron) with an increase in yield of 21.29 per cent with respect to control. In the variety *vs.* treatment interaction, T_3 of variety Ezhome-1 recorded the highest significant yield. Liu *et al.* (2010) reported an average boost in rice yield of 1.12, 2.47 and 2.98 t ha^{-1} on application of phosphogypsum at the rate of 15, 30 and 45 tha^{-1}

respectively in saline-sodic soils of North-East China. This may also be due to the ameliorating effect of lime in reducing iron and aluminium toxicity, increased presence of calcium content and also the better soil conditions for improved plant growth. Nhung and Ponnamperuma (1966) reported that liming could help in raising the pH of acid sulphate soils. Similar results were also reported by Crusciol *et al.* (2016). Appropriate combinations of lime and nitrogenous and phosphatic fertilizers were reported to give a reasonable yield (Maneewan *et al.*, 1981). The beneficial effect of silicon on rice yield on application of Silicon fertilizers was reported by Aryalekshmi and Jayasree (2017).

The straw yield was maximum in Ezhome-1 variety as given in Figure 17. The treatment T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime) recorded the highest significant straw yield compared to all other treatments. On comparing the variety x treatment interaction also, T_3 of variety Ezhome-1 recorded the highest significant straw yield. Application of phosphogypsum and liming materials to rice crop might have facilitated better partitioning of translocates into the various plant parts resulting in higher yield. This may be due to the superior growth of rice plants by the action of lime, calcium and phosphorus. All the other treatments yielded lower straw yield compared to T_3 (lime). Amanullah and Inamullah (2016) reported that application of phosphorus sources is an essential factor for improving the accumulation of total dry matter and partitioning of larger quantities into the panicles and thus increasing the yield of rice.

Chaffiness percentage was minimum in Kuthiru variety compared to Ezhome-1. Thus from the present study it is evident that Kuthiru, the local land race of Kaipad has recorded lower chaffiness percentage because of its genetic ability to tolerate adverse conditions of iron and aluminium toxicity coupled with salinity. Even though Ezhome-1 is a popular high yielding variety, it showed greater chaffiness percentage. The treatment T_1 with application of lime alone showed lower chaffiness percentage than other treatments. The variety x treatment interactions revealed that significantly lowest chaffiness percentage was

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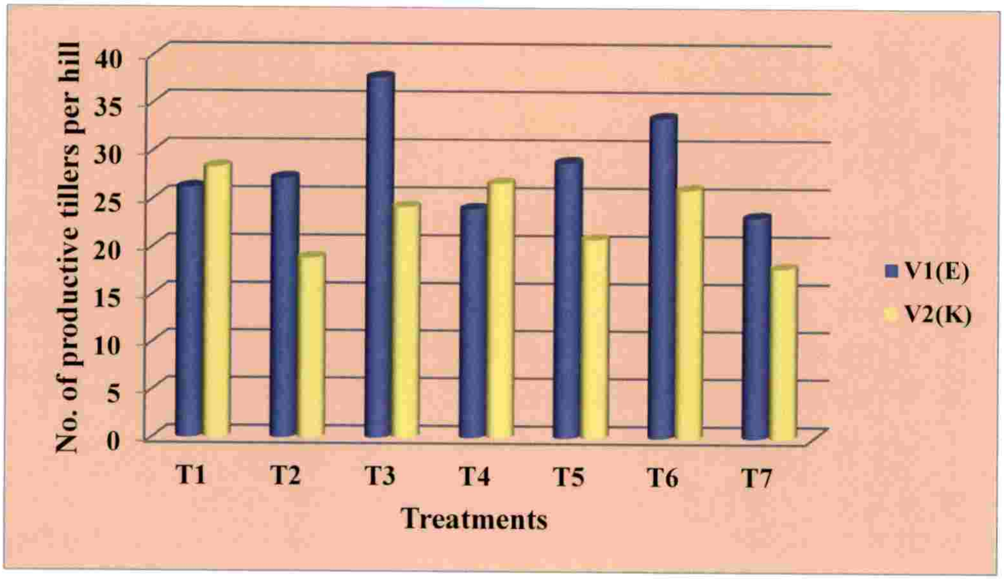

Figure 14: Effect of different amendments on the number of productive tillers

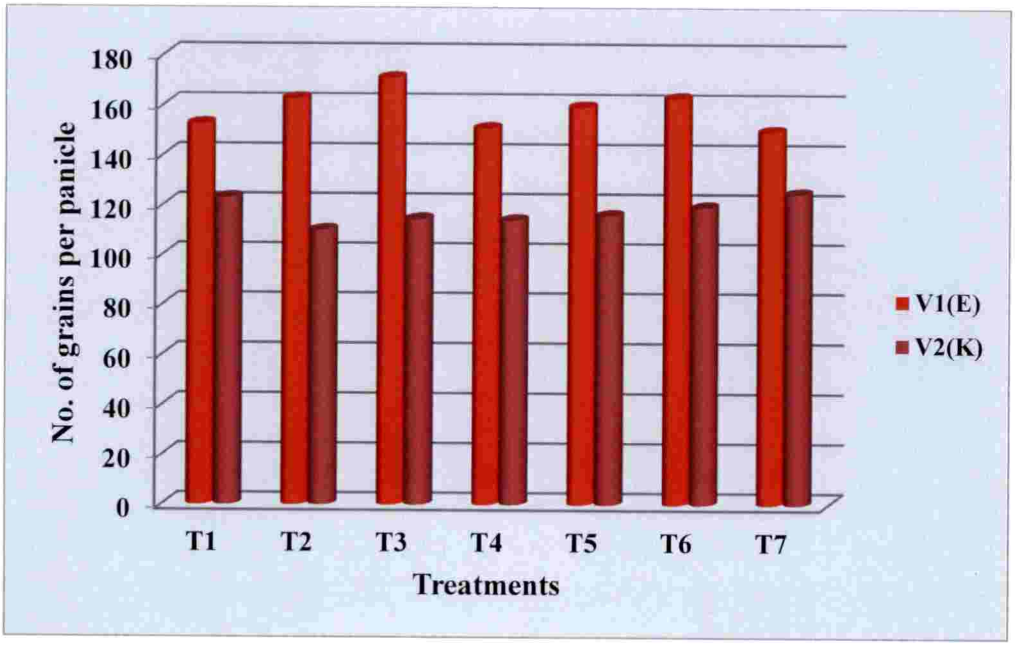

Figure 15: Effect of different amendments on number of grains per panicle of rice varieties

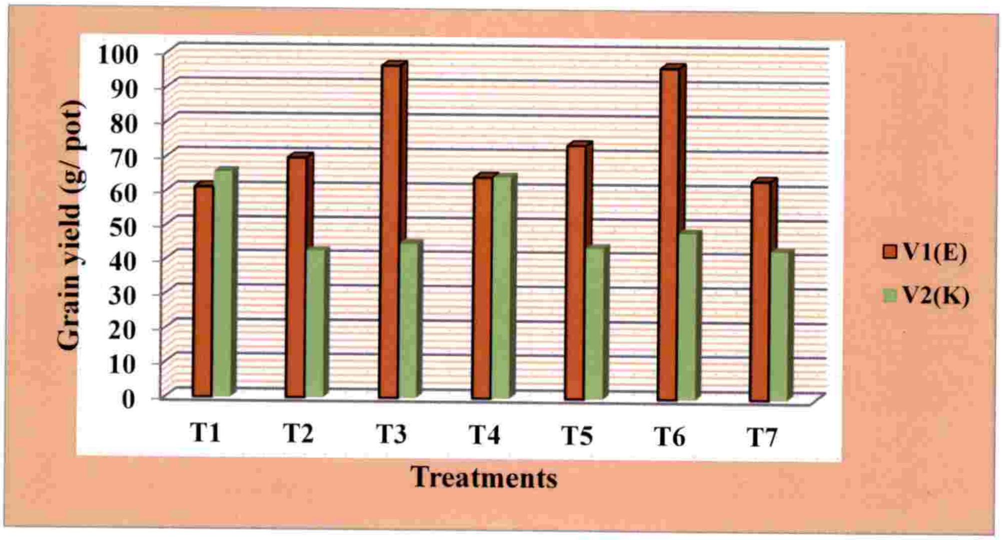

Figure 16: Effect of different amendments on grain yield of rice varieties

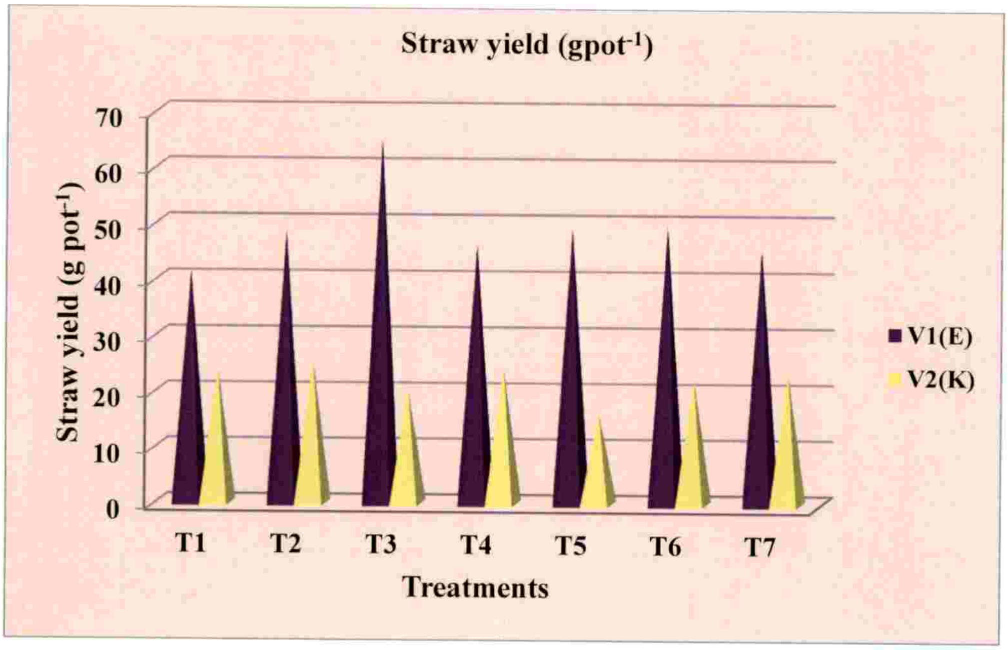

Figure 17: Effect of different amendments on straw yield of rice varieties

observed in treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate - 0.25% + 0.25% boron) of variety Ezhome-1. This might be due to the capacity of phosphogypsum and lime in alleviating iron and aluminium toxicity thus resulting in excellent plant growth and yield.

The variety Ezhome-1 showed a significantly higher seed index value compared to Kuthiru. Among the treatments, the treatment T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime) exhibited a significantly higher weight for one thousand grains (24.75 g pot^{-1}). The higher thousand grain weight recorded with the application of phosphogypsum + ½ lime might be due to its beneficial effect on yield attributes. The beneficial effect of phosphogypsum may also be due to the presence of Ca, P, S, F, K, Mg etc. The variety x treatment interactions for seed index revealed a significantly higher weight in case of T_3 of Ezhome-1. Phosphogypsum is positively correlated to higher yield in rice as reported by Liu *et al.* (2010).

5.4.3 Residual nutrient status of soil

The effect of different treatment combinations as amendments on the pot culture experiment were studied and the discussion on the residual nutrient status of soil is as given below.

There was a profound effect in soil pH with respect to the treatment combinations. The pH was higher in case of Kuthiru variety compared to Ezhome-1. Application of the treatment T_4 (Lime as per KAU POP + potassium silicate 0.25% +0.25 % boron) chronicled the significantly highest pH. The higher pH obtained may be attributed to the effect of lime. The presence of calcium in lime helps in reducing the soil acidity. Application of lime to the soil surface is the most efficient practice to reduce soil acidity and thereby increase soil pH (Crusciol *et al.*, 2016). Among the variety x treatment interactions, significantly highest pH was noticed in treatment T_6 of variety Kuthiru. Acidity due to the presence of exchangeable aluminium and hydrogen can be effectively controlled on application of phosphogypsum and lime (Deepa, 2008).

The electrical conductivity of soil showed significant changes with respect to the application of amendments. The least significant value of electrical conductivity was spotted in the treatment T_4 (Lime as per KAU POP + potassium silicate 0.25% +0.25 % boron). Application of amendments might have resulted in providing a favourable environment for root growth. The pot culture study was carried out during rainy season (July-October 2016). The heavy rainfall might have washed out the soluble salts from the soil into the perforated PVC pipes placed at the centre of the pot. The collected leachates from the PVC pipes were removed using siphoning mechanism. The leachate so removed was analysed for electrical conductivity. The electrical conductivity values ranged from 4.72 to 6.54 dS m^{-1}. The dioxide silicon present in phosphogypsum may act as a salt coagulator for the toxic salts.

Ezhome-1 recorded higher organic carbon compared to Kuthiru. Among the treatment mean, T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per + potassium silicate-0.25% + 0.25% boron) discerned the significantly highest organic carbon content. There was no significant difference in the variety x treatment interaction. The soils of Kaipad are generally rich in organic carbon. This high organic matter also facilitates favourable soil conditions providing better availability of nutrients for crop growth.

Available nitrogen content in the soil was influenced by the application of amendments. Among the two varieties, Ezhome-1 exhibited significantly higher available nitrogen content than Kuthiru. This might be due to the higher uptake of nitrogen by Kuthiru. The treatment T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime) recorded the highest significant amount of available nitrogen. This might be attributed to the action of calcium and phosphorus which helps in improving the soil physical and chemical conditions and also enhances microbiological activity in soil thus facilitates more nitrogen fixation. There was no significant difference in available nitrogen content in the variety x treatment interaction.

The varieties had no significant difference in the residual available phosphorus content. It was noted that the treatment T_4 (Lime + potassium silicate

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- 0.25% +0.25 % Boron) showed the significantly highest available phosphorus content. Even though phosphogypsum contains phosphorus, the higher available phosphorus was recorded in the treatment T_4 (lime). This can be attributed to the more significant effect of lime in increasing the pH thus favouring the greater availability of phosphorus in soil as compared to phosphogypsum. The plants must have also taken up more phosphorus for their growth and metabolism leading to lesser quantity of phosphorus in soil. The variety *vs.* treatment interaction revealed that T_6 of Kuthiru showed significantly higher available phosphorus content. This may be because of the action of phosphogypsum which is a very good source of phosphorus in the soil. Kordlaghari and Rowell (2006) also reported similar results. The lowest available phosphorus content was witnessed in T_7 of Ezhome-1 (control).

The variety Ezhome-1 indicated significantly higher soil available potassium than Kuthiru. The treatments indicated that T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron) showed the significantly highest available potassium. On comparing the variety x treatment interactions also, it was revealed that T_6 of variety V_1 showed the significantly highest available potassium content. The lowest available potassium content was observed in T_7 of Kuthiru *i.e.* control. Many research works conducted on the use of phosphogypsum as an ameliorant and fertilizer revealed that the physical and agronomic properties of soil are enriched thereby increasing the yield of agricultural crops due to the presence of different macro and micro nutrients such as Ca, Mg, P, Zn, Na, K and Fe (Basu *et al.*, 2009; Mittra *et al.*, 2003). The release of Fe^{2+}, Mn^{2+} and NH_4^+ occurs under reducing conditions through various processes and potassium gets displaced from the exchange sites leading to its increased concentration in soil solution and eventually its availability to rice (Patrick and Mikkelsen, 1971).

The available calcium content was significantly higher in soils of Ezhome-1 than in Kuthiru. Among the different treatments, T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron) indicated the highest significant available calcium content. On considering the variety x treatment interactions, T_3 (Phosphogypsum + ½ lime) of Ezhome-1 indicated significantly highest available calcium content. This indicates the capacity of phosphogypsum and lime to increase the calcium content in soil. Phosphogypsum and lime might have contributed to increased calcium concentration of soil leading to improved soil physical conditions and increased exchangeable base status thus increasing fertility of soil. Similar reports were put forward by Crusciol *et al.* (2016). Merino *et al.* (2010) stated that calcium in the form of limestone or gypsum plays a vital role in correcting the soil pH and toxicity of aluminium through the Al-Ca interactions and thus improves the physiological and biochemical processes in plants grown in acid soils. Application of lime at the rate of 6 to 12 t ha^{-1}+ gypsum at the rate of 6 t ha^{-1}) was found to decrease the soil acidity and increase the calcium levels as reported by Fouche and Sautoy (1995).

Available magnesium status in soil was significantly higher in the variety Ezhome-1 compared to Kuthiru. On comparing the treatments, T_2 (Magnesium sulphate + ½ lime) recorded the significantly highest amount of available magnesium. This might be due to the addition of magnesium sulphate along with lime. A five year liming trial was conducted by Raji (1982) and she found out that soil acidity could be ameliorated by liming up to a favourable limit and also stated that liming considerably increased the calcium plus magnesium status and the lime potential in soil. In the variety x treatment interactions, T_2 of Kuthiru recorded the significantly highest available magnesium content.

Kuthiru recorded significantly higher amount of available sulphur compared to Ezhome-1. The treatment T_6 recorded the highest significant amount of available sulphur. Among the variety *vs.* treatment interaction, significantly highest amount of available sulphur was noticed in T_6 of Kuthiru. The presence of sulphur in phosphogypsum has resulted in increased available sulphur in soil for plant uptake.

A significantly lower amount of available iron in soil was recorded with Kuthiru over Ezhome-1 (Figure 18). The cultivation of Kuthiru rice variety was more effective in reducing the effects of iron toxicity in Kaipad soil. The lowest significant amount of iron was recorded in treatment T_3 (Phosphogypsum + ½ lime). Among the treatments T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime) was highly effective in lowering the iron toxicity of Kaipad soil. The variety x treatment interactions indicate that the treatment T_1 (lime) of Kuthiru recorded the significantly lowest iron content. The experimental results proved the ability of phosphogypsum along with lime in alleviating iron toxicity of soils. Benckiser *et al.* (1984) suggested that calcium and magnesium plays a pivotal role in alleviating iron toxicity in rice. Chang and Thomas (1963) also reported that the amount of iron and aluminium released in to the soil solution decreased with the application of gypsum. Nhung and Ponnamperuma (1966) reported that lime ($CaCO_3$) decreases the iron content of the soil.

A significantly higher available copper content of soil was recorded with the variety Kuthiru compared to Ezhome-1. Among the treatments, T_1 and T_4 recorded significantly highest available copper contents in soil. The higher availability of available copper in soil might be due to the liming action along with the improvement of physical properties of soil. No significant difference was observed in the variety *vs*. treatment interaction.

Significantly lower available manganese content in the soil was observed in Ezhome-1 than Kuthiru. Among the treatments, the lowest significant amount of available manganese content in soil was observed in T_1 (lime). On comparing the variety *vs*. treatment interactions, the treatment T_4 of Ezhome-1 recorded the lowest significant available manganese. Liming helps to alleviate the toxicity of available iron and aluminium along with available manganese.

Higher available zinc content was observed in the variety Kuthiru over Ezhome-1. With respect to treatments, the treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate-0.25% + 0.25% boron) recorded highest significant amount of available zinc content. The variety x treatment interaction was non-significant. The presence of zinc in phosphogypsum might have resulted in increased available zinc in soil. Liming and alternate flooding and drying during the growth period of rice helped in improving the rice yield and its response to application of nutrients such as sulphur, boron, copper and zinc (Karan *et al.*, 2014).

The variety Kuthiru showed significantly higher available boron content in soil compared to Ezhome-1. Among the treatments, T_4 and T_6 (1.33 mg kg^{-1}) recorded the highest significant available boron content in soil. In the variety x treatment interactions, the treatments T_4 and T_6 of Kuthiru noted the highest significant available boron contents. The leaching losses of boron can be prevented by liming. The lesser the soil acidity, more is the chemisorption of boron (Soares *et al.*, 2005; Rosolem and Biscaro, 2007)

There were no significant difference observed between the varieties and as well as in the variety *vs.* treatment interaction with respect to available silicon. Among the treatments, significantly highest silicon content was observed in the treatment T_1 (lime). Liming action of soil might have resulted in increased availability of most of the plant available nutrients.

The variety Kuthiru recorded significantly lower exchangeable aluminium content over Ezhome-1(Figure 19). This might be the capability of the local cultivar Kuthiru to overcome the aluminium toxicity. The lowest exchangeable aluminium content was observed in treatment T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime). The nethermost exchangeable aluminium content in the variety x treatment interaction was observed in T_6 of Kuthiru. Calcium application was reported to decrease the aluminium content in root tips without displacement (Shen *et al.*, 1993). Aluminium toxicity could also be alleviated by the application of magnesium in wheat which is similar as in the case of calcium application (Watanabe and Okada, 2005). Phosphogypsum is a by-product of the phosphoric acid industry and their addition as amendments helps in the formation and retention of aluminium hydroxyl polymers (Illera *et al.*, 2004b). Reeve and Sumner (1972) suggested that aluminium toxicity can be overcome by self-liming effect wherein, the hydroxyl ions are displaced by the sulphate ions from hydrous oxides of aluminium and iron.

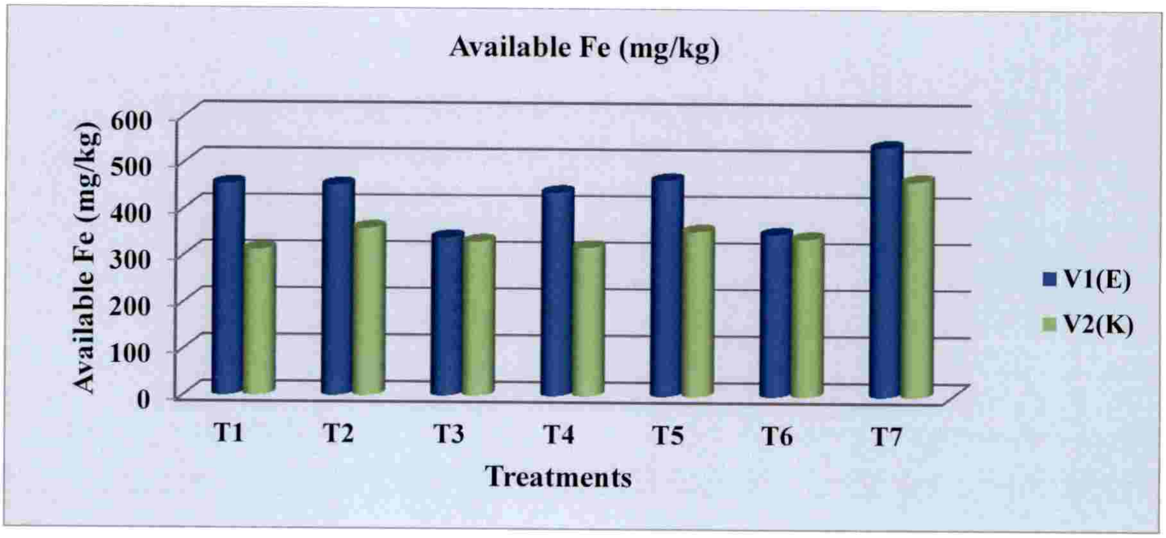

Fig. 18: Effect of amendments on available iron status of the soil in pot culture experiment

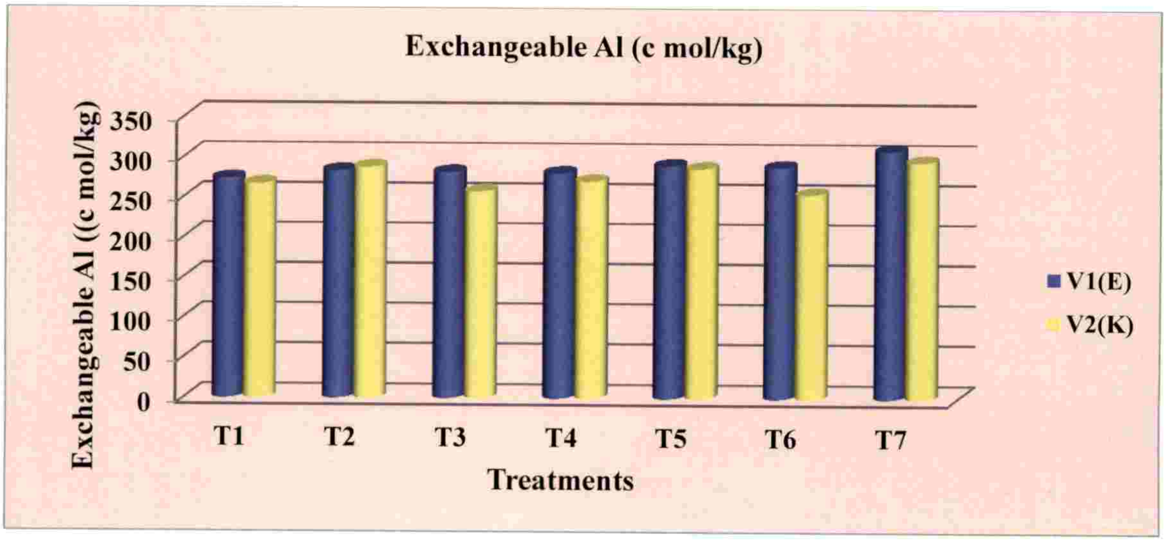

Fig. 19: Effect of amendments on exchangeable aluminium status of the soil in pot culture experiment

Significantly lower exchangeable sodium content was observed in Ezhome-1 compared to Kuthiru. Ezhome-1 and Ezhome -2 which are saline tolerant, non-lodging and high yielding varieties have been released using land races like Kuthiru and Orkayama as donor parents (Vanaja and Mammootty, 2010). The treatment T_4 (Lime as per KAU POP + potassium silicate 0.25% +0.25 % boron) recorded the lowest exchangeable sodium content). The variety *vs.* treatment interactions indicated that the treatment T_4 of variety Ezhome-1 (782.67 mg kg^{-1}) exhibited the lowest significant value of exchangeable sodium content. Liming supplies Ca to the soil which replaces Na from the exchange sites. Significant reduction in the damages caused due to various abiotic stresses like drought, salinity and nutrient imbalance have been reported by the application of silicon (Nakata *et al.*, 2008). Silicon plays an important role in alleviating various abiotic stresses *viz.* salinity, metal toxicity, drought stress, nutrient imbalance etc. by the mechanism of accumulation of silica on the surface of the tissues (Ma, 2004).

5.4.4 Influence of treatments on the nutrient content in plants in pot culture experiment

The nitrogen content in plants showed non-significance with respect to varieties V_1 (Ezhome-1) and V_2 (Kuthiru). On comparing the treatments, the highest significant nitrogen content (3.55 %) was observed in treatment T_2 (Magnesium sulphate + ½ lime). The variety *vs.* treatment interactions revealed that the significantly highest concentration of nitrogen was observed in the treatment T_3 of Kuthiru variety (3.62 %). This may be due to the action of calcium present in phosphogypsum. Application of calcium containing amendments might have resulted in increased nitrogen use efficiency leading to more nitrogen concentration in the plants. Naeem *et al.* (2009) reported that calcium containing materials increased the absorption of NH^{4+}, eventually leading to the increased tillering, and thus leading to higher grain yields. Fenn *et al.* (1995) indicated that calcium increases the nitrogen use efficiency in the plant tissues through greater metabolite deposition in seeds and also increases the photosynthesis rate. The lowest nitrogen content was was recorded in control. Yamauchi and Winslow (1989) based on their studies in upland rice reported that nitrogen, potassium, silicon and magnesium were necessary to produce high dry matter. They also reported that magnesium and silicon were necessary for protecting the rice plants against grain discolouration and in increasing the grain yield by an average of 34 per cent.

The treatments, varieties and interaction between variety and treatment were found to be significant in case of phosphorus content in plants. Ezhome-1 recorded a significantly higher phosphorus content compared to Kuthiru. The highest significant phosphorus content was observed in the plants in the treatment T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime) and T_6. In the variety x treatment interactions, T_6 of variety V_1 showed the highest phosphorus content. The lowest phosphorus content was observed in control of Kuthiru variety. This may perhaps be due to the enhanced availability of phosphorus from the applied phosphophogysum. Ayadi *et al.* (2014) reported that application of phosphogypsum (40% phosphogypsum) increased the inorganic phosphorus content and uptake of phosphorus by plants.

The treatments, varieties and interaction between varieties and treatments showed significant effect with respect to potassium content in plants. The comparison of two varieties revealed that the variety Ezhome-1 had significantly higher potassium content than Kuthiru. The significantly highest potassium content was seen in the treatment T_4 (Lime as per KAU POP + potassium silicate 0.25% +0.25 % boron) and the lowest was recorded in control. The variety x treatment interaction reveals that T_4 of Ezhome-1 recorded the significantly highest potassium content. The lowest potassium content among all was observed in control of Kuthiru. This might be due to the increased absorption of potassium by rice plants in the treatment T_4. Application of lime might have resulted in lowering the concentration of toxic elements in the soil solution. The beneficial effect of lime helps in better uptake of nutrients. This result might also be due to the production of hydrogen ions during reduction of iron and aluminium toxicity that caused the release of potassium from the exchange sites or from the fixed sites to the soil solution. Similar results were reported by Patrick and Mikkelsen (1971) as discussed earlier.

Application of amendments showed significant effect in calcium content by the rice plants. A significantly higher uptake of calcium was observed in the variety Ezhome-1 than Kuthiru. The treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate-0.25% + 0.25% boron) recorded the highest significant content of calcium (0.88 %) in plants. The presence of calcium in phosphogypsum coupled with lime in T_6 might have resulted in high concentration of calcium in the rice plants receiving the treatment T_6. Application of lime at the rate of 18.4 t ha^{-1} showed a significant increase in the concentration of calcium, magnesium and potassium concentration in the top soil (Blaszcyk *et al.*, 1986). Application of amendments containing calcium to soil converts the insoluble iron and aluminium phosphates to calcium phosphates by increasing the pH of acid soils to neutrality. The lowest calcium content was observed in T_7 (control) *i.e.* with no amendments. The variety *vs.* treatment did not show any significant differences in their calcium contents.

The variety V_2 *i.e.* Kuthiru exhibited a significantly higher magnesium content than Ezhome-1. Among the treatments, the treatment T_5 (Magnesium sulphate + ½ lime (as per KAU POP, 2011) +0.25% potassium silicate + 0.25 % boron) recorded the highest amount of magnesium which was followed by T_2. There were no significant differences in the variety x treatment interactions. Bhaskar *et al.* (2013) reported that the application of magnesium sulphate at the rate of 3 g m^{-2} showed significant increase in growth and grain yield compared to the control. The uptake of magnesium is highly influenced by the availability of other cations like NH_4^+, Ca^{2+} and K^+ (Romheld and Kirkby, 2007).

Application of amendments showed significant effects in sulphur content of rice plants. The local landrace Kuthiru recorded significantly higher sulphur content than Ezhome-1 variety. The significantly highest sulphur contents were observed in T_3 and T_6, and the lowest value was seen in T_7 (control). The variety x treatment interactions indicated that T_6 of Kuthiru (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron) showed the highest sulphur content. The higher sulphur contents recorded in the treatments T_3 and T_6 might be due to the beneficial effect of phosphogypsum along with lime. Soratto *et al.* (2008) noted from his studies on rice cultivation that the application of phosphogypsum when combined with lime showed positive effects on the amount of sulphur in leaves and yield.

The effect of treatments on concentration of iron in plants was found to be significant. Significantly lower iron content was observed in Ezhome-1 over Kuthiru. Though the highest iron content was recorded in the local variety Kuthiru, no toxicity symptoms were visible in the leaves and above ground parts. The treatment T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011) recorded the minimum iron content demarcating lowest toxicity of iron in rice. This can be attributed to the ability of phosphogypsum and lime in overcoming iron toxicity. Phosphogypsum has calcium in soluble form which is capable of correcting subsoil acidity also when it is applied to the surface (Deepa, 2008; Alcordo and Recheigl, 1993). Breemen and Moormann (1978) opined that iron toxicity can be alleviated by liming the soil, delaying the planting or through late flooding to avoid excess iron in the early stages and providing sufficient iron in the reproductive phase of the plant development. Control plants recorded the greatest toxicity of iron in rice. These results proved that iron toxicity of saline hydromorphic soils of Kaipad can be reduced through combined application of phosphogypsum and ½ lime.

The manganese content in plants was not significant with respect to the varieties as well as the variety *vs.* treatment interaction. However, comparing the treatments, T_1 (lime alone) was highly effective in reducing the manganese toxicity of rice plants. The severe manganese toxicity was observed in T_7 (control). Mandal *et al.* (1975) and Tripathi *et al.* (1997) recognised the beneficial role of liming materials such as lime stone, calcite, slaked lime etc. in reducing the Fe, Al and Mn toxicity.

The varieties, treatments as well as their interaction did not have any significant impact on the plant's zinc and copper contents.

There were no significant differences in the total boron content in case of varieties as well as the variety *vs.* treatment interaction. However, the effect of treatments on boron content in plants showed that the treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate-0.25% + 0.25% boron) recorded the maximum significant boron content. Boron helps in stimulating the activity of enzymes, sugar availability and respiration process which leads to improved pollen growth (Garge *et al.*, 1979). Boron application at the rate of 1.5 kg ha^{-1} to salt affected soils improved number of tillers per plant, panicle length, and straw and paddy yield of rice (Ehsan-Ul-Haq *et al.*, 2009). Rashid *et al.* (2004) reported a positive behaviour of rice plants with optimum boron dosage at the rate of 0.75 kgha^{-1}. A steady increase in paddy yield was seen on boron fertilization (Rakshit *et al.*, 2002; PARC, 2002).

There were no significant differences between the varieties as well as variety *vs.* treatment interaction in the concentration of silicon. Among the treatment means, the treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate-0.25% + 0.25% boron) exhibited the highest significant silicon content, which was on par with T_3. The presence of adequate amount of silicon and potassium in the soil solution were found to increase the oxidizing power of rice roots and thereby decreased the excessive iron uptake by the plants (Tadano, 1976; Yoshida, 1981). Silicon fertilization has found to increase both the quality and quantity of crops such as rice and sugar cane (Korndorfer & Lepsch, 2001). Barcelo *et al.* (1993) reported that silicon is efficient in reducing aluminium toxicity.

There was no significant difference between the varieties on the aluminium content. The treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime + potassium silicate-0.25% + 0.25% boron) was highly effective in significantly reducing the aluminium content in rice plants. From these results, it is proved that phosphogypsum is highly effective in lowering the aluminium toxicity. Zsoldos

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et al. (2013) confirmed that application of silicon to the plants growing in an acidic medium helps in ameliorating aluminium toxicity in rice plants. Cameron *et al.* (1986) opined that application of phosphogypsum would be more effective in reducing the toxicity caused by aluminium than by the use of pure calcium sulphate due to the presence of fluorine in phosphogypsum. Fluorine is an anion capable of forming more stable complexes with aluminium than SO_4^{2-}. The variety x treatment interaction revealed that the lowest significant uptake of aluminium was seen in T_3 of Kuthiru.

The variety Ezhome-1 recorded lower sodium content compared to Kuthiru. The treatments T_1, T_3 and T_6 were effective in lowering the sodium contents in rice plants. The variety x treatment interaction indicated that the treatment T_1 of Kuthiru recorded lowest significant concentration of sodium. Application of amendments to saline hydromorphic soil might have attributed to the low sodium content in the rice plants. High salt concentration increases osmotic stress (Mohanty *et al.*, 2002) and leads to the accumulation of excess amount of sodium in plants (Zhu, 2001). The electrical conductivity and exchangeable sodium percentage values were found to decrease on application of a mixture of farm yard manure and gypsum (Abou El- Defan *et al.*, 2005).

The nutrient ratio for calcium to potassium on plant analysis revealed that the highest ratio was obtained in the treatment T_6 with application of phosphogypsum + ½ lime along with foliar sprays of boron and potassium silicate.

This proves that use of amendments enhances the available Ca in soil. Presence of Ca improves the soil structure, increases the soil pH to neutral and reduces EC of soil.

Summary

6. SUMMARY

The salient findings on the investigation entitled "Dynamics of iron and aluminium toxicity on rice (*Oryza sativa* L.) in saline hydromorphic soils of Kaipad" is presented in this chapter. The study was carried out in four parts.

Part A: Collection of soil samples and analysis of physical and chemical properties

Part B: Incubation study to know the release pattern of nutrients in the soil

Part C: Solution culture experiment

Part D: Pot culture experiment

The investigations were carried out at College of Agriculture, Padannakkad during the academic year 2015-17.

The saline hydromorphic soil samples of Kaipad, taxonomically falling under the Chelapram series (Premachandran, 2012) were collected from fifteen study locations during the month of April 2016 and the GPS co-ordinates were recorded. The samples were studied for different physical properties like bulk density and particle size distribution. The samples were also studied for various chemical properties like pH, EC, organic carbon, available nutrients like N, P, K, Ca, Mg, S, B, Si, Fe, Mn, Zn, Cu, exchangeable Na and Al and CEC. The main conclusions of the initial collection and analysis are summarised below.

The bulk density varied from 1.06 Mg m^{-3} in location number 11 to 1.17 Mg m^{-3} in location number 9. The textural class of the sampled locations ranged from sandy loam to sandy clay loam. The loamy nature may be related to the fluffiness of the soil. The predominant fraction observed in the sampled locations was sand.

- There was a wide variation in pH ranging from ultra-acidic to slightly acidic pH (3.40 to 6.48). The range of electrical conductivity recorded in the soil samples of Kaipad was from 9.72 to 29.00 dS m^{-1}.
- The organic carbon status of the sampled locations of Kaipad varied between 5.30 to 33.40 g kg^{-1} over the fifteen locations.

The results revealed that the macro and micro nutrient status of Kaipad soils was generally very high.

- The available nitrogen status of the sampled locations of Kaipad regions varied from 173.47 kg ha^{-1} to 1083.80 kg ha^{-1} with a mean value of 544.95 kg ha^{-1} which was medium to high in nature. The available phosphorus content varied from 8.65 kg ha^{-1} in location number 6 to 50.27 kg ha^{-1} in location number 10. The available potassium content observed in the soils was extremely high ranging from 1239.02 to 4630.05 kg ha^{-1}.
- The contents of available calcium recorded from the 15 locations were very high ranging from 826.25 mg kg^{-1} to 3275.00 mg kg^{-1}. The status of available magnesium content of the study locations ranged from 21.30 mg kg^{-1} to a maximum value of 43.60 mg kg^{-1}. The available sulphur content of the soils varied from to 748.77 mg kg^{-1} in location number 7 to 1534.62 mg kg^{-1} in location number 3. The available iron content in these soils varied from 702 to 1250 mg kg^{-1} which was in toxic range. The available manganese content in these soils varied from 3.4 to 25.46 $mgkg^{-1}$.
- The available zinc values ranged from 1.81 to 11.50 mg kg^{-1} and the available copper content ranged from 2.07 to 6.78 mg kg^{-1} over the locations. The status of available boron content in the sampled locations ranged from 1.29 to 1.79 mg kg^{-1}.
- The exchangeable aluminium was found in higher concentrations varying from 160 to 434 c mol (P^{+}) kg^{-1} and available silicon content was also very high varying from 48.90 c mol (P^{+}) kg^{-1} to 195.00 c mol (P^{+}) kg^{-1}.
- The exchangeable sodium content in the soils varied from 530 c mol (P^{+}) kg^{-1} to 1080 c mol (P^{+}) kg^{-1} which was very high. The cation exchange capacity ranged from 21.91 c mol (P^{+}) kg^{-1} to 184.46 c mol (P^{+}) kg^{-1} in location numbers 13 and 10 respectively.

Relatively high values of pH, organic carbon, available nitrogen, potassium and calcium can be attributed to the fallow nature of the sampled sites compared to other sites where rice-fish aquaculture is regularly practised.

The incubation study was conducted using the saline hydromorphic soil collected from location 2 with four treatments and two levels of submergence (5 cm and 10 cm) in factorial CRD. The treatments used were T_1: Lime as per KAU POP, 2011; T_2: Magnesium sulphate + ½ lime (as per KAU POP, 2011); T_3: Phosphogypsum at the rate of 500 kg ha^{-1} + ½ lime as per KAU POP, 2011; T_4: Control. The soil samples were analyzed at 30, 60, 90 and 120 days after incubation.

- The submergence levels were found to have no significant effect with respect to soil pH at 30 and 90 DAI, whereas the effect was significant at 60 and 120 DAI. The soil pH displayed an increase in trend with increase in duration of incubation. The treatment T_1 (lime as per KAU POP) recorded the significantly highest values of soil pH at 30, 60 and 90 DAI. At 120 DAI, the treatment T_3 (Phosphogypsum + ½ lime) recorded significantly higher pH.
- The addition of amendments showed a steep decline in electrical conductivity from the initial level. Application of phosphogypsum + ½ lime (T_3) recorded the lowest EC at 30, 60 and 90 DAI.
- The organic carbon content was found to show a decreasing trend over the four months period. There were no differences between the organic matter contents in the two submergence levels. Application of lime (T_1) showed higher organic carbon content at 30 and 60 DAI whereas at 90 and 120 DAI, T_2 (Magnesium sulphate + ½ lime as per KAU POP, 2011) had a significantly higher organic carbon content.
- The available nitrogen content exhibited an increasing trend at 30, 60, 90 and 120 DAI. The submergence levels did not show any significant difference in the availability pattern of nitrogen. Among the treatments, T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011) showed higher nitrogen content at 30 DAI whereas at 60, 90 and 120 DAI, the treatment T_2 showed significantly higher available nitrogen content.

- The levels of submergence had no significant difference in available phosphorus content at 30 and 60 DAI. However at 90 and 120 DAI, 5 cm level of submergence recorded significantly superior values of soil available phosphorus. The treatment T_3 (phosphogypsum + ½ lime) showed higher available phosphorus contents at 30, 60, 90 and 120 DAI.

- There was significant effect of submergence levels on the available potassium content at 60, 90 and 120 DAI. Among the submergence levels, 5 cm level recorded significantly superior values of available potassium. Application of magnesium sulphate + ½ lime (T_2) recorded higher available potassium content at 60 DAI. However at 90 and 120 DAI, the treatment T_3 (phosphogypsum + ½ lime) showed superior available potassium content.

- Higher available calcium and sulphur contents were observed on application of the treatment T_3 (phosphogypsum + ½ lime) at 30, 60, 90 and 20 DAI. In all the four months of incubation, treatment T_2 (magnesium sulphate + ½ lime) displayed higher magnesium content (67.75, 72.68, 75.07, 78.16 mg kg^{-1} respectively).

- The level of submergence had no significant difference on available iron content but, it was observed that the lower concentration of available iron was recorded at 10 cm level of submergence. The application of treatments showed a suggestive effect on iron content over these four months. The diminution in values of iron was least in treatment T_1 (lime) at 30 and 120 DAI. At 60 and 90 DAI, the least iron content was observed in the pots treated with the treatment T_3.

- The decline in the manganese and copper and zinc contents was mostly evident in the treatment T_1 (lime). The submergence levels showed no significant difference in manganese and copper contents at 30, 60, 90 and 120 DAI. However, with respect to zinc content at 120 DAI, submergence level S_2 at 10 cm showed significantly higher values.

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- Though there was no significant difference in the levels of submergence at 30 and 60 DAI, there was profound effect at 90 and 120 DAI. The treatments T_2 showed higher available boron content at 30, 60, 90 and 120 DAI.

- The treatment T_3 (phosphogypsum + ½ lime) exhibited a grander value of available silicon content at 30, 60 and 90 DAI.

- The aluminium toxicity was reduced to a maximum level at 30, 60 and 120 DAI by treatment T_3 *i.e.* on application of phosphogypsum at the rate of 500 kg ha^{-1} + ½ lime. However at 90 DAI, the least aluminium content was observed in soil treated with lime alone.

- Application of lime (T_1) was found to decrease the exchangeable sodium contents at 30, 60, 90 and 120 DAI.

The solution culture experiment was conducted by maintaining a nutrient solution (Hoagland's solution) containing 3 levels of iron (400, 800, 1200 mg L^{-1}), 2 levels of aluminium (15 and 30 mg L^{-1}) and 2 levels of salinity (5 and 10 dS m^{-1}) along with one control. The two selected rice varieties Kuthiru and Ezhome-1 were evaluated for their tolerance to iron and aluminium coupled with salinity.

- There were no remarkable differences in percentage of increase in plant height between the varieties as well as the variety x treatment interaction. The least increase in plant height was observed in T_{12} with 1200 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and 10 dS m^{-1} salinity.
- Among the varieties, significantly higher increase in root length was observed in Kuthiru over Ezhome-1. The lowest significant increase in root length was noted in T_{12} (6.02 %) with 1200 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and 10 dS m^{-1} salinity.
- The patterns of iron coating on the roots were observed. Formation of iron plaque on the root surface was most prominent in the solution containing 1200 mg L^{-1} of iron in Ezhome-1 and Kuthiru varieties. There was no iron

coating around the root cells of control. Maximum iron coating around the root among the treatments was displayed by solution containing the treatment T_{12} (1200 mg L^{-1} iron, 30 mg L^{-1} aluminium and 10 dS m^{-1} salinity). The thickness of iron plaque was greater in the variety V_2 (Kuthiru), the local landrace of Kaipad which clearly indicates the root exclusion principle for reducing iron and aluminium toxicity, thus preventing its translocation to the above ground plant parts.

- The highest significant root dry weight (3.45 mg each) was observed in T_8 with (800 mg L^{-1} iron, 30 mg L^{-1} aluminium and 10 dS m^{-1} salinity)
- Highest plant height and root length were observed in T_{13} (Control).

The summary on whole plant analysis of the plants grown in solution culture experiment is given below.

Among the varieties, higher total N and Fe contents were observed in Ezhome-1 compared to Kuthiru. However, the contents of total P, K, Mn, Al and Na contents were high in Kuthiru variety than Ezhome-1. The chloride content was non-significant with respect to the varieties.

The highest N and P contents were shown by the treatments T_9 (1200 mg L^{-1} of iron, 15 mg L^{-1} of aluminium and 5 dS m^{-1} salinity) and T_3 (400 mg L^{-1} of iron, 15 mg L^{-1} of aluminium and 10 dS m^{-1} salinity) respectively. The potassium content was highest in T_8 and T_{10}.

The treatment T_4 (400 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and 10 dS m^{-1} salinity) recorded the highest total Na, Cl and Mn contents. The highest significant total Al content was observed in T_{10} (1200 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and 5 dS m^{-1} salinity). The highest significant content of total Fe was observed in T_9 (1200 mg L^{-1} of iron, 15 mg L^{-1} of aluminium and 5 dS m^{-1} salinity).

The lowest Na concentration was recorded in T_5 (800 mg L^{-1} of iron, 15 mg L^{-1} of aluminium and 5 dS m^{-1} salinity).

The root partitioning studies showed that significantly higher Fe, Al, Na and root CEC values were obtained in Kuthiru variety over Ezhome-1. Significantly low concentration of chlorine was recorded in Kuthiru variety.

The significantly highest iron content (2736 µg g^{-1}) and root CEC (4.27 c mol (P^{+}) kg^{-1}) values were obtained in the treatment T_{12} (1200 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and 10 dS m^{-1} salinity). Among all the treatments, the maximum significant amount of aluminium was observed in the treatment T_{10}. The highest chlorine content was observed in T_7 (0.98 %). The highest significant root CEC was recorded in the treatment T_{12} (1200 mg L^{-1} of iron, 30 mg L^{-1} of aluminium and 10 dS m^{-1} salinity).

Pot culture experiment was carried out during the months of July to October 2016 at COA, Padannakkad with the two selected rice varieties Kuthiru and Ezhome-1 in the saline hydromorphic soils of Kaipad collected from Punnachery. The summary on the effect of amendments on growth attributes in pot culture experiment is given in this part of the chapter.

The variety Ezhome-1 recorded the maximum significant plant height at 30, 60 and 90 DAT. The yield attributes like number of productive tillers, grains per panicle, grain yield, straw yield and 1000 grain weight were significantly higher in Ezhome-1 over Kuthiru.

Application of the treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron) recorded the maximum significant plant height and grain yield. The maximum significant number of productive tillers/ panicles, grains per panicle, straw yield and 1000 grain weight were observed on application of the treatment T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011). The lowest significant chaffiness percentage was recorded in the treatment T_1 (lime).

The residual nutrient status of the soil was also checked out.

Among the varieties, significantly higher content of organic carbon, available N, K, Ca and Mg was observed in pots with Ezhome-1variety than Kuthiru. The pots with Kuthiru variety recorded significantly higher soil pH, available S, Cu, Zn and B content over Ezhome-1.

The lower available Fe and exchangeable Al contents were recorded in the pots containing Kuthiru variety than Ezhome-1. Significantly lower available Mn and exchangeable Na contents were recorded in the pots with Ezhome-1 variety than Kuthiru.

With respect to the treatments, the highest significant pH, available P and lowest EC and exchangeable Na contents were observed in the treatment T_4 (Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron). The treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron) recorded the maximum significant organic carbon, available K, Ca, S and Zn. The highest available N, lowest available Fe and exchangeable Al contents were recorded by the treatment T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011). The treatment T_1 (lime) recorded the significantly highest available Si and lowest Mn contents. Maximum significant available Mg was observed in the treatment T_2. The maximum significant available copper was recorded in the treatments T_1 and T_4. The highest boron content was observed in the treatment T_4 and T_6.

The influence of amendments on the nutrient content in plants in pot culture experiment revealed the following results.
Among the two varieties, significantly higher total P, K, Ca and lower Fe and Na contents were observed in Ezhome-1. Kuthiru variety recorded the significantly maximum Mg and S contents.

With respect to the treatments, the treatment T_6 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011 + potassium silicate-0.25% + 0.25% boron) recorded the maximum significant Ca, B, Si and lowest Al content. The maximum significant content of phosphorus and sulphur were observed in T_3 and

T_6. The treatment T_2 (Magnesium sulphate + ½ lime (as per KAU POP, 2011)) recorded the highest total N content. The total potassium content was maximum in the treatment T_4 (Lime as per KAU POP + potassium silicate 0.25% +0.25 % Boron). The lowest content of total iron was recorded in T_3 (Phosphogypsum @ 500 kg ha^{-1} + ½ lime as per KAU POP, 2011). Application of lime recorded the lowest total Mn content in plants. The lowest total sodium contents were observed in the treatments T_1, T_3 and T_6. The treatments were not significant with respect to total Zn and Cu.

The severe constraints of acidity, extreme toxicity of iron and aluminium coupled with high salinity in the saline hydromorphic soils of Kaipad can be ameliorated using combinations of amendments including phosphogypsum, lime and foliar application of boron and silicon to enhance the growth and yield of rice crop. Adoption of aforementioned management strategy could help in improving the soil health and thereby increasing the yield potential of Kaipad rice.

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Dynamics of iron and aluminium toxicity on rice (*Oryza sativa* L.) in saline hydromorphic soils of Kaipad

by

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ABSTRACT

An investigation entitled "Dynamics of iron and aluminium toxicity on rice (*Oryza sativa* L.) in saline hydromorphic soils of Kaipad" was carried out at College of Agriculture, Padannakkad during the academic year 2015 to 2017. The objectives of the study were to investigate the status of iron and aluminium in saline hydromorphic soils of Kaipad, evaluate the performance of popular rice varieties to varying levels of iron and aluminium concentration at different salinity levels, and examine amelioration strategies for iron and aluminium toxicity. The study was carried out in four parts namely collection and soil analysis, incubation study, solution culture and pot culture experiments.

As a part of the initial study, representative surface soil samples were collected from 15 selected locations of Kaipad areas comprising of Muttil and Cherukunnu panchayath during the first week of April 2016 to assess the different physical and chemical properties. The GPS data for the sites were also recorded. The pH of the soils varied from ultra-acidic to slightly acidic. The electrical conductivity during the summer months was very high. Among the macro and micro nutrients studied, very high available K and Ca values were observed and extreme toxicity of available Fe and Al were also recorded.

An incubation study was conducted with four treatments at two levels of submergence (5 cm and 10 cm) in factorial CRD. The treatments were fixed based on the recommendations of KAU POP, 2011 *viz.* lime (T_1); magnesium sulphate + ½ lime (T_2); phosphogypsum + ½ lime (T_3) and control (T_4). The application of treatments showed a positive effect in reducing iron and aluminium toxicity. The toxic levels of available Fe were significantly reduced in T_1 at 30 and 120 DAI whereas, at 60 and 90 DAI, T_3 was significantly superior in reducing the iron toxicity. The aluminium toxicity was reduced to minimum level at 30, 60 and 120 DAI in treatment T_3. However at 90 DAI, the least aluminium content was recorded in the soil treated with lime alone.

The solution culture experiment was conducted by maintaining Hoagland's nutrient solution containing 3 levels of iron (400, 800, 1200 mg L^{-1}), 2

levels of aluminium (15 and 30 mg L^{-1}) and 2 levels of salinity (5 and 10 dS m^{-1}) along with one control in factorial combinations using CRD. The two selected varieties, Ezhome-1 and Kuthiru were evaluated for their tolerance to iron and aluminium toxicity coupled with salinity. Maximum iron coating around the roots with respect to the treatments were displayed in T_{12} (1200 mg L^{-1} iron, 30 mg L^{-1} aluminium and 10 dS m^{-1} salinity) solution. Increase in levels of iron, aluminium and salinity significantly reduced the plant height, root dry weight, root length and root CEC of rice plants.

The pot culture experiment was conducted with seven treatments as amendments and two varieties Ezhome-1 and Kuthiru in factorial CRD during July to October 2016. The treatment combinations were: Lime (T_1); Magnesium sulphate + ½ lime (T_2); Phosphogypsum + ½ lime (T_3); Lime + potassium silicate 0.25% + 0.25% boron (T_4); Magnesium sulphate + ½ lime + potassium silicate 0.25% + 0.25% boron (T_5); Phosphogypsum + ½ lime + potassium silicate 0.25% + 0.25% boron (T_6) and control (T_7). The leachate was collected and analysed by inserting a perforated pipe at the centre of each pot. The variety Ezhome-1 recorded maximum significant plant height at 30, 60 and 90 DAT. The number of productive tillers/ number of panicles, grains per panicle, grain yield, straw yield and 1000 grain weight were also significantly superior in Ezhome-1. Among the amendments, T_6 recorded significantly superior plant height, grain yield, total Ca, B, Si and lowest Al content in rice. The treatment T_3 recorded maximum significant number of panicles, productive tillers, grains per panicle, straw yield, 1000 grain weight and lowest Na and Fe content in plant tissue. The treatments receiving phosphogypsum + ½ lime (T_3 and T_6) were highly effective in reducing the toxic levels of available Fe and Al whereas, application of lime (T_4) was significantly superior in increasing the soil pH, available P and reducing the EC and exchangeable Na status of Kaipad soil.

The saline hydromorphic soils of Kaipad are having severe constraints of acidity, extreme toxicity of iron and aluminium coupled with high salinity. These problems can be ameliorated using combinations of amendments including phosphogypsum, lime and foliar application of boron and silicon to enhance the growth and yield of rice crop. Adoption of aforementioned management strategy could help in improving the soil health and thereby increasing the yield potential of Kaipad rice.

Appendices

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APPENDIX I

MONTHLY WEATHER DATA DURING THE CROP PERIOD

Period	Maximum temperature (^{0}C)	Minimum temperature (^{0}C)	Rainfall (mm)	Relative humidity (%)	Evaporation (mm)
June 2016	32.62	23.94	126.10	78.03	3.29
July 2016	30.76	22.75	532.60	85.03	1.97
August 2016	29.96	23.42	902.00	88.08	2.43
September 2016	30.35	23.41	17.62	87.24	2.94
October 2016	31.21	23.44	12.51	87.91	3.48
November 2016	31.35	23.62	265.70	84.57	3.15
December 2016	31.39	23.05	106.80	81.75	2.95

APPENDIX II

MOISTURE PERCENTAGE OF DIFFERENT SOIL SAMPLES COLLECTED FROM KAIPAD

Location	**Moisture (%)**
1	19.95
2	55.38
3	19.31
4	15.74
5	86.76
6	49.28
7	20.21
8	28.55
9	41.81
10	15.27
11	24.65
12	31.25
13	23.45
14	29.54
15	18.56

APPENDIX III

THICKNESS OF IRON COATING AS INFLUENCED BY TREATMENTS ON RICE ROOTS OF EZHOME-1 AND KUTHIRU IN SOLUTION CULTURE EXPERIMENT

Treatment	**Thickness-Ezhome-1 (µm)**	**Thickness- Kuthiru (µm)**
T_1	2.10	2.14
T_2	8.60	9.10
T_3	17.56	18.10
T_4	22.65	23.19
T_5	25.14	26.28
T_6	26.47	26.92
T_7	27.32	27.85
T_8	28.60	29.63
T_9	31.44	31.95
T_{10}	32.31	30.27
T_{11}	35.24	37.98
T_{12}	38.65	41.28
T_{13}	0	0